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THESIS

A SYSTEM ENGINEERING STUDY AND CONCEPT DEVELOPMENT FOR A HUMANITARIAN AID AND DISASTER RELIEF OPERATIONS MANAGEMENT PLATFORM

by

Julie A. Reed

September 2016

Thesis Advisor: Eugene Paulo
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13. ABSTRACT (maximum 200 words)

This thesis develops a concept and initial system definition of a Humanitarian Aid and Disaster Relief (HADR) Operations Management Platform (OMP) that supports various stakeholders involved in time critical humanitarian response efforts. The concept for the OMP explores the various functions necessary to manage HADR operations to include facilitation of information exchange, collaboration among disaster responders, and a common operating picture (COP) that informs decision makers of the operational environment. The development of the OMP uses system engineering methodologies and a tailored development process to identify the requirements, functions, and architecture necessary to support the platform. The OMP concept also includes multiple data sources for near real-time information and support tools for assessments, planning, implementation, execution, and evaluation. This thesis also assesses advances in technology and applications to more effectively support and manage HADR efforts. As such, the OMP takes into consideration how current HADR operations are conducted today, and the role of virtual volunteers in supporting the platform. These virtual volunteers support the HADR effort by conducting tasks virtually via their computers and an internet connection anywhere in the world.

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A SYSTEM ENGINEERING STUDY AND CONCEPT DEVELOPMENT FOR A HUMANITARIAN AID AND DISASTER RELIEF OPERATIONS MANAGEMENT PLATFORM

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis develops a concept and initial system definition of a Humanitarian Aid and Disaster Relief (HADR) Operations Management Platform (OMP) that supports various stakeholders involved in time-critical humanitarian response efforts. The concept for the OMP explores the various functions necessary to manage HADR operations to include facilitation of information exchange, collaboration among disaster responders, and a common operating picture (COP) that informs decision makers of the operational environment. The development of the OMP uses system engineering methodologies and a tailored development process to identify the requirements, functions, and architecture necessary to support the platform. The OMP concept also includes multiple data sources for near real-time information and support tools for assessments, planning, implementation, execution, and evaluation. This thesis also assesses advances in technology and applications to more effectively support and manage HADR efforts. As such, the OMP takes into consideration how current HADR operations are conducted today, and the role of virtual volunteers in supporting the platform. These virtual volunteers support the HADR effort by conducting tasks virtually via their computers and an internet connection anywhere in the world.

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LIST OF ACRONYMS AND ABBREVIATIONS

BBC	British Broadcast Corporation
CDAC	Communicating with Disaster Affected Communities
CFE-DMHA	Center for Excellence in Disaster Management and Humanitarian Assistance
CMCS	Civil-Military Coordination Section
CONOPs	Concept of Operations
COP	Common Operating Picture
DH	Digital Humanitarians
DOD	Department of Defense
EDP	External Data Processing
ETL	Extract Transform Load
FCSS	Field Coordination Support Section
GDACS	Global Disaster Alert and Coordination System
GUI	Graphical User Interface
HADR	Humanitarian Aid and Disaster Relief
HBKU	Qatar Computing Research Institute
HDX	Humanitarian Data Exchange
HPC	Humanitarian Programme Cycle
HXL	Humanitarian Exchange Language
IASC	Inter-Agency Standing Committee
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGOs	International government Organizations
INCOSE	International Council on Systems Engineering
ISO	International Organization for Standardization
LEMA	Local Emergency Management Authority
MNMCC	Multi-National Military Coordination Center
MOEs	Measures of Effectiveness
NEOC	National Emergency Operations Center
NGOs	Non-governmental Organizations

OCC	Operations Coordination Centers
OCHA	Office for Coordination of Humanitarian Affairs
OMP	Operations Management Platform
OSOCC	On-Site Operations Coordination Center
OV-1	Operational View-1
PoP	Point-of-Presence
PSE	Project Support Environment
R&R	Roles and Responsibilities
RDC	Reception and Departure Center
SDN	Software Defined Networking
SEBoK	System Engineering Body of Knowledge
SMS	Short Message Service
UAV	Unmanned Aerial Vehicles
UN	United Nations
UN-CM Coord	United Nations Humanitarian Civil-Military Coordination
UNDAC	United Nations Disaster Assessment and Coordination
UN-OCHA	United Nations Office for Coordination of Humanitarian Affairs
UNOSAT	Operational Satellite Applications Program
USAR	Urban Search and Rescue
V&TCs	Volunteer and Technical Communities
VOSOCC	Virtual On-Site Operations Coordination Center

EXECUTIVE SUMMARY

Advances in technology such as information systems, crisis mapping, and crowd sourcing change how we respond to humanitarian aid and disaster relief (HADR) efforts, and provide an avenue to improve the management and effectiveness of HADR operations. Large quantities of data are becoming available, resulting in operations management becoming more complex, challenging, and critical. HADR operations also require working with a widely diverse group of organizations with different cultures and languages, different standards and protocols, and competition for resources (UN-OCHA 2013, 24). This thesis focuses on the concept development and initial system definition of a HADR Operational Management Platform (OMP) for use by various stakeholders involved in a time critical humanitarian response effort. It includes inputs from multiple sources of information, and explores ways to provide information and tools to more effectively manage HADR efforts.

Currently, there is no single consolidated network-based platform that provides a common operating picture, software based applications, and tools to aid HADR responders in the management of operations in a rapid, succinct, and coordinated fashion. The HADR OMP's primary mission is to create a network-based platform to rapidly provide common situational awareness and management tools focused on the early phases of a HADR event, and to support the affected people impacted by the disaster. The ultimate goal is to efficiently manage HADR operations to save lives and alleviate human suffering.

Using a tailored system engineering framework, a methodology, procedures, and tools are applied to develop the concept and initial system definition for a HADR OMP. This includes an iterative process that includes mission analysis, problem definition, identifying key stakeholders, needs analysis, functional analysis, concept development, mission requirements, and architecture development.

During the concept definition phase a mission analysis is conducted by first identifying challenges responders face in HADR operations. Second, a mission scenario is created based on a recent HADR event, the 2015 Nepal Earthquake. From this mission scenario, a problem statement and mission objective are defined and an operational concept is developed. Also from the scenario, stakeholders involved in the HADR event are identified and their needs are analyzed and prioritized, producing the key stakeholder needs. From these key stakeholder needs and operational concept, the measures of effectiveness (MOEs) for the OMP are identified. The MOEs help define how well a system carries out the operational objective within specified boundary conditions (AcqNotes 2015).

System definition is the next phase after completion of the initial concept definition. This phase includes development of system requirements, logical architecture, and physical architecture. The system definition begins with identifying the OMP high-level functions required to meet the mission objective and MOEs. The high-level functions are then decomposed into lower tier sub-functions. These high-level functions and sub-functions are the initial foundation for system requirements and the logical architecture. The platform functional decomposition is focused on managing and coordinating HADR operations vice developing functions to conduct every aspect of the operations. The modes of operation identified in the operational concept are used as the basis for many of the high level functions. The modes categories include needs assessment and analysis, planning, resource mobilization, implementation and monitoring, and peer review and evaluation.

The next activity in the system definition phase is developing the logical architecture (also known as a functional allocated architecture) of the HADR OMP. The logical architecture, defines what the system must do to meet the functional requirements identified previously (Buede 2009, 27). The logical design provides the major functions and system boundaries of the platform along with their relationships. The high-level data flows and connections are also defined, and the HADR OMP software applications and system support components are identified. An organization interaction behavior model is developed to show the interaction between HADR OMP and the various HADR responders, the host nation, and the affected population. The initial logical architecture is used to ensure all components and functionality necessary is accounted for and is well understood within the platform (TechieDolphin 2006).

Next, the high-level physical architecture was developed after the initial iteration of the logical architecture and includes the physical infrastructure necessary to support the HADR OMP to include the hardware, software, and network. The computing and network hardware are identified and include routers, servers, firewalls, laptops, backup hard drives, smart phones, tablets, smart watches, and deployable backup units for the primary operation centers. Projectors and screens, printers, copiers, fax machines, phone lines, and internet connections are also required to support the HADR OMP. A software focused reference architecture to support the software application components is also identified, and includes the software module decomposition. This software architecture more specifically addresses the information management function of the HADR OMP to support large quantities of data and the management of the data to support the software applications utilized in the Graphical User Interface (GUI). The HADR OMP network architecture must be dynamic, manageable, cost-effective, and adaptable to meet the mission and stakeholder requirements. For this reason a software-defined networking (SDN) architecture with distributed computing is proposed to support the HADR OMP.

The next step is to refine the concept and system definition by receiving feedback from stakeholders involved in HADR operations to ensure all necessary requirements are captured appropriately and that the proposed solution meets the needs as expected. In addition, partnerships will need to be made between many humanitarian organizations with agreements for sharing data. United Nations Office for Coordination of Humanitarian Affairs (UN-OCHA) would need to endorse and lead the effort on creating the platform as well as advocacy from multiple humanitarian response stakeholders. Standards for data sharing will need to be agreed upon with externals starting with the Humanitarian Exchange Language (HXL) standard as the baseline.

Engineering teams need to be created to further define the solution for the platform. This includes further development and detailed design of the platform applications, application interfaces, visualizations, data management (including “big data”), network architecting, network management, software management services, training programs, and deployment hardware. Follow-on research and trade-space analysis should be conducted to more thoroughly assess the existing platforms, new data sources and software based applications that can be incorporated into the HADR OMP.

Finally, the system definition should include an agile software development process that allows for expandability, flexibility, and adaptability with open source software. A prototype should be created to aid in the development of the platform, and allow for applications to be added easily for testing for functionality and interoperability with already existing applications.

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I. INTRODUCTION

The evolution of mobile technology, social media, IT networking, and big data changes how our societies communicate on a local and global scale, providing a wealth of information at our fingertips. In today's connected and technology driven world, utilizing mobile technology, information systems, crisis mapping, crowd sourcing, and other developments in technology, can help save lives in the aftermath of a humanitarian crisis or natural disaster. Humanitarian Aid and Disaster Relief (HADR) operations can harness these technologies to improve crisis response. These technologies supply new capabilities to help decision makers manage operations at the tactical, operational, and strategic levels.

For example, responders use social media in disaster relief efforts to save lives in threatening situations. However, there is no single consolidated platform that takes advantage of the new advances in technology, with new data sources, including social media and drone imagery, to help personnel manage a HADR operation that is networked and interconnected with cross flows of timely communication. This thesis uses system engineering methodologies, processes, and tools to develop an operational concept. This thesis also develops the basic functions the platform must provide to meet mission objectives and requirements. It also researches various technologies and information that responders can use to support HADR operations management and provides possible solutions for incorporation into a single platform. Research is also conducted on how governments, organizations, and individuals respond to HADR operations today.

A. SCOPE

The scope of this thesis is to develop an operational concept for a Humanitarian Aid and Disaster Relief (HADR) Operations Management Platform (OMP) that takes inputs from multiple sources of data and displays them in a way that aids personnel in managing HADR operations.

1. Primary Objective

This thesis focuses on the concept development and system definition of a HADR OMP to be used by various stakeholders involved in a time critical humanitarian response effort. It includes multiple sources of information, and explores ways to provide information and tools to more effectively manage HADR efforts. This thesis describes a mission scenario based on how HADR operations are conducted today. From this scenario, an operational concept of the system/platform is developed to aid in the definition of the platform.

2. Secondary Objective

As a secondary objective, this thesis determines whether the HADR OMP can also incorporate "virtual volunteers" to aid in the relief efforts. For the purposes of this thesis, virtual volunteers are defined as people volunteering their time to conduct tasks to support the HADR response effort via their computers over an internet connection.

B. RESEARCH QUESTIONS

This thesis works to solve the following research questions listed below to fulfill the thesis objectives:

1. What are the functions and operational requirements for HADR operations, and how can these requirements be managed more efficiently through the use of a HADR OMP?
2. What type of data and technologies can be utilized to support a management platform?
3. How can "virtual volunteers" most effectively be utilized to help in HADR operations?

C. METHODOLOGY OVERVIEW

Using a system engineering framework, a tailored methodology, procedures, and tools are applied to develop the concept for a HADR OMP. This includes problem definition, identifying key stakeholders, needs analysis, functional analysis, concept development, system requirements, and architecture development. Further details of the framework and methodology are discussed in Chapter III.

D. BENEFITS OF THE STUDY

The benefit to developing a HADR OMP for government and non-government organizations is the potential improvement in managing HADR events which can save lives in the process. A HADR OMP provides new ways of measuring the effectiveness of relief efforts by establishing the framework to analyze the collected data and compare it to expected levels of performance. This analysis allows HADR leaders and participants to learn where they can make improvements for future HADR events. Lastly, the HADR OMP opens new doorways for “virtual volunteers” to help during a crisis.

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II. BACKGROUND

A. HADR OVERVIEW

There are a multitude of events that can create a disaster that requires Humanitarian Aid. According to the U.S. military's Foreign Humanitarian Assistance Joint Publication 3-29, these events are caused by acts of nature or caused by human activities. Examples due to acts of nature include floods, droughts, fires, hurricanes, earthquakes, volcanic eruption, and epidemics. Human activity-related disasters include riots, violence, civil unrest, acts of genocide, and war (Joint Publication 3-29 2014). Figure 1 provides a depiction of the types of disasters along with the various types of humanitarian services that may be required; depending on the severity of the disaster.

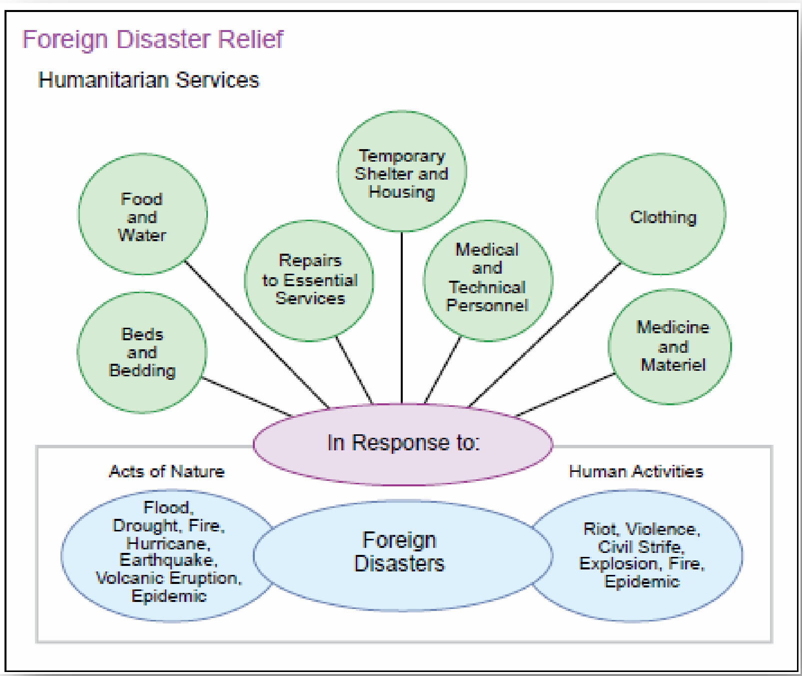

Figure 1. Responses to Foreign Disasters. Source: Joint Publication 3-29 (2014).

The United Nations defines a humanitarian crisis as "a situation in which the health, lives and well-being of people are in danger as a consequence of the disruption of their daily routine and access to basic goods and services" (UN-OCHA, CMCS 2015, 10). Humanitarian assistance seeks to save lives and alleviate suffering of those affected by a crisis.

When planning to respond to a humanitarian crisis, it is important to keep in mind the overall objective of helping those impacted by the disaster. The United Nations, through the Inter-Agency Standing Committee (IASC), provides humanitarian principles to help guide the response effort to ensure that the responders meet the overall objectives without biases, hidden political agendas, or taking of "sides" in a conflict (UN-OCHA, CMCS 2015). Table 1 provides the humanitarian principles that responders must consider when conducting HADR operations.

Table 1. Humanitarian Principles. Source: UN-OCHA, CMCS (2015).

HUMANITY	
Human suffering must be addressed wherever it is found. The purpose of humanitarian action is to protect life and health and ensure respect for human beings.	
NEUTRALITY	IMPARTIALITY
Humanitarian actors must not take sides in hostilities or engage in controversies of a political, racial, religious or ideological nature.	Humanitarian action must be carried out on the basis of need alone, giving priority to the most urgent cases of distress and making no distinctions on the basis of nationality, race, gender, religious belief, class or political opinions.
OPERATIONAL INDEPENDENCE	
Humanitarian action must be autonomous from the political, economic, military or other objectives that any actor may hold with regard to areas where humanitarian action is being implemented.	

HADR operations are complex tasks with a combination of efforts from multiple organizations, many of which have overlapping goals, objectives, and responsibilities. These organizations do not only include U.S agencies, but also third-party government agencies, non-government organizations, international organizations and Host Nation agencies (Joint Publication 3-29 2014).

The U.S. military's Foreign Humanitarian Assistance Joint Publication 3-29 describes the importance of coordination and cooperation of HADR operations with the terms "unified action" and "unity of effort." These terms are defined as follows:

> Unified Action is the synchronization, coordination, and/or integration of the activities of governmental, nongovernmental, and international entities with military operations to achieve unity of effort. Unity of effort is the coordination and cooperation toward common objectives, even if the participants are not necessarily part of the same command or organization, which is the product of successful unified action. Unity of effort in an operation ensures all means are directed to a common purpose. (Joint Publication 3-29 2014, I-2)

This unified action, also known as a unified response, can be a challenge in real-time operations, but is critical for the success of relief efforts. Situational awareness as well as effective leadership, management, communication, and coordination are all imperative in time sensitive operations where medical care and resources are essential to those affected in a disaster or humanitarian crisis (Joint Publication 3-29 2014).

Figure 2 provides the various humanitarian stakeholders during a humanitarian crisis. The stakeholders include organizations from the Host Nation as well as organizations providing support and aid. These stakeholders are discussed in further detail during the stakeholders' needs assessment in Chapter IV.

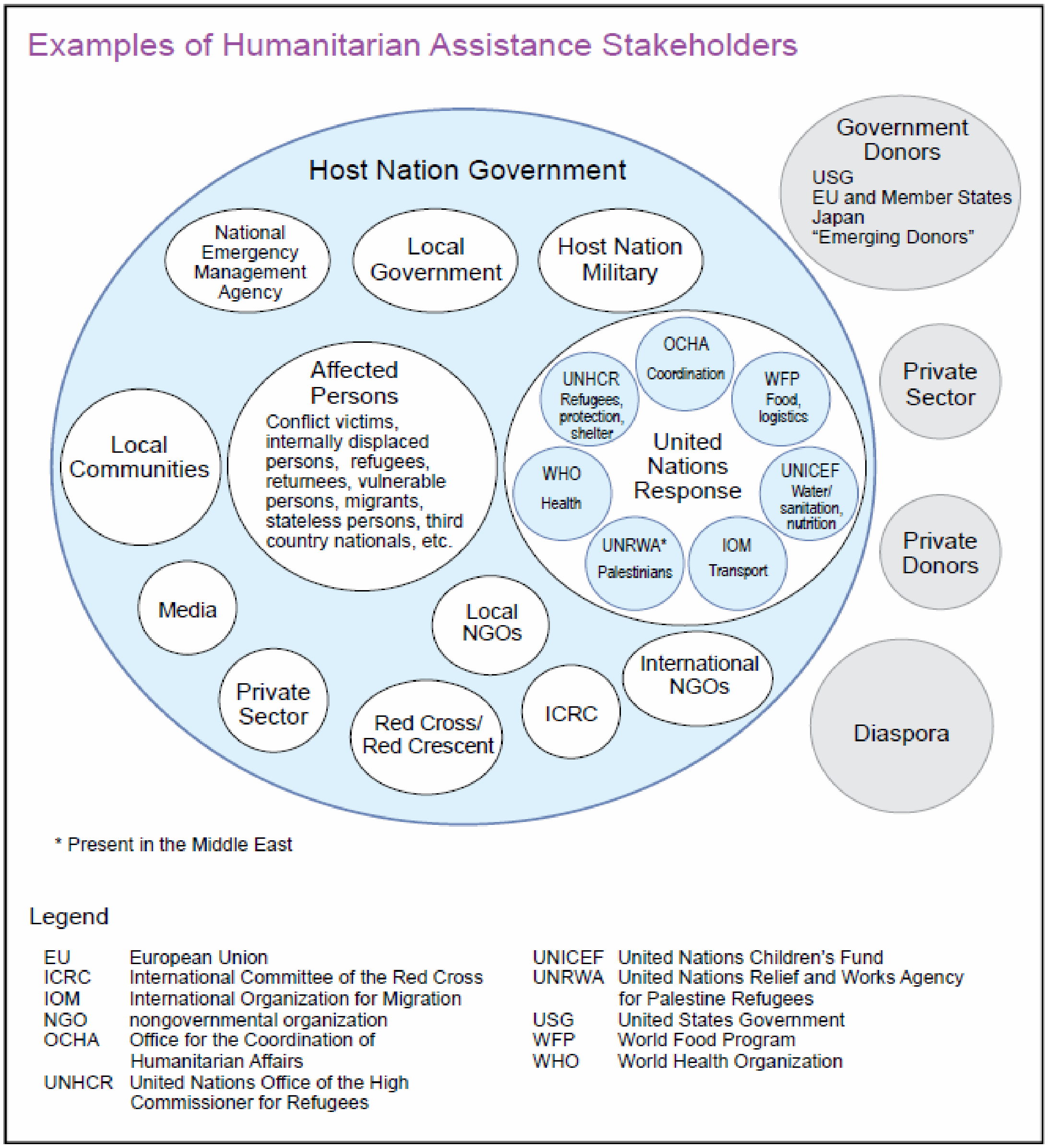

Figure 2. Humanitarian Stakeholders. Source: Joint Publication 3-29 (2014).

B. LESSONS LEARNED WITH TECHNOLOGY

Advances in technology and communications change how we respond to HADR efforts. They also provide an avenue to improve the management and effectiveness of HADR operations. As organizations incorporate these technology advances into HADR operations, the world is also learning lessons. Three examples from more recent natural disaster relief operations include the Haiti Earthquake in 2010, the Typhoon Haiyan in 2013, and the Nepal Earthquake in 2015.

One key technology that is changing the landscape of response efforts is networking and communication. In 2013, the Office for Coordination of Humanitarian Affairs, under the United Nations (UN-OCHA), conducted a study titled, "Humanitarianism in the Network Age." This study emphasizes the criticality of communication in HADR events and how advancements in communication shape the way global organizations conduct HADR operations. For instance, in the 2010 Haiti earthquake, various agencies that supported the response effort did so with their own data connectivity equipment. Significant cost could have been saved if these various organizations shared equipment rather than each having their own. The resulting cost savings could have freed up additional funding for resources, such as food, water, or medical supplies (UN-OCHA 2013).

During Typhoon Haiyan in the Philippines in November 2013, there were over 2000 response workers using communication services that were coordinated by the Emergency Telecommunications Cluster. By making these services more predictable and established, it can help to reduce costs. In addition, it would provide the ability to train response workers on established protocols with the communication systems, resulting in more effective operations (CDAC Network 2014).

The Nepal Earthquake in 2015 is the most recent major disaster to occur during the writing of this thesis. The HADR response to this event is unprecedented in the number of new technology and information applications utilized. These technologies include real-time satellite imagery, new data collection tools, virtual volunteer networks, and crisis mapping. This is also one of the first major disasters where Unmanned Aerial Vehicles (UAVs) are widely used with over nine independent teams flying drones over Nepal to support the response effort. However, drone operators face significant challenges in Nepal. Without an understood standardized process many drone operators did not register with the Nepalese government and face arrest and confiscation of their equipment. Lessons learned that emerged from the addition of new drone technology is (1) to have better coordination with local communities, and (2) to develop a shared platform/repository for imagery and videos being collected (Bollettino and Kreutzer 2015). A humanitarian organization known as Team Rubicon also deployed to Nepal to aid in the response efforts. An additional lessons learned from their assessment is the need for prioritized, quantified needs information to responders to ensure effectiveness and minimize duplication of effort (Schwartz 2015).

III. SYSTEM ENGINEERING METHODOLOGY

This thesis utilizes a tailored systems engineering approach to develop a concept and system definition for a platform to effectively manage foreign HADR operations focusing on the coordination and managing of resources needed in the initial phases of a disaster. It also provides an outline of the tailored systems engineering process that addresses the system functions and potential solutions, allowing for better management of HADR operations.

A. SYSTEM ENGINEERING METHODOLOGY AND APPROACH

This thesis utilizes a tailored system engineering analysis framework, which includes concept and system definition in a combined top-down and bottom-up approach to develop requirements, functionality, and architecture design.

1. Iterative System Definition and Analysis Approach

This thesis utilizes an iterative system definition approach that links the problem statement to an end solution. The analysis uses background and lessons learned research to aid in the concept and system definition for a HADR OMP. In addition, this process defines the high level functions, requirements, and architecture necessary to meet the problem statement and mission objective (ISO/IEC/IEEE 2015*)*.

Figure 3 shows the analysis' concept and system definition approach. It includes mission analysis, stakeholder needs assessment, and requirements phase during concept definition. In the system definition phase, the system requirements are defined along with the development of a logical architecture and physical architecture. This thesis focuses on the initial definition of the system as a starting point with the expectation that follow-on efforts will refine the definitions as the concept and system matures with feedback provided by stakeholders (Faisandier 2012).

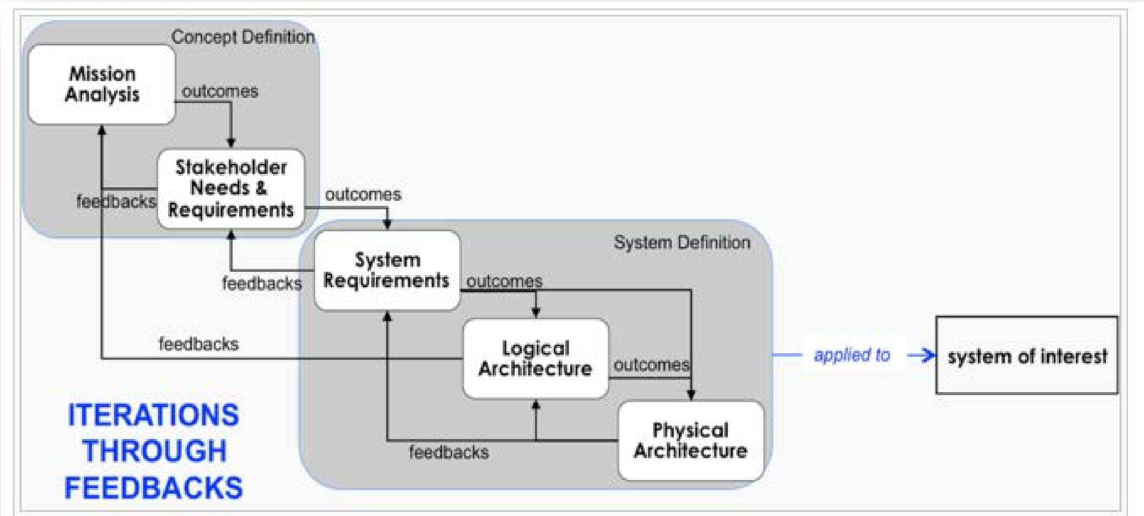

Figure 3. Iterative Approach to Concept and System Definition. Source: Faisandier (2012, 230)

2. Top-Down / Bottom-Up Development Approach

This approaches uses a combined top-down and bottom-up methodology to develop the requirements and architecture for the HADR OMP. From a top-down perspective, requirements are decomposed from a high level down to the lower levels with an emphasis on understanding the overall system and how it aids in solving the problem statement. From a bottom up perspective, the functionality and design will also be developed to account for the operational environment as well as existing technology that can be incorporated into the platform. By utilizing both these approaches simultaneously the system definition focuses on meeting user needs and on "whole system" challenges and integration. Based on the Systems Engineering Body of Knowledge (SEBoK), "Applying Life Cycle Processes," Figure 4 shows examples of focus areas that are taken into consideration while developing requirements and the architectural design for the HADR OMP.

Figure 4. Top-Down / Bottom-Up Approach to Requirements Development and Architecture Design for the OMP

a. Top-Down Approach: From Problem to Solution

According to SEBoK, "Systems Approach to Solution Synthesis," a top down approach during concept definition helps to define she problem that needs to be solved, and in turn, identify the operational needs/requirements. It aids in better defining the solution space along with the constraints/limitations of the system. After the mission context is defined, the top-down approach is used to define the initial design solution related to meeting the operational requirements. It is important throughout the development of the system that the requirements and design are mapped and traced back to the original problem statement to ensure that the system is developed to meet user needs (BKCASE Editorial Board 2015).

b. Bottom-Up Approach: Evolution of the Solution

The concept and system definition phases also takes a bottom-up approach in terms of incorporating new and existing capabilities that are relevant to supporting the needs of the system as well as designing the system to have feedback mechanisms starting at the lowest level. The SEBoK, "Systems Approach to Solution Synthesis," explains this is necessary in order to modify or adapt structural, functional, behavioral elements to optimize the effectiveness of the system. This can be accomplished by leveraging existing capability, while at the same time ensuring growth and feedback within the system for future capability. The bottom-up approach evaluates the initial design considerations and functional requirements developed in the top-down approach, and utilizes existing capabilities to meet these requirements. A form of "reverse engineering" is required to a certain extent to understand the current systems in place, and how they can be utilized and incorporated into the new system in development (BKCASE Editorial Board 2015).

B. SYSTEMS REALIZATION AND DESIGN CONSIDERATIONS

This thesis focuses on concept and system definition previously shown in Figure 3; however, this is only one phase in the development of realizing a deployable system. Figure 5 shows a simplistic view of the activities required in the system realization phase with the goal of ultimately deploying a system that meets user needs. After completion of the initial system definition, follow-on efforts are required to move into the system realization phase which include the implementation, integration, verification, and validation of the system prior to deployment (BKCASE Editorial Board 2015). The initial implementation activity includes the development of a prototype that will aid in further iterations of the system definition.

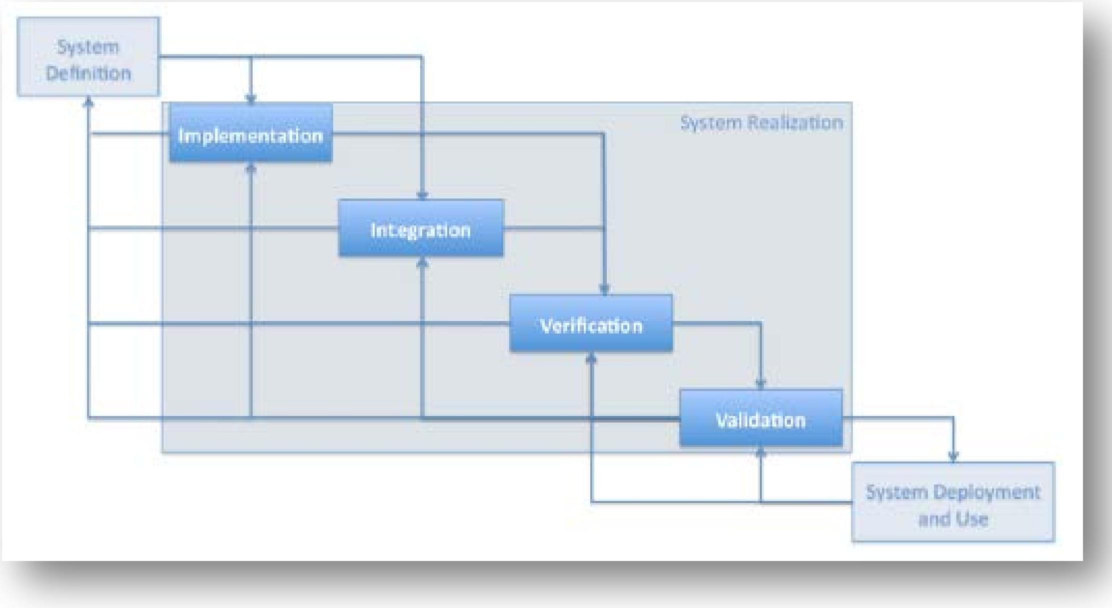

Figure 5. Phases of System Realization. Source: BKCASE Editorial Board (2015).

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IV. CONCEPT DEFINITION

According to the Systems Engineering Body of Knowledge (SEBoK), the concept definition phase provides understanding of the problem space by identifying a capability gap or opportunity within the assessed mission environment. The mission requirements and stakeholders are examined by applying systems engineering tools and processes. The problem statement is determined during mission analysis, where the stakeholders are identified. Then the stakeholders' needs are defined and requirements are developed (BKCASE Editorial Board 2015). Figure 6 shows the system definition process that was discussed in Chapter III, and highlights the concept definition within the process.

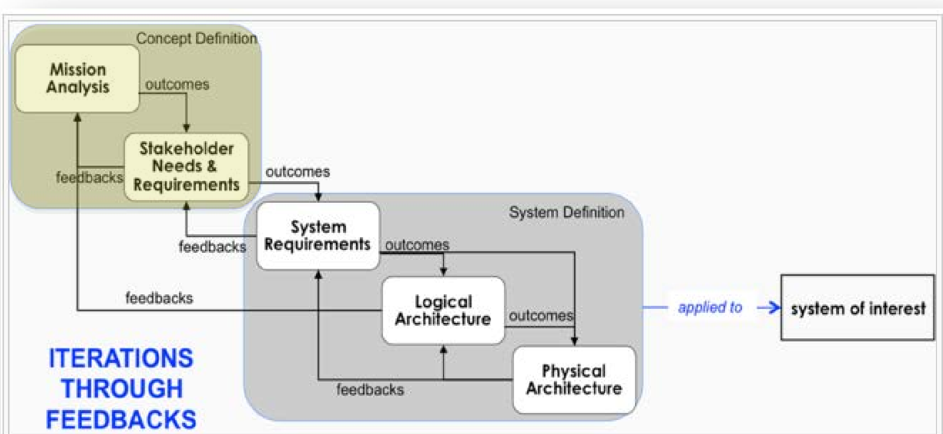

Figure 6. Concept Definition Phase within the System Development Process. Adapted from Faisandier (2012, 230).

A. MISSION ANALYSIS

The mission analysis phase defines the problem space, determines the scope of the effort, and identifies the limitations and constraints. (BKCASE Editorial Board 2016). In this section HADR response challenges are identified and a mission scenario is developed to aid in analysing the problem space.

1. Challenges with HADR Operations

A common theme within the research is that better communication and coordination between all parties would greatly enhance the effectiveness of HADR relief efforts. A review conducted by UN-OCHA identified factors hindering effective civil-military coordination and developed recommendations to break down the hindering factors. These recommendations came from a review of Typhoon Haiyan, Cyclone, Pam, and the Nepal Earthquake lessons learned. One of the findings concludes the following, "A humanitarian civil-military coordination capacity in domestic (national) and international rapid response mechanisms should be institutionalized in order to optimize interaction and interoperability and contribute to the establishment of a common situational awareness" (Reario 2015, 9).

Communication is also critical and paramount when HADR organizations develop a response to a disaster. According to "Humanitarianism in the Network Age," OCHA Policy and Studies Series, 2012, the traditional model that responders use for managing information during a crisis revolves around four steps: collect, analyze, decide, and deliver. Today, HADR operations are evolving with advancements in technology, as more and more organizations and people want to help during a disaster. Large quantities of data are becoming available, resulting in HADR operations management becoming more complex, challenging, and critical. HADR operations also require working with a widely diverse group of organizations with different cultures and languages, different standards and protocols, and competition for resources. (UN-OCHA 2013, 24).

In 2010, the Nethope Group conducted a study on the Pakistan floods that concluded that international humanitarian organizations did not effectively take advantage of information accessibility. Instead, information remained quarantined and was not always disseminated to the affected communities. The root cause of this deficiency traces back to the lack of a common operational picture, lack of standards, and lack of organizational coordination. There was also poor information sharing between HADR responders with critical disconnects between international organizations and the host country district authorities. (UN-OCHA 2013, 24).

The Logistics Cluster is responsible for facilitating the unified response for logistics activities, and includes multiple humanitarian organizations (Logistics Cluster 2015a). A challenge identified by the Logistics Cluster during the 2015 Nepal Earthquake concluded that operation planning was hindered by the following:

> An incomplete overview of the requirements, including upstream pipeline information, future needs and importance/prioritization of needs. Though partners were requested to share information in Nepal, the information provided was scarce. This affects planning and use of resources and creates potential accountability issues. (Logistics Cluster 2015a)

Incorporating better planning tools for prioritization, along with better monitoring, information sharing, and dissemination into the OMP ensures that responders use resources more effectively, minimize duplication of effort, and ensure accountability.

Also, during the Nepal Earthquake response, responders used mobile smartphone technology to provide needs assessments and monitoring. However, according to the Nepal Earthquake Appeal Response Review provided by the Humanitarian Coalition, there were inefficiencies in the large amounts of information exchanged between organizations. In many cases the information was poorly communicated and overly complex. This leaves opportunities for improvement in data sharing and dissemination (Sanderson et al. 2015).

Though technology is becoming more accessible, in some underdeveloped countries there is a risk for biases within the data collected because only certain people may have access to the technology to provide feedback or to request help. These biases include gender, education level, ethnicity, religious affiliation, and those with access to technology. In certain countries there is the potential for gender bias where men have greater access to mobile phones and the internet than women (UN-OCHA 2013, 20). Therefore, it is important to ensure that there are multiple methods of communication with the affected population to ensure proper feedback is provided, and that the support is not directed towards certain groups of people.

Another challenge is the accuracy and utility of the data being provided. With big data and automated systems being developed from open-data sources the risk of compound errors increase. To mitigate this risk, the OMP needs to include a data validation feature (UN-OCHA 2013, 34).

With these challenges comes room for improvement with new technologies that can enhance situational awareness by creating a common baseline for all stakeholders, provide faster access to data and information sharing, more accurate response to the affected population's needs, real-time feedback from responders and the affected population, a greater understanding of lessons learned, accountability, and greater involvement from communities. Table 2 outlines these potential opportunities and impacts and what stage of the humanitarian process they support (UN-OCHA 2013).

Challenges should not hinder the advancements in HADR operations, but instead should be acknowledged, considered, and addressed as necessary in the on-going development of a new HADR OMP to include new applications and technology.

Table 2. Improvements to Incorporating New Technology to HADR Operations. Source: UN-OCHA (2013).

Stage	Opportunities	Impact
Preparedness	Agreements to enable automatic access to key data	Faster access to accurate data in emergencies
	Shared, standard country profiles	Common baseline; no need to re-gather basic information
Needs assessment & analysis	Easy sharing of information across needs assessments; access to underserved populations	Reduced duplication, faster assessments
	Real-time verification of analysis through two-way communication	Greater involvement of communities in process
Joint planning	Decisions based on more robust analysis using more accurate data	Response better meets needs
	Real-time feedback from communities;	Real-time feedback from communities
Resource mobilization & allocation	Greater ability to access and track sources of funding	More accurate budgeting and efficient use of resources
	Dynamic re-allocation in response to changing circumstances	Response better meets needs
Implementation	New partners and new models of delivery	Faster, better response
	Real-time feedback from communities;	Real-time feedback from communities;
Monitoring & evaluation	Better cross-case comparison of data	Greater understanding of what works, what doesn't & how to improve action
	Real-time feedback from communities	Greater involvement of communities in process

2. Mission Scenario

In developing mission requirements, an operational scenario is used. During the writing of this thesis, a 7.8 magnitude earthquake struck Nepal on April 25, 2015, followed by aftershocks and another 7.3 earthquake on 12 May. Overall, the earthquakes killed over 8,600 people and injured over 100,000 people (UN-OCHA, Resident and Humanitarian Coordinator for Nepal 2015). This event is chosen as the operational scenario for the initial concept development of the HADR OMP due to its recent occurrence during the writing of this thesis, and also due to its relevance with one of the most recent HADR events available where the use of new technologies were used to support the response effort.

One of the main concerns during the response effort was logistics. There is only one major international airport in Nepal near Kathmandu and it has only one airstrip. This caused congestion at the airport and delayed the delivery of relief supplies. In addition, Nepal is a very mountainous region and many people were affected by the earthquake in remote locations. The number of helicopters was very limited. Damage to the roads made the task of providing supplies to these locations even more difficult. In some cases supplies had to be airlifted or transported by porter/pack animal transport (Logistics Cluster 2015a). Figure 7 provides a geographic map of Nepal displaying the epicenter of the 2015 Earthquake.

Figure 7. Nepal Map Displaying 2015 Earthquake Epicenter. Source: BBC (2015).

3. Problem Statement and Mission Objective

Based on the research conducted on HADR operations which included identified challenges and lessons learned from technology and the mission scenario, the following problem statement was identified for the OMP:

The overarching goal that drives the conduct of all HADR operations is to save lives and alleviate human suffering through efficient management of information and resources. Currently, the ability to provide this efficient management is lacking, as there is no single consolidated network-based platform that provides a common operating picture, software based applications, and tools to aid HADR responders in the management of operations in a rapid, succinct, and coordinated fashion. For the purposes of this thesis, the HADR OMP is a network-based platform that includes the physical hardware, software, and network necessary to support the functions to effectively manage HADR operations. The following mission system objective is developed based on the identified problem statement:

The HADR OMP's primary mission is to create a network based platform to rapidly provide common situational awareness and management tools focused on the early phases of a HADR event, and to support the affected people impacted by the disaster.

4. Operational Concept Definition

According to Buede, an operational concept is "a vision for what the system is, a statement of mission requirements, and a description of how the system will be used" (Buede 2009, 196). The operational concept also includes the high level interactions with other systems (Buede 2009). The operational concept for the HADR OMP (or rather how the system will be used) stems from the scenario and research conducted on how HADR operations are conducted today. The operational concept includes the modes of operation, the interactions in the operational environment, timeline in the first 48 hours of initiation, identification of platform boundaries, external system interaction, environment constraints, and the use of virtual volunteers.

It is also important to note that there is not one person in charge making decisions over the entire HADR operation. Instead, there are many people from many different organizations that have to make decisions continuously throughout the response effort at multiple levels. Coordination allows everyone involved in the humanitarian response effort to share information helping to ensure that the affected people's needs are met adequately, and allowing humanitarian actors to use resources more effectively and efficiently (Harvard Humanitarian Initiative 2016).

a. Operational Modes

The operational modes of HADR operations is important to understand to ensure each activity is accounted for within the OMP. The modes of operation are based on the Humanitarian Programme Cycle (HPC) elements developed by UN-OCHA and endorsed by the IASC (UN-OCHA 2015a). However, the description of these modes are modified from the HPC elements to focus on the management of HADR operations at the tactical level versus strategic level. These modes are broken into five different categories as shown in Figure 8. The mode categories include needs assessment and analysis, planning, resource mobilization, implementation and monitoring, and review and evaluation.

The needs assessment and analysis mode provides rapid analysis of the overall crisis situation based on inputs primarily provided by HADR responders, host nation, and the affected population. It also includes country specific information. During this mode needs are prioritized. This information feeds into the planning mode where the most pressing needs are identified, the scope of the response is determined, roles and responsibilities are established, and the mission objectives of the relief effort are identified. In addition, target and indicators are established to track progress and ensure accountability. This planning feeds into the resource mobilization to support decision on initial tasking, requests, and allocation of personnel and resources. This mode also includes the status of these resources, and feeds into the implementation and monitoring mode. The implementation and monitoring mode provides the situational awareness necessary to monitor performance and identify gaps in meeting mission objectives. It is also where the implementation of the response takes place. Decisions are made on re-allocation of resources real-time to support dynamic changes impacting prioritized objectives. This mode is also coupled with the coordination and collaboration necessary to support the HADR response (UN-OCHA 2015a).

Though the modes are shown in sequential order it is important to note that these actions happen continuously and in parallel during the HADR response effort. These modes are the basis for the high-level functional decomposition of the OMP and aid in identifying the various components necessary to support the management of these operations.

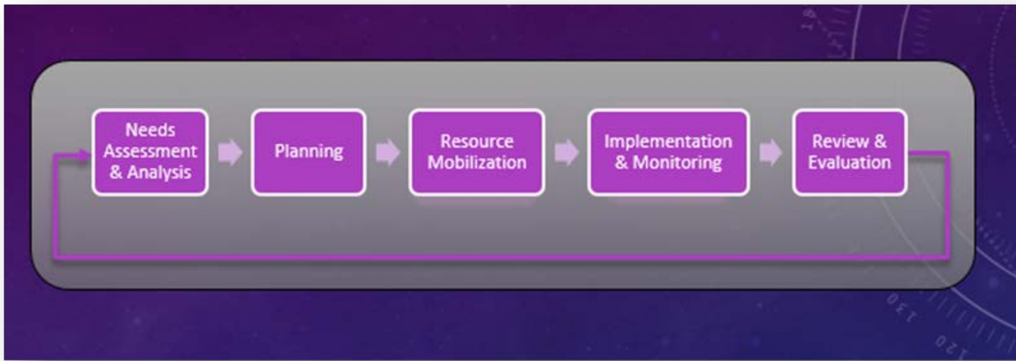

Figure 8. Operational Modes based on the HPC. Adapted from UN-OCHA (2015a).

b. Operational Environment

To develop an OMP it is important to understand the operational environment in which the platform will operate and the relationships between the various elements. Figure 9 shows a graphical representation of the HADR response effort at the high operational view level known as an Operational View-1 (OV-1). This OV-1 shows the operational environment the OMP will need to operate in. The HADR response includes providing support and essential needs to the affected population with shelters, medical care, and aid to injured or trapped victims with support from search and rescue teams. Essential supplies are needed to support the victims such as food, water, and medicine. These supplies are transported primarily by trucks or helicopters. In this "Nepal" scenario, water transport is unavailable, and poses a challenge for transporting supplies. Communications are essential in supporting the HADR effort and are provided through radio broadcast towers, satellite communications, internet communications, phone lines, and mobile communication. Drone footage and satellite imagery is collected, and provided for analysis to support the operations.

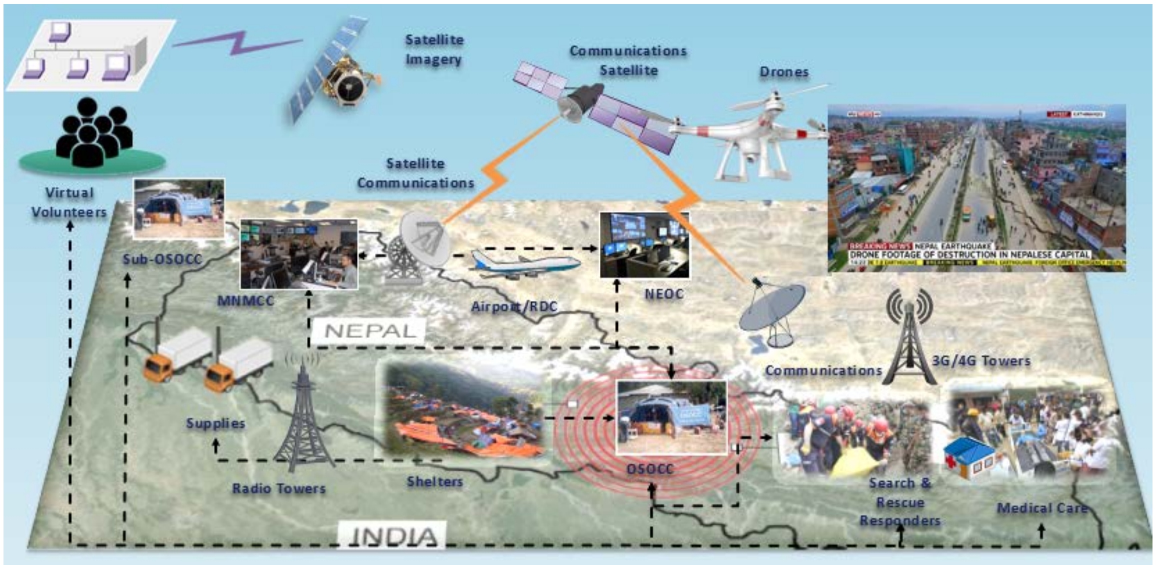

Figure 9. HADR Operations OV-1

The airport is the primary Reception and Departure Center (RDC), and is the main point of entry and exit for HADR responders traveling to Nepal to support the response effort. The On-Site Operations Coordination Center (OSOCC) is responsible for rapidly providing coordination and information management between various NGOs, cluster teams, foreign militaries, the host nation, and response teams. (UN-OCHA, FCSS 2014). All of these humanitarian responders make decisions that impact the response effort, thus all responders have access to the HADR OMP with the OSOCC as the primary user.

The Multi-National Military Coordination Center (MNMCC) facilitates the collaboration and coordination with foreign militaries supporting the HADR response, and play an active role in the mobilization of resources. The National Emergency Operations Center (NEOC) or the Local Emergency Management Authority (LEMA) are typically run by the Host country. The NEOC/LEMA is responsible for the overall command, coordination, and management of the response operation, and works closely with the OSOCC (UN-OCHA, FCSS 2014).

The operations use virtual volunteers to analyze satellite and drone imagery for infrastructure and damaged roadways, as well as analyzing Short Message Service (SMS) texts to identify specific needs of the population.

c. First 48 hours after a HADR Event

After a new HADR event takes place, a UN Disaster Assessment and Coordination (UNDAC) team is deployed to assess the humanitarian impact as well as to assist in the coordination of incoming international relief support. The UNDAC members and search and rescue teams are on standby to respond within 12–48 hours anywhere in the world. The virtual OSOCC is setup within 12 hours, and the physical OSOCC is established within 24–48 hours. Figure 10 shows the UN-OCHA response nominal timeline within the first 48 hours after a crisis occurs. The HADR OMP is incorporated into the timeline with the virtual platform operational within the first 12 hours (same timeline as the virtual OSOCC). The deployed HADR OMP units are operational within the first 48 hours after a crisis begins. These units are deployed to the OSOCC, MNMCC, and the NEOC. This timeline is taken into consideration when developing mission requirements for the HADR OMP (UN-OCHA, CMCS 2015).

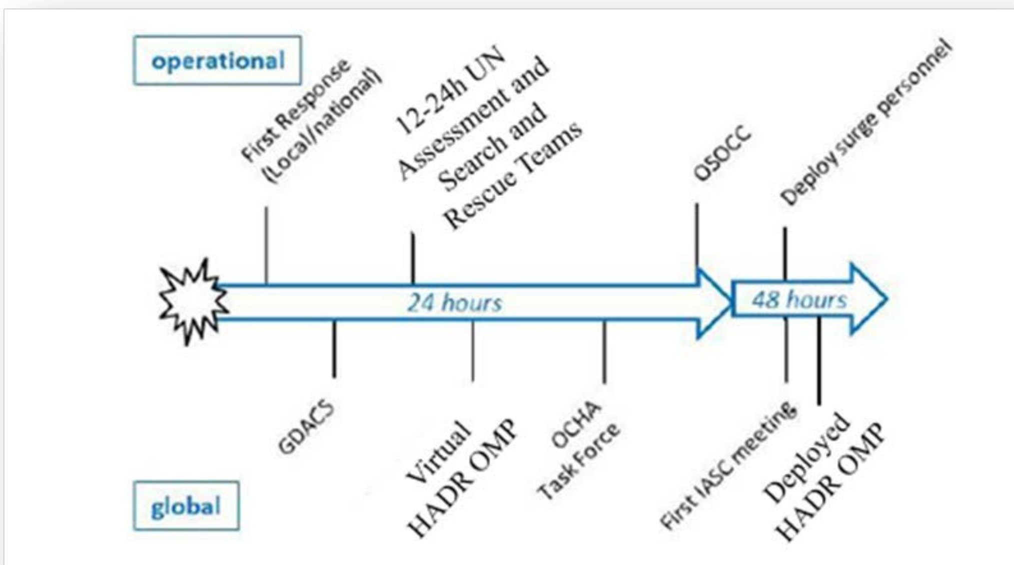

Figure 10. UN-OCHA Timeline with HADR OMP Incorporated. Adapted from UN-OCHA, CMCS (2015).

d. *System Boundary Definition*

It is important to define the boundaries of the system to help scope the problem and better define possible design solutions. The context diagram shown in Figure 11 defines the system boundaries compared to the external factors that will interact with the platform. These interactions are essential to fulfill the mission objective, and for effective support to the victims of the disaster. The external factors to the OMP include data sources, people, logistics, communication nodes, medical support, repair of critical services, search and rescue efforts, and survival essentials. Included within the system boundary of the OMP is platform support, training, and network communications.

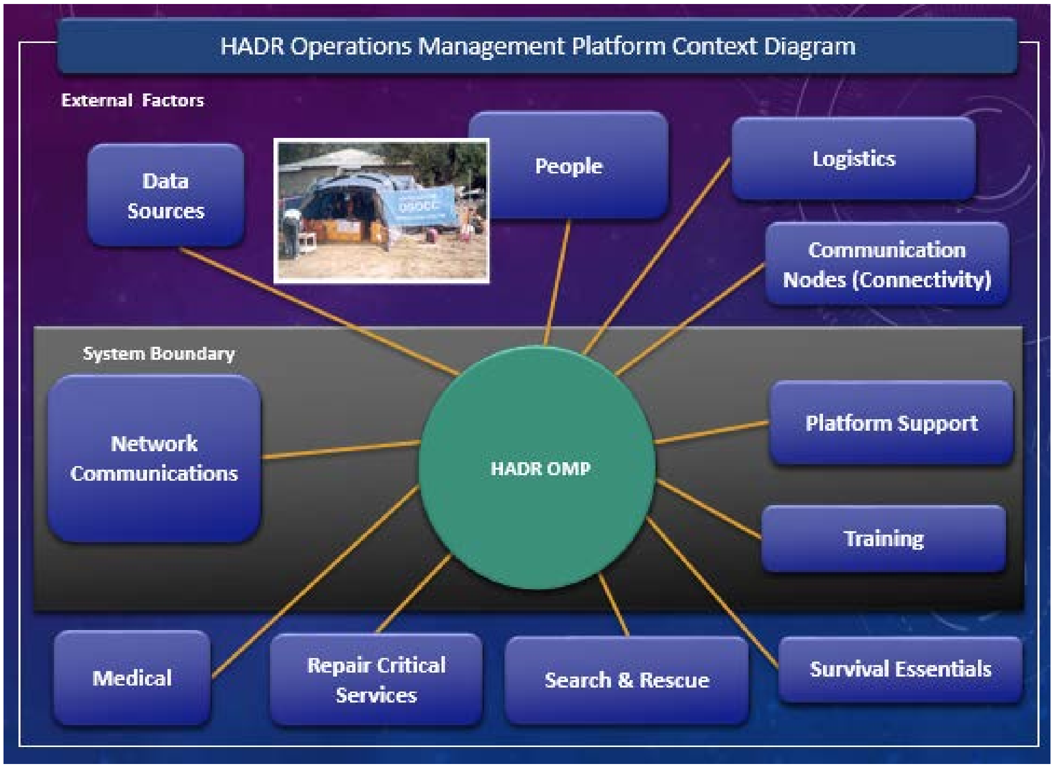

Figure 11. HADR OMP Context Diagram

e. *External Systems Diagram*

According to Buede, an external systems diagram "defines the interactions in terms of inputs and outputs with other systems and is consistent with the operational concept" (Buede 2009, 70–71). It is important to identify the external systems that the

HADR OMP will interface to, either for inputs into the system or as an output. Figure 12 shows the external system diagram developed with potential data source initial inputs and information provided to external users via a graphical user interface. However, it is important to note that the platform will also need to be adaptable and expandable to incorporate new input and output sources as the system matures.

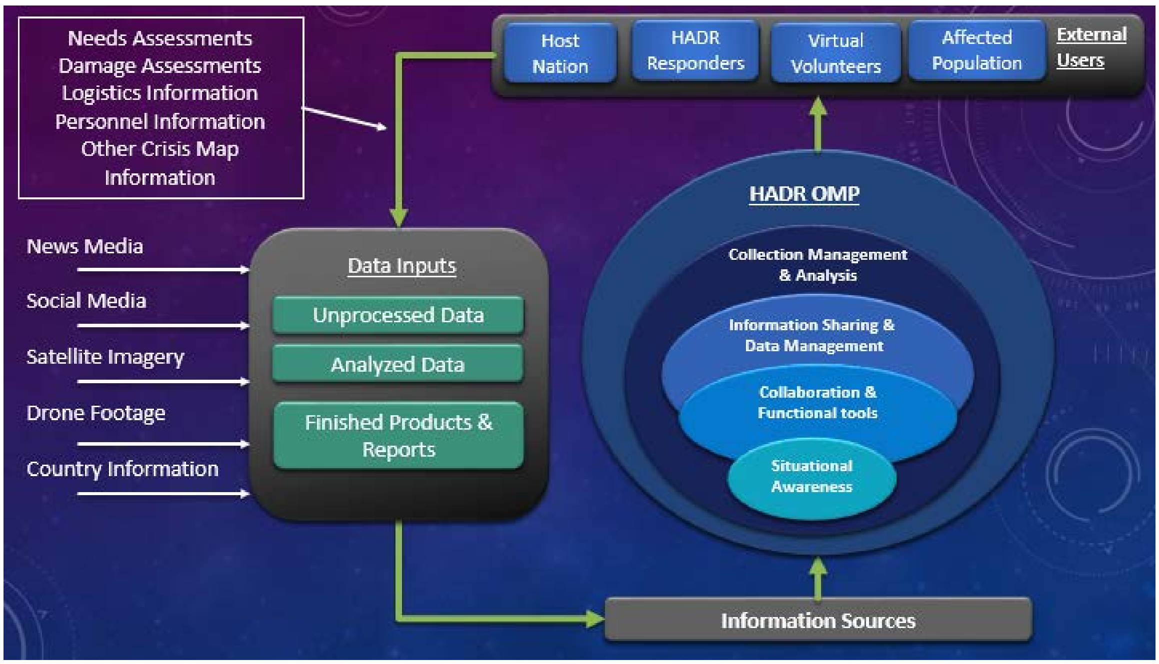

Figure 12. High Level External System Diagram with Input/Outputs

The external users of the HADR OMP include the host nation, HADR responders, virtual volunteers, and the affected population. These users are seen as the customers of the platform, but also contribute to providing the information necessary for the OMP to meet its mission objective and MOEs.

The external data sources at the high level can be broken into three main categories: unprocessed data, analyzed data, and finished products and reports. The unprocessed data is used in the HADR OMP for analysis such as drone imagery foots or satellite imagery. The analyzed data is data that was analyzed by an external source before being provided to the HADR OMP. This includes social media such as Twitter and SMS texts pertinent to the HADR operations, or crisis map information. Analyzed data can also include crisis map information. The finished products and reports can include needs assessments and damage assessments provided by HADR responders. Many of these finished products can be provided by the Humanitarian Response Information platform. The HADR OMP includes a common operating picture for better situational awareness, collection management and analysis, information sharing and data management, along with software based collaboration and functional tools to support the various modes of HADR operation.

f. Virtual Volunteers

Virtual volunteers can play a critical role in supporting HADR operations. The advancements in technology are opening a new doorway and opportunities for people to help in disasters remotely. One of the first major examples of virtual volunteering was during the Haiti Earthquake in 2010 (Meier 2010). During the recovery, a group of "virtual volunteers" through a system of SMS messaging and social media aided in crisis mapping efforts to help victims who were trapped or injured during the disaster. Virtual volunteers known as the Standby Task Force were also utilized during the 2015 Nepal Earthquake to help identify urgent needs, infrastructure damage, and response efforts to aid in situational awareness during the response and recovery efforts. Figure 13 shows an example of the crisis mapping developed by MicroMappers with the Standby Task Force and Qatar Computer Research Institute utilizing Open Street Maps (MicroMappers 2015b).

Figure 13. Example of Crisis Mapping Used in Kathmandu after the Nepal Earthquake in April 2015. Adapted from MicroMappers (2015b).

Figure 14 summarizes the texts and images that were reviewed during the response with over 2,800 volunteers contributing to the effort from across the globe. These volunteers identified, collected, and processed 234,727 images and 55,044 Tweets about damage assessments, needs, and deployments in Nepal. The HADR OMP will incorporate the ability for virtual volunteers to support the relief efforts to include crisis mapping (MicroMappers 2015a).

Figure 14. Virtual Volunteer Support the 2015 Nepal Earthquake. Source: MicroMappers (2015a).

Crisis mapping is included in the HADR OMP to aid in providing the COP as well as the ability to incorporate other applications that virtual volunteers can help support. Figure 15 shows the potential supporting roles that virtual volunteers can have during a HADR response effort.

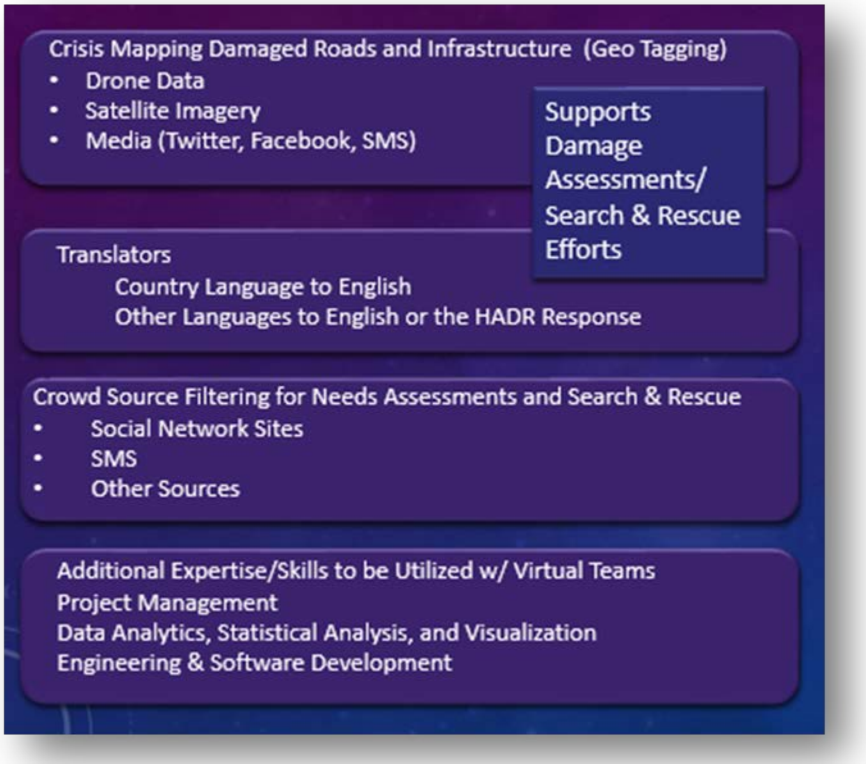

Figure 15. Virtual Volunteer Functions for HADR OMP

The United Nations also has an online volunteering search engine that allows individuals to search for volunteer opportunities by needed task, development topics, or by region where support is needed. These opportunities are not focused on immediate HADR response efforts, instead, they are focused on continued humanitarian support in countries where continued aid is needed. However, a similar approach can be incorporated and developed for HADR operations to support a response after a disaster occurs (UN 2016). Figure 16 shows the various virtual volunteer opportunity categories available from onlinevolunteering.org as well as the regions they are supporting.

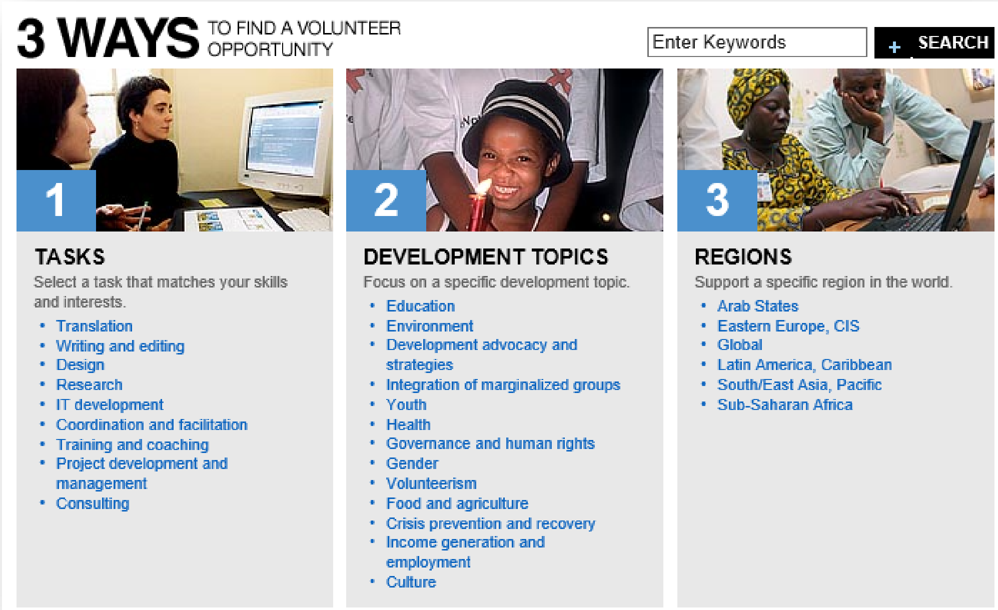

Figure 16. UN Virtual Volunteer Opportunities. Source: UN (2016).

A non-governmental organization (NGO) known as the Digital Humanitarians (DH) Network brings communities together by facilitating the coordination of requests for virtual volunteer support from traditional humanitarian actors such as UN-OCHA, governments, the Red Cross, etc. These virtual volunteer organizations provide technical skills in support of humanitarian response, and are known as Volunteer and Technical Communities (V&TCs) (DH Network 2016). Figure 17 shows the interaction between the various traditional humanitarian actors, the DH Network, and the V&TCs.

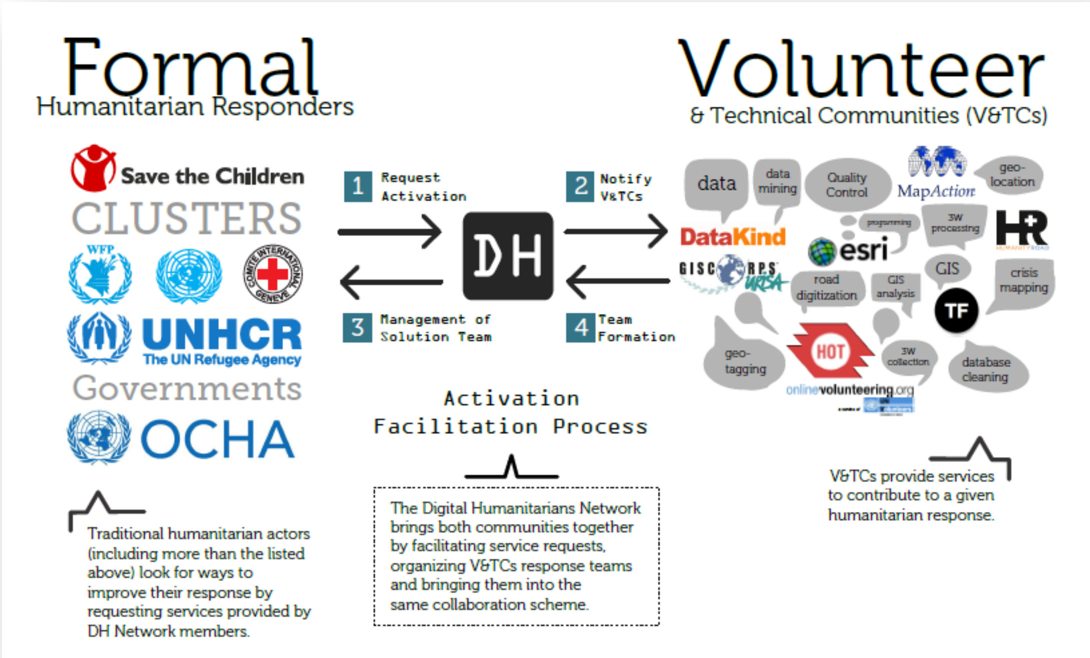

Figure 17. Digital Humanitarians Community Interaction Diagram. Source: DH Network (2014).

g. Design Constraints

Though this operational scenario is used to help determine mission requirements, the system will not be limited to only supporting in the Nepal region. Depending on where a disaster takes place the operational environment will be different. For this reason a HADR OMP must be capable of operating in various types of environments. This will be reflected in the system requirements, and will influence the infrastructure/hardware that will be used to support the system. It is expected that many disaster areas will not have adequate infrastructure to support the HADR OMP. Therefore, a deployable system must be part of the platform to meet system requirements. It is expected that a telecommunications cluster will be responsible for deploying the communications infrastructure necessary to support the platform. This communications infrastructure is considered an external interface, however, the HADR OMP will need to include the network infrastructure to support the platform. Table 3 outlines identified system requirements and possible solutions based on known environmental, technical, and local resource constraints.

Table 3. Identified System Requirements Based on Constraints

Constraint	System Requirements	Possible Solution
Environment	The HADR OMP must be a capable of operating in multiple types of environments to include desert, jungle, mountainous, near oceans, etc.	Utilizing Military Grade Hardware capable of withstanding extreme environments.
Communications	The HADR OMP must be capable of providing adequate network communications between various stakeholders	Have a dedicated team to deploy the HADR OMP infrastructure necessary to support the platform to include the network hardware infrastructure necessary for collection, analysis, tasking/ requests, information management, and dissemination, Develop tools that aid in collaboration and communication flow within the OMP.
Local Resources	The HADR OMP will make use of local resources to the greatest extent possible. The HADR OMP will coordinate the needs for additional resources needed that are outside the ability of the local resources available.	Incorporate logistics system tool to identify, request, track, and task needed resources. Within the logistics system, setup a mechanism/tool that allows local businesses/communities/groups to provide information on the resources available for purchase to aid in the effort. (i.e., food, water, shelter, clothing, machinery, medical supplies)

B. STAKEHOLDER NEEDS AND REQUIREMENTS

The next activity within concept definition is the stakeholder needs and requirements analysis. This activity identifies the stakeholder's needs, importance, and priority. Following that, mission and user requirements are established. Overall, the purpose is to ensure that the development of the system meets the necessary primary stakeholder needs. With the complexity of HADR operations, not all stakeholders' needs can be met. Therefore, this analysis will prioritize stakeholders to ensure that critical needs are identified and addressed within the development of the platform.

1. Stakeholder Needs Analysis

Research was conducted on the stakeholders involved in HADR operations as well as lessons learned from previous HADR events. This research included documentation policies, guidelines, and procedures by well-established HADR organizations such as the UN-OCHA. The stakeholder needs assessment is a critical aspect to the development of a system, and ensures that the needs of the users are clearly identified and defined. It provides an opportunity for stakeholders to give consensus and/ or feedback on the priorities in developing the system. This initial assessment is the view of the author after conducting stakeholder research as well as considerations from HADR challenges, lessons learned, and the operational concept previously described. Stakeholders should validate this assessment in future efforts.

This section shows the identified high-level needs of various stakeholders involved in a HADR event. The stakeholders' needs were prioritized by importance for developing a HADR OMP from one (1) through five (5), with five being the highest priority and one being the lowest. The stakeholder analysis uses the following priority definitions:

Priority Five is any group that has been deprived of basic necessities due to a disaster and requires immediate life-saving assistance (i.e., the Affected Population).

Priority Four comprises groups that exercise command and control over HADR operations, any host nation group that provides direct support to victims in the disaster area, or any group that provides direct coordination between the UN and HADR organizations.

Priority Three groups serve a necessary communication and coordination role between governments and/or NGOs during a HADR event, but do not exercise Command and Control and do not expose themselves to the disaster environment.

Priority Two groups are organizations that do not exercise Command and Control and do not expose themselves to the disaster environment, but provide logistical support to the HADR area of operations.

Priority One groups consist of any stakeholders that do not meet the criteria of priorities two through five.

This stakeholder needs assessment is an initial examination and should be re-evaluated with feedback from stakeholders to ensure that the needs are accurately defined in a future iteration.

a. United Nations, OCHA: Priority 4

The UN-OCHA is responsible for the overall coordination and collaboration between the Host Nation government, the UN, and other International government Organizations (IGOs) and NGOs aiding in the relief efforts (UN-OCHA 2015b). UN-OCHA needs to have the ability to coordinate and collaborate effectively with other Humanitarian Actors aiding in the HADR efforts. To accomplish this, the UN-OCHA must possess the capability to collect data to understand the severity of the disaster, analyze, and respond.

b. Governments: Priority 4

Various governments involve themselves with the disaster relief efforts, including the Host Nation and Supporting Nations). They require a capability to maintain situational awareness on the status of relief efforts and the ability to make decisions based on relevant and timely information. governments also need to understand resource gaps and the severity of the situation to ensure funding and resources are allocated appropriately.

c. Military Support: Priority 2

HADR operations often include various support from military units. These military units may include foreign and host nation support. This support includes, but is not limited to supplies, logistics, transportation, and medical. Military units require the ability to adequately collaborate and interface with the Humanitarian operations to understand how to best support the response effort. This includes having near real-time information to adequately respond, understanding gaps in resources, establishment of coordination mechanisms to relay status of activities, and requests for support (Joint Publication 3-29 2014).

d. Emergency Responders: Priority 4

The first-line defenders in HADR operations are Emergency Responders such as search and rescue teams, fire-fighters, and medics. These responders must have a capability to have timely and pertinent information that provides situational awareness and allocation tasking of where to best support during HADR operations.

e. Other IGOs: Priority 2

According to the Joint Publicatoin 3-29, "An IGO is an organization created by a formal agreement (e.g., a treaty) between two or more governments. It may be established on a global, regional, or functional basis for wide-ranging or narrowly defined purposes. It is formed to protect and promote national interests shared by member states" (Joint Publication 3-29 2014, II-11). While they are not directly involved in the operations, they do require information and status of the response efforts to be adequately communicated. The HADR OMP is focused on supporting the operations from a tactical and operational level, however, the OMP will also need to provide information to the strategic level to aid in higher level decision making.

f. NGOs: Priority 3

According to the Joint Publication 3-29, "An NGO is a private, self-governing, not-for profit organization dedicated to alleviating human suffering; promoting education, health care, economic development, environmental protection, human rights, and conflict resolution; or encouraging the establishment of democratic institutions and civil society" (Joint Publication 3-29 2014, xii).

NGOs need to be informed on how best to support the HADR response effort. This can include tasking and resource allocation. Also, NGOs require the ability to provide feedback such as damage assessments, and casualty information. Finally, NGOs require stronger coordination, compiling, and information sharing between the various actors in order to raise issues of common concern hampering the response; mitigate any duplication of efforts; and maximize the use of available people and resources (Logistics Cluster 2015b).

g. Cluster Members: Priority 4

According to UN-OCHA, the cluster approach is a needs-based response system that focuses on various functions to support HADR operations to include health, protection, food security, emergency telecommunications, early recovery, education, sanitation, water, hygiene, logistics, nutrition, emergency shelter, camp management and coordination, and information management. These various clusters perform specific functions or tasks and can be activated at different phases of a disaster (UN-OCHA 2015c). Cluster Teams need information management and situational awareness to support operational decision making, and to improve the efficiency of the response to the operation. These services need to include consolidated sharing of information from the humanitarian community and local authorities on the overall situation, including logistical gaps and bottlenecks (Logistics Cluster 2015b). According to the Logistics Cluster, the cluster teams require:

1. Updated operational information, such as road conditions, warehouses and customs procedures as well as the publication of situation reports, bulletins, snapshots, flash news and briefings.
2. Tools and products, inclusive of specific maps related to logistics infrastructure.
3. Capability to monitor the situation and to receive updates on assessments. These assessments will be regularly shared with the humanitarian actors to ensure efficient delivery objectives (Logistics Cluster 2015b).

h. Operational Coordination Centers (OCCs): Priority 4

The Operations Coordination Centers (OCCs) are the various coordination centers and committees activated during a HADR event such as the OSOCC, MNMCC, and the NEOC. They require a HADR OMP that can be used by various stakeholders that are involved in a time critical humanitarian response effort. This platform must include multiple sources of up-to-date information to ensure the most comprehensive understanding of the situation, gaps is resources, and needs of the people affected by the crisis.

i. Media: Priority 3

The news media outlets that report on the HADR event have the ability to support HADR operations by distributing needed information to the affected population. These media outlets need to be provided with current crisis information that can be relayed to the people involved in the crisis.

j. Virtual Volunteers: Priority 4

The virtual volunteers associated in supporting the HADR effort need to have established roles agreed to and understood by the HADR responders responsible for coordination to ensure their utility. The tasks they will be performing will need to be planned for within the design of the OMP to ensure the appropriate functionality and/or external interfaces are present. This can be achieved with existing or newly developed applications. Virtual volunteers need the ability to access timely information to

k. Affected Population: Priority 5

The affected population is the victims and family members of those effected by a disaster. Their primary needs include safety from harm, locating family members, and recovery from the disaster. They also require adequate food, water, shelter, medical services, and support if injured in the crisis. Finally, affected populations must be informed on where to find help and support and have the ability to provide feedback on the relief efforts to ensure the responders are meeting the needs of those affected.

2. Summary of Key Stakeholder Needs

After analyzing, prioritizing, and integrating the various stakeholder needs, ten key needs were identified. These key stakeholder needs are shown in Table 4. These needs are critical to the success of meet the objective of the HADR OMP.

Table 4. Key Stakeholder Needs

No.	Key Stakeholder Needs
1	Rapid and Persistent Information
2	Enhanced Data Exploitation & Analysis
3	Enhanced Common Situation Overview
4	Enhanced Collaboration
5	Enhanced Communication
6	Enhanced Information Collection
7	Enhanced Metrics and Accountability of Ops
8	Interoperability with Existing Systems and Applications
9	Incorporation of Virtual Volunteers
10	Sharing of Information to Affected Population
11	Meet Operational Timelines
12	Meets Environment Constraints

3. Measures of Effectiveness Requirements

According to AcqNotes, a source of Department of Defense (DOD) acquisition knowledge, Measures of Effectiveness (MOEs) "are measures designed to correspond to accomplishment of mission objectives and achievement of desired results. They quantify the results to be obtained by a system and may be expressed as probabilities the system will perform." In addition, the MOEs will help define how well a system carries out the operational objective within specified boundary conditions (AcqNotes 2015).

According to the Sphere Project, their initiative is "to determine and promote standards by which the global community responds to the plight of people affected by disasters." Their handbook, the Humanitarian Charter and Minimum Standards in

Humanitarian Response, is used to establish the minimal standard of care for food, water, hygiene, shelter, and medical for the affected population during a crisis (The Sphere Project 2015). The HADR OMP will be developed in a way that will allow event specific target and indicators to be established and monitored per each HADR crisis and response.

Based on the mission analysis and stakeholder needs previously discussed, a listing of the identified MOEs for the HADR OMP are developed and shown in Table 5. It is important to show traceability of these MOEs back to the mission analysis and stakeholder needs analysis. By showing traceability it ensures that all the essential stakeholder's needs are met. Table 6 provides the traceability to the key stakeholder needs that were identified previously in Table 4.

Table 5. HADR OMP Measures of Effectiveness

MOE	Description	Objective	Threshold
1.0	The OMP shall provide access to persistent situational awareness to all stakeholders in supporting the HADR response effort.	100%	90%
2.0	The OMP shall provide timely information to enable collaboration, coordination, and decision making. This includes the ability to place request or task resources.	Near real-time 95% Availability, w/ 90 days storage.	Within 2 hours 70% Availability, w/ 30 days storage.
3.0	The OMP shall be globally deployable to disaster locations. This includes network communications and infrastructure to support the platform offline. (Requires a point-of-presence communications node)	Virtual OMP within 6 hours Physical Platform within 24 hours	Virtual OMP within 12 hours Physical Platform within 48 hours
4.0	The OMP shall provide metrics for accountability based on indicators and targets agreed to by HADR response leads.	Near real-time	Updates every 2 hours
5.0	The OMP shall allow virtual volunteers to aid damage and needs assessments, and to sift social media for response efforts.	10,000 Virtual Volunteers	2,000 Virtual Volunteers
6.0	The OMP shall provide management tools to support all modes of operation and will include enhanced information management for collection, processing, analysis, visualizations, and dissemination.	95% Data Accuracy	85% Data Accuracy
7.0	The OMP shall provide Interoperability with existing systems to support platform functions.	Interoperability with established HADR platforms	Interoperability with established and future platforms
8.0	The OMP shall provide up-to-date relief effort information to the affected population, and provide feedback mechanisms to identify needs of the affected population.	Updates every 30 minutes	Updates every hour

Table 6. HADR OMP MOEs Traceability Matrix

HADR OMP MOE to Stakeholder Needs Traceability Matrix												
Stakeholders Needs / MOEs	Rapid and Persistent information	Enhanced Data Exploitation & Analysis	Enhanced Common Situation Overview	Enhanced Collaboration	Enhanced Communication	Enhanced Information Collection	Enhanced Metrics and Accountability of Ops	Interoperability with Existing Systems and Applications	Incorporation of Virtual Volunteers	Sharing of Information to Affected Population	Meets Operational Timelines	Meets Environment Constraints
1.0	X		X	X	X		X				X	
2.0	X			X	X							
3.0											X	X
4.0							X					
5.0		X				X			X			
6.0		X				X				X		
7.0						X		X				
8.0										X		

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V. SYSTEM DEFINITION

The next phase of the development process is system definition. This phase includes development of system requirements, logical architecture, and physical architecture based on the stakeholder needs, operational concept and MOEs identified during the concept definition phase. Figure 18 shows the systems engineering development process, and highlights the system definition phase.

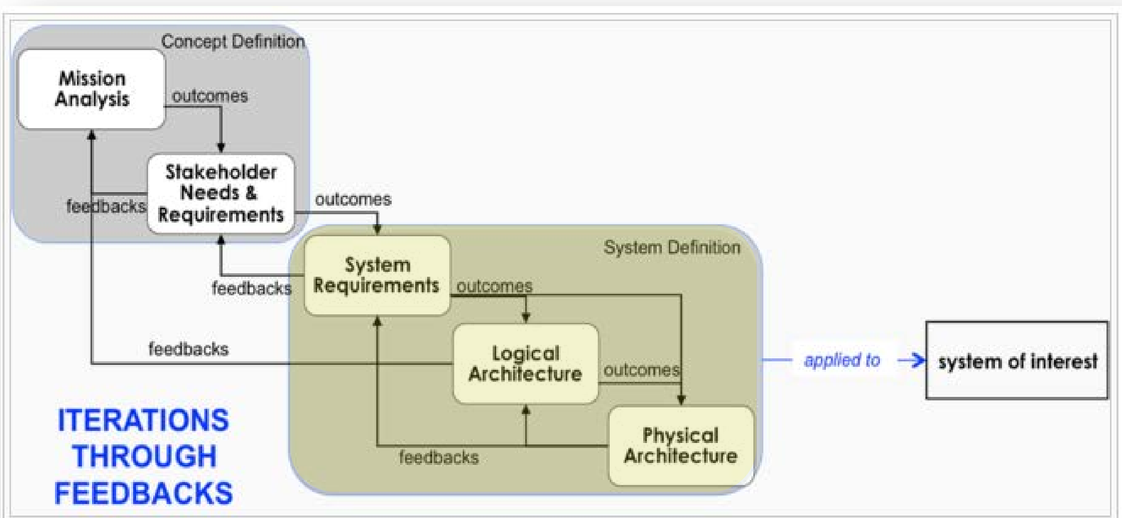

Figure 18. System Requirements Phase within the System Development Process. Adapted from Faisandier (2012, 230).

A. SYSTEM REQUIREMENTS

According to the International Council on Systems Engineering (INCOSE) Systems Engineering Handbook,

> System requirements are all of the requirements at the system level that describe the functions which the system as a whole should fulfill to satisfy the stakeholder needs and requirements, and is expressed in an appropriate combination of textual statements, views, and non-functional requirements; the latter expressing the levels of safety, security, reliability, etc., that will be necessary. (BKCASE Editorial Board 2016, 331)

These system requirements begin to form the basis of the architecture, design, integration, and verification activities while also acting as a reference for validation of stakeholder needs (BKCASE Editorial Board 2016).

1. Functional Decomposition

The HADR OMP system functions and decomposition diagram are derived from the operational concept and mission requirements, and show the operational functions and support behaviour the platform must perform to meet mission/stakeholder requirements. It is important to understand the various functions necessary for overall HADR operations in order to develop a functional decomposition for the HADR OMP. The platform functional decomposition is similar but distinct given the focus on managing and coordinating HADR operations vice developing functions to conduct every aspect of the operations. The modes of operation identified in the operational concept are used as the basis for many of the high level functions. Figure 19 provides the high level functional decomposition. Each of these high level functions will be further described in the proceeding paragraphs.

Figure 19. HADR OMP High Level Functional Decomposition Diagram

2. Functional Requirements

A review of the needs of HADR operations, coupled with the functional analysis, resulted in eight top-level functions and sub-level functions. Many of these functional requirements are based on the modes of operation described previously, and an accumulation of the literature research conducted. These functions are described in the proceeding sections.

a. Provide Assessments and Analysis

The "Provide Assessments and Analysis" (1.0) function shown in Figure 20 contains four sub-functions: (1.1) Provide Affected Population Needs based information, (1.2) Provide Foundational Information, (1.3) Provide Search and Rescue Information, (1.4) Provide Assessment Analysis.

Each sub-function brings a specific functionality to the OMP. The (1.1) sub-function provides the ability to effectively conduct needs assessments to understand the severity and level of support needed by the affected population. Sub-function (1.2) provides the ability to quickly understand reference information about the country and affected people in which the HADR effort is taking place. Finally, sub-function (1.3) provides the ability to quickly assess and prioritize requests for help in life threatening situations. Finally, sub-function (1.4) provides the tools that aid in analyzing the data to be effective for the various functions being addressed within the HADR operations.

In the case of (1.1), tools include, but are not limited to, needs, gaps, and constraints analysis and the ability to prioritize and categorize information.

Figure 20. Assessment and Analysis Function

b. Provide Planning Mechanisms

The "Provide Planning Mechanisms" (2.0) function shown in Figure 21 encompasses four sub-functions: (2.1) Set Objectives, Targets, and Indicators, (2.2) Provide Planning & Guidance Communication Mechanisms, (2.3) Provide Roles & Responsibilities (R&R) Communication Mechanisms, (2.4) Provide Accountability of Operations.

Sub-function (2.1) provides the ability to identify indicators and targets that can be tracked and continuously assessed to meet overall objectives of the HADR response. In addition, sub-function (2.2) provides tools that will aid in the communication of strategic, operational, and tactical planning and guidance of the operations. Sub-function (2.3) delivers the ability to quickly establish roles and responsibilities of various stakeholders supporting the HADR response effort. Finally, sub-function (2.4) provides the ability to ensure that there is proper accountably through the HADR operations by clearly defining roles & responsibilities and establishing tracking metrics.

Regarding (2.3), a large portion of these responsibilities should be pre-established prior to a HADR event occurring. However, it will be necessary to define more specific roles and responsibilities to various location sectors. Tools should be established to communicate these roles and responsibilities.

Figure 21. Planning Mechanisms Function

c. Provide Resource Mobilization

The "Provide Resource Mobilization" (3.0) function shown in Figure 22 envelopes three sub-functions: (3.1) Provide Personnel and Supply Resource Status, (3.2) Provide Personnel and Supply Resource Request, and (3.3) Provide Personnel and Supply Resource Tasking and Allocation.

Each sub-function traces to lower tier sub-functions that it delivers to the system. The sub-function (3.1) delivers the ability to status where all HADR materials are located and their current status (inventory, transit, onsite, etc.). It also provides the ability to maintain logs of supplies and provides the ability to status where all HADR personnel are located and their current status (on locate, in-route, etc.). Finally, sub-function (3.1) provides the ability to develop contact lists.

Sub-function (3.2) presents two lower tier sub-functions. The first is the ability for Cluster Leads or Site Leads to input requests for additional supplies such as food, water, and medicine. The second is the ability for Cluster Leads or Site Leads to input requests for additional personnel to aid in HADR response efforts.

Sub-function (3.3) traces to four lower tier sub-functions. The first is the ability to transport supplies where needed within an identified timeframe. Second, sub-function (3.3) provides tools that aid in optimization of supply routes and allocation of supplies to desired locations. Third, it affords the ability to allocate personnel where needed within an identified timeframe. Finally, sub-function (3.3) provides tools that aid in optimization of personnel resources to cover the needs of the overall HADR effort to meet identified objectives.

Figure 22. Resource Mobilization Management Function

d. Provide Command and Control (C2) Implementation & Monitoring

The "Provide Command and Control Implementation and Monitoring" (4.0) function shown in Figure 23 divides into four sub-functions: (4.1) provide Situational Awareness (Common Operating Picture); (4.2) provide Essential Cluster Function Coordination; (4.3) provide Search & Rescue Teams Status & Requests; and (4.4) provide Monitoring, Tracking, Metrics, and Alert Notifications.

The (4.1) sub-function provides the system with a COP capable of ensuring that all HADR actors responsible for making decisions during the response have access to the correct information necessary to make timely decisions. Further, sub-function (4.2) grants the ability to provide status immediate health services, food/nutrition, food security, protection, shelter, camp management, water, sanitation, hygiene products, education, and early recovery services to the affected population. Sub-function (4.3) provides the ability to status Search and Rescue operations to include, manning, equipment, and information. It also delivers the ability to task or send requests for aid to specific Urban Search and Rescue (USAR) teams, and/or provide them with the COP to help them task based on their resources available. Finally, (4.4) grants the ability to monitor and track logistics, supplies, HADR response personnel, search and rescue, cluster performance (progress of response based on defined objectives), safety and security levels, etc., on the COP. In addition, it provides the ability to track metrics on the COP of progress towards the identified Objectives, Targets, and Indicators. Provide alert notifications to identified stakeholders.

Figure 23. Command and Control (C2) Implementation and Monitoring Function

e. Provide Communication Mechanisms

The "Provide Communication Mechanisms" (5.0) function shown in Figure 24 sub-divides into four sub-functions: (5.1) Provide Information to Affected Population, (5.2) Provide Liaison/ Collaboration Mechanisms, (5.3) Provide Foreign Military Collaboration Mechanisms, (5.4) Provide Operational Review & Evaluation.

The (5.1) sub-function delivers the ability to communicate information to the affected population that is necessary to aid in alleviating suffering. This includes tools for finding missing persons, providing medical, food, and water location information, etc. The (5.2) sub-function grants the ability to collaborate at multiple levels with multiple organizations in an effective manner to meet agreed to objectives. Provide tools to quickly define collaboration and communication mechanisms if not previously established. The (5.3) sub-function delivers the ability to incorporate communication tools specific to foreign military support collaboration at the operational/tactical levels. These tools should include the ability to quickly define collaboration and communication procedures if not previously established. Finally, the (5.4) sub-function gives responders and affected populations the ability to provide feedback and to document lessons learned from the response.

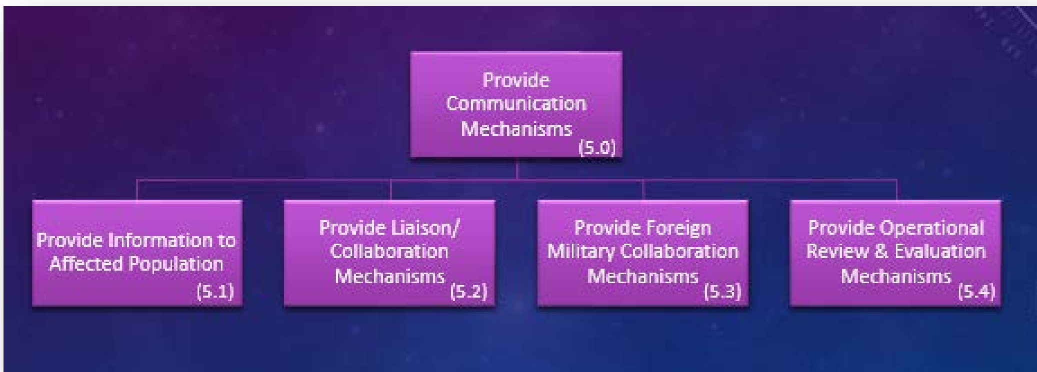

Figure 24. Communication Mechanisms Function

f. Provide Ops Support

The "Provide Ops Support" (6.0) function shown in Figure 25 expands into four sub-functions: (6.1) Provide Personnel & Administration Management, (6.2) Provide Information Management, (6.3) Provide Management of Financial Needs & Tracking,

Each of these sub-functions on-boards a critical OMP function. The (6.1) sub-function delivers tools for managing the inflow/outflow of personnel in the HADR response zone, maintaining contact lists, providing tools for funds transfers and tracking. The (6.2) sub-function provides the ability to manage the information and make it easily accessible to users. This includes the collection, processing, analysis, visualization, and dissemination of information. The (6.3) sub-function endows the platform with the ability to manage financial needs, and track inflow/outflow of funds provided to support the HADR effort. Finally, the (6.4) sub-function provides the ability for virtual volunteers to support the OMP. This can include the functions described previously in Figure 15.

Figure 25. HADR Operations Support Function

g. Provide System Support

The "Provide System Support" (7.0) function shown in Figure 26 expands into five sub-functions: (7.1) Provide System Management; (7.2) Provide System Security; (7.3) Provide Network Management; (7.4) Provide System Support Infrastructure; and (7.5) Provide Training & IT Support.

The (7.1) sub-function ensures that all the HADR OMP software applications and components are working properly, and includes the ability to manage the software applications that are developed. These software applications support the functionality of the platform to the user. The (7.2) sub-function provides the system security of the HADR OMP and ensures that the platform is protected against unauthorized access. The (7.3) sub-function bestows the ability to monitor platform communication status and outages and ensures the OMP is operating in expected parameters on the network. The (7.4) sub-function ensures the necessary platform infrastructure is provided to support the HADR OMP. This includes software, hardware, and network communications. One of the lower level third tier sub-functions under (7.4) would include interoperability to meet MOE 7.0 described in Table 5. Finally, the (7.5) sub-function provides the necessary training that is required for HADR responders to interface with the platform. This sub-function also provides the support necessary to fix technical problems with the platform while in operation.

Figure 26. HADR OMP System Support Function

3. HADR OMP Function Traceability

It is important to show traceability of the HADR OMP functions back to the MOEs. By showing traceability it ensures that all the essential stakeholders' needs, mission objectives, and MOEs are through the functions of the platform. Table 7 provides the traceability to the MOEs that were identified previously in Table 5.

Table 7. HADR OMP Functional Traceability Matrix

HADR OMP Functional Traceability Matrix								
MOEs / High Level Functions	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
1.0 Provide Assessments and Analysis						X		
2.0 Provide Planning Mechanisms		X				X		
3.0 Provide Resource Mobilization Managment						X		
4.0 Provide Command and Control (C2) Implementation and Monitoring	X			X		X		
5.0 Provide Communications Mechanisms		X				X		X
6.0 Provide Operational Support					X	X		
7.0 Provide System Support			X				X	

B. LOGICAL ARCHITECTURE DEFINITION

The next step in the system definition process is developing the logical architecture of the system (also known as a functional allocated architecture). The logical architecture, defines what the system must do to meet the functional requirements identified previously (Buede 2009, 27). The logical design provides the major functions and system boundaries of the platform along with their relationships. This allows for more detailed system design to be developed. The high level data flows and connections are also defined. The initial logical architecture is used to ensure all components and functionality necessary is accounted for and is well understood within the platform (TechieDolphin 2006). The proposed logical architecture presented is an initial assessment that can be approved upon with additional stakeholder feedback and future iterations.

1. Organizational Interaction Behavior Model

The organizational interaction for HADR operations can be very complex with multiple organizations from multiple countries helping to support the host government and affected population in the humanitarian response effort. Figure 27 provides the high level organizational view of the many stakeholders involved in HADR operations and how these stakeholders will interact with the HADR OMP. This interaction with the platform is important to understand how best to develop the coordination mechanism applications, the Graphical User Interfaces (GUIs), and to ensure that all stakeholders' requirements are being met.

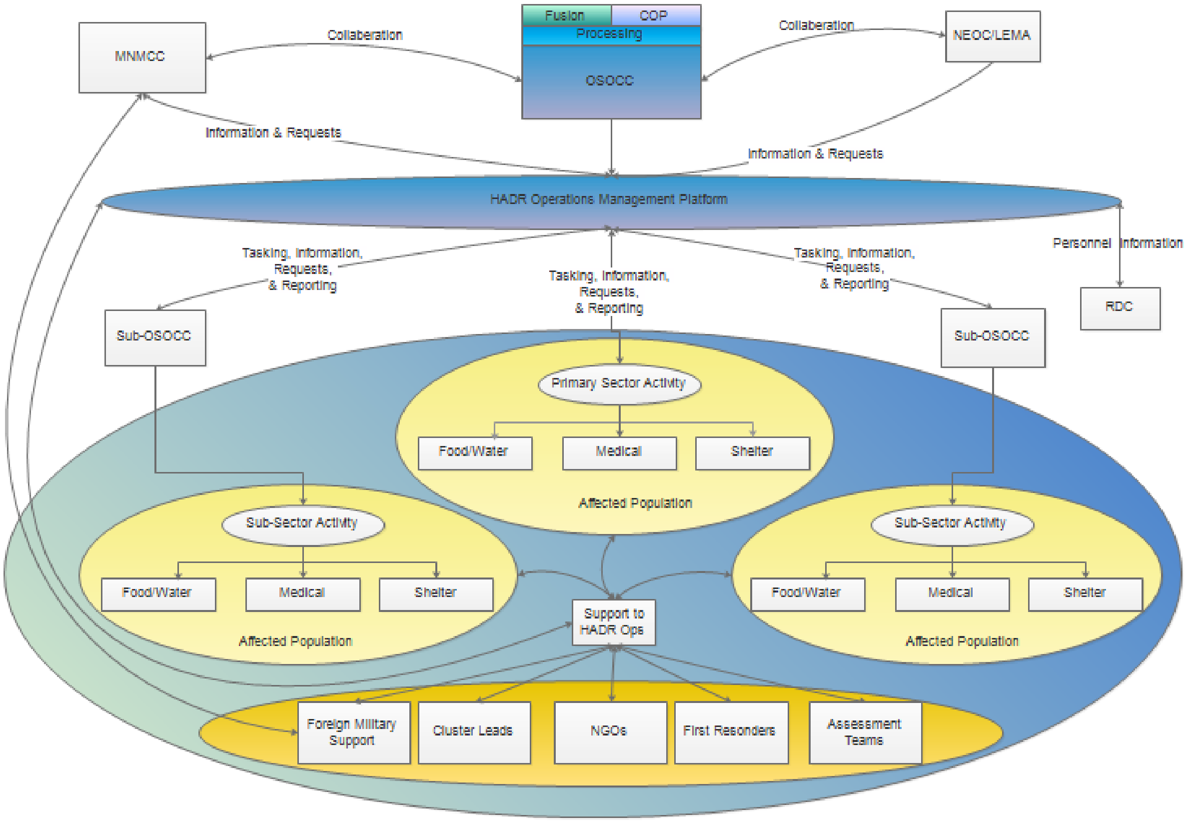

Figure 27. Interaction Organization Behavior Model for HADR OMP

2. Information Flow between Application Components

The information flow that will be required for the platform is very dynamic with large amount of information used to support many different application components. Figure 28 provides an example of the information flow that will be required between the various application components of the platform. This diagram can aid in identifying the more detailed input and output data requirements for each application component in the detailed system design. The flow of information within the platform will be managed by the data management module.

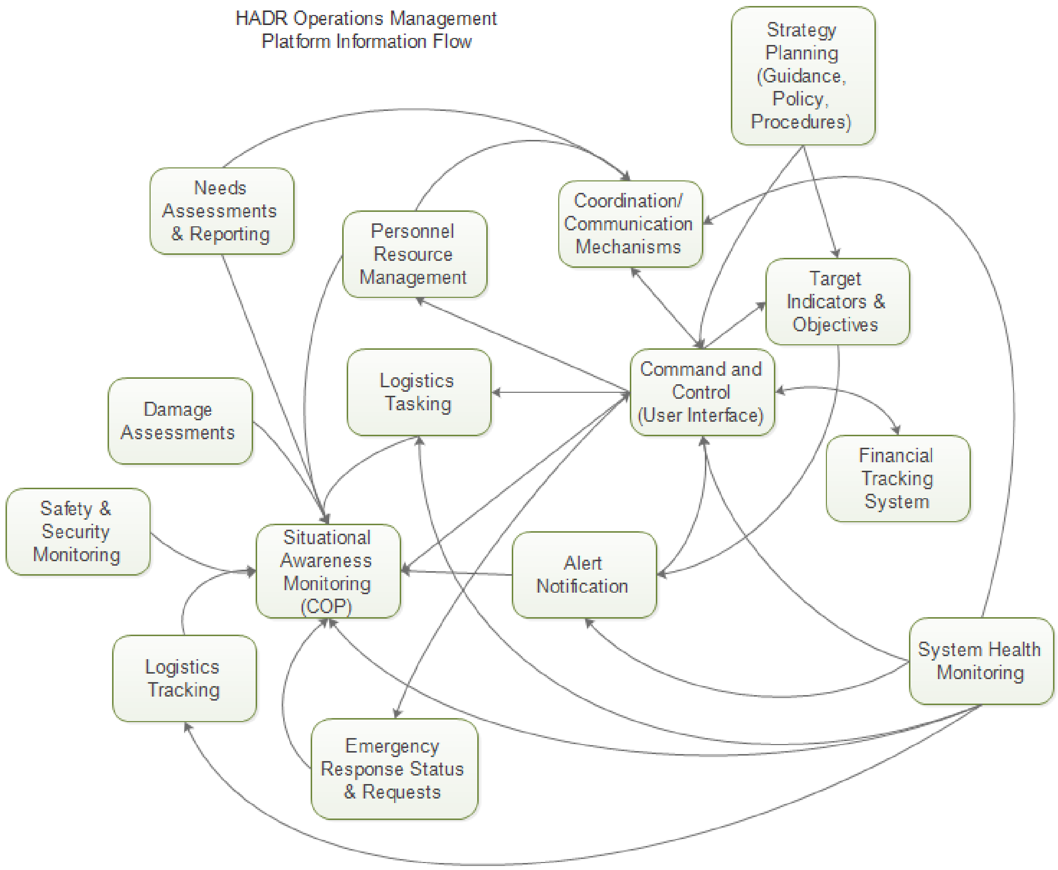

Figure 28. High Level Data Information Flow for the HADR OMP

3. HADR OMP Components

The logical architecture shown in Figure 29 provides the HADR OMP components. These components are primarily software application components and platform support components. The components are divided into four primary system components: modes of operations, support to operations, system support, and coordination mechanisms. The software application components provide the necessary functions, tasks, or activities that will be required by the various users. The architecture also shows the system boundaries with GUI visualizations as the primary output. The option for exportable data features or data sharing with other external systems may also be a consideration during the finalization of the system definition.

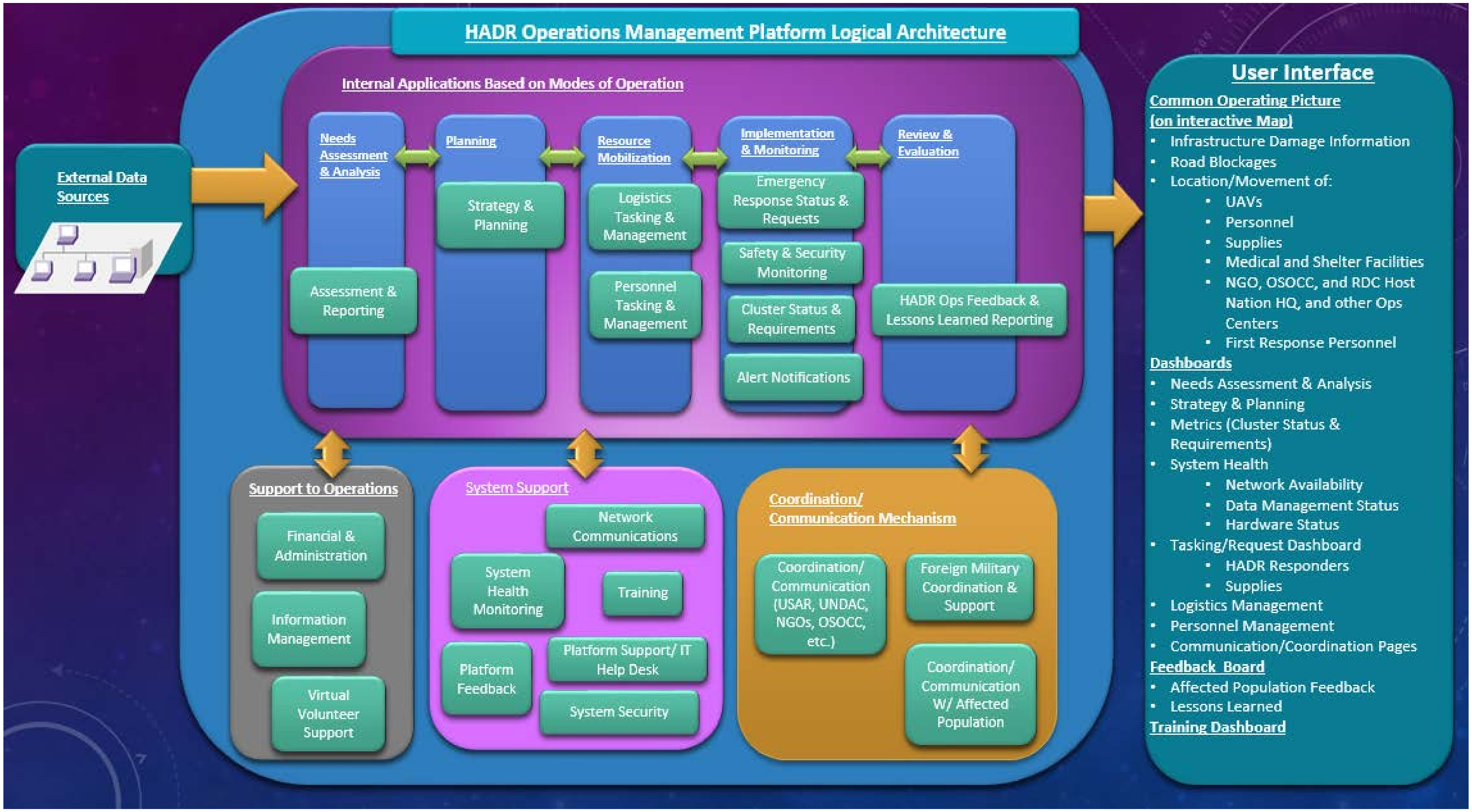

Figure 29. HADR OMP Logical Architecture

4. Function Traceability to System Application and Platform Support Components

Based on the functions developed previously, components of the HADR OMP were identified. These HADR OMP components identified in the logical architecture in Figure 29 are traced back to the high level OMP functions identified previously in Figure 19. These components are made up of software applications and platform support, and provide the functionality necessary to meet mission objectives and stakeholder requirements during various modes of operation. Table 8 provides the traceability matrix back to the high level functions.

Table 8. Software Application and Platform Support Components Traceability

HADR OMP Software Application & Platform Support Components Traceability Matrix

Components: X = Software Applications; O = Platform Support

Software Application & Platform Support Components \ High Level Functions	1.0 Provide Assessments and Analysis	2.0 Provide Planning Mechanisms	3.0 Provide Resource Mobilization Managment	4.0 Provide C2 Implementation and Monitoring	5.0 Provide Communications Mechanisms	6.0 Provide Operational Support	7.0 Provide System Support
Common Operating Picture				X			
Strategy & Planning		X					
Military Coordination & Support					X		
Personnel Tasking & Management			X	X			
Logistics Tasking & Management			X	X			
Safety & Security Monitoring				X			
Financial & Administration						X	
Coordination and Communication					X		
Assessment Analysis & Reporting	X						
Emergency Response Status and Requests				X			
Cluster Status and Requirements				X			
System Health Monitoring							X
Virtual Volunteer Support						X	
User Feedback (Operations & Platform)					X		X
Training							O
Platform Support/ IT Help Desk							O
Alert Notifications				X			
Network Communications							O
System Security							O
Physical Infrastructure							O

Figure 30 provides a pictorial representation of the traceability between the stakeholders, coordination mechanisms, modes of operation, identified data sources, and functional decomposition to the identified components of the platform. Now that the various high level functions and components of the HADR OMP have been identified definition of the logical architecture can begin to be refined.

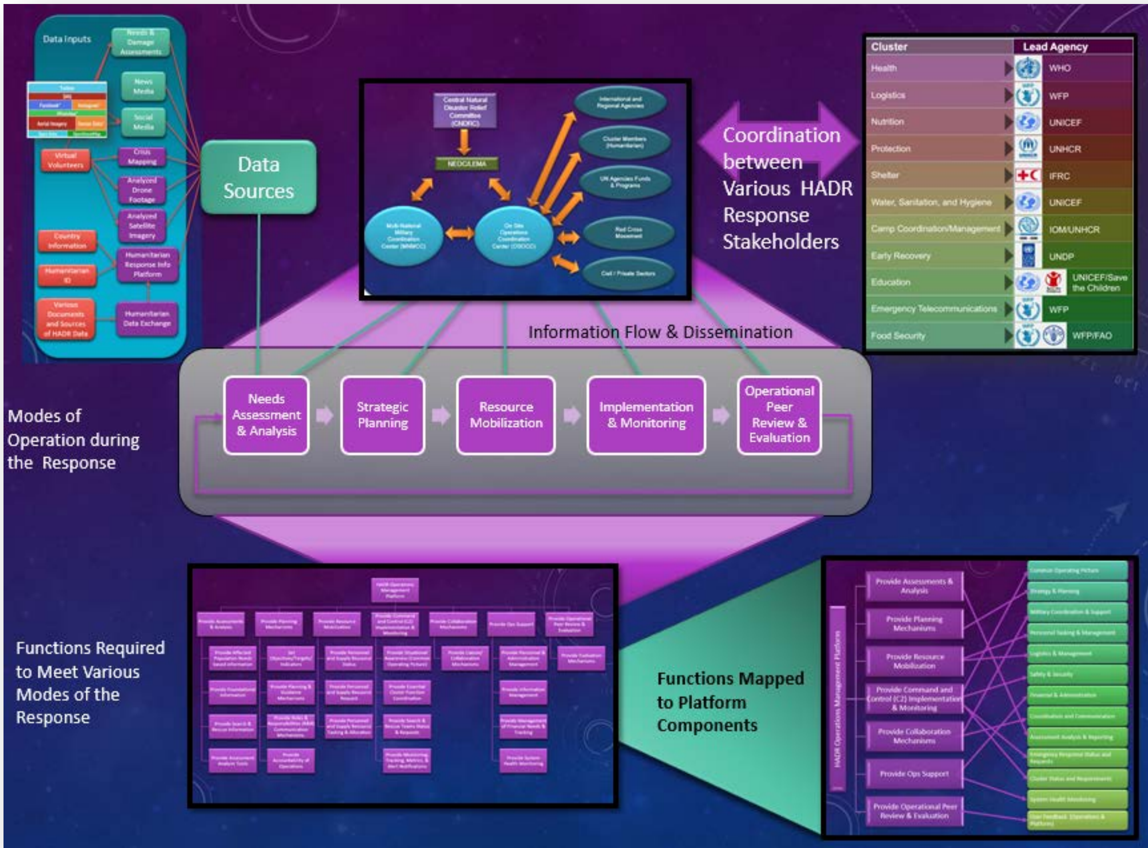

Figure 30. Traceability to HADR OMP Components

5. Common Operating Picture User Interface

The Common Operational Picture (COP) is a map with overlaid information that can be filtered from multiple data sources. This information would include personnel and supply locations while in-route to tasked locations, damage assessment information, requests for help by survivors via social media or other means such as SMS texting. Other relevant features can also be provided from satellite and drone imagery. In general the COP is a large "fused meta-data crisis map," that multiple decision makers in various roles can utilize to support the humanitarian operations effort. Figure 31 provides an example of a COP that can be displayed to a HADR responder on their tablet. This example COP is currently under development by MicroMappers (Meier 2014).

Figure 31. Example COP. Source: Meier (2014).

6. Mapping Current Technology to the Platform and Applications

Many technologies were accessed during the background and research phase of this thesis. No single consolidated platform currently exists to effectively manage HADR operations, however, there are many new applications and platforms providing information and capabilities. Many of these new applications and platforms are still in development or in beta testing, and are helping to contribute to support HADR operations. If these tools and applications are combined into a single platform they will be more effective in aiding decision makers in various functional areas and at various levels (strategic, operational, and project levels). The existing applications shown in Figure 32 and Figure 33 were identified during the research phase, and are potential data sources and applications to be incorporated into the platform to meet the system requirements. Additional information on these technologies can be found in Appendix A.

Figure 32. Applications Identified for Incorporation into the Platform.

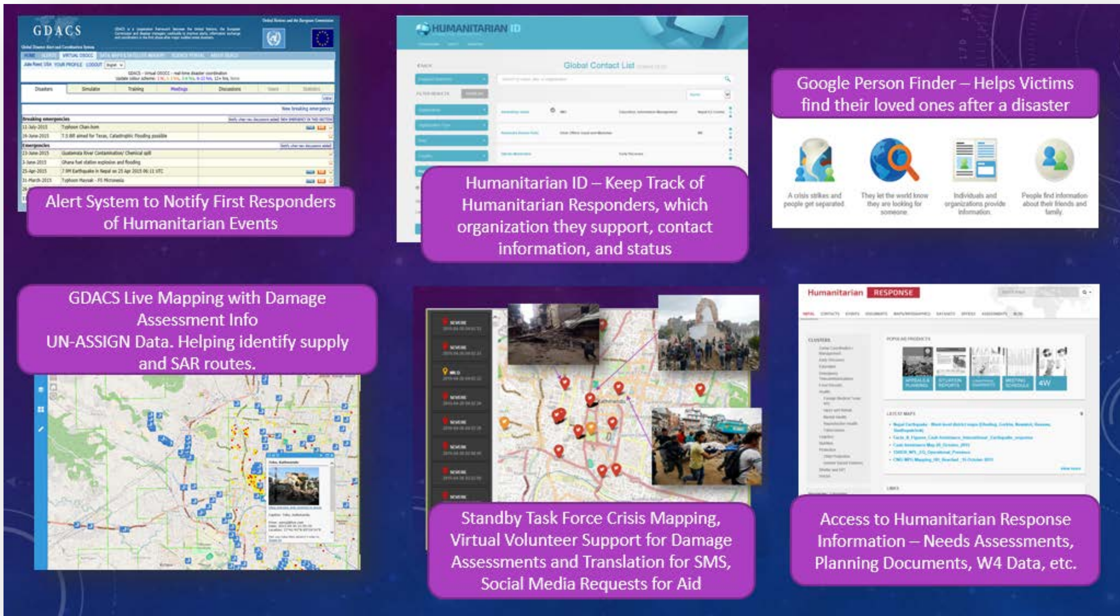

Figure 33. Data Sources and Applications to Meet Functions within the Platform.

C. PHYSICAL ARCHITECTURE

The last step in the system definition process is developing the physical architecture of the system. The physical architecture provides the physical resources necessary for every function identified in the logical architecture. Every phase of the system life cycle should be considered when developing the physical architecture (Buede 2009, 253).

1. Platform Hardware in Theater

As part of the HADR OMP, deployable hardware units will be necessary. This includes the use of ruggedized laptops and desktop computers, a projector system, communications system with radios, phones, webcam, and conferencing. A fax/printer/ copier with a backup will also be required as well as a deployable half rack (15 units) of hardware to support the local substantiation of the platform. The half rack includes switches, router, servers for local processing, a raid unit for local storage, and uninterruptible power supply (UPS) unit to protect against power shortages, and a power strip. These deployable units would be small enough to be transported on two standard shipping pallets, and be provided to the On-Site Operation Coordination Center (OSOCC), the National Emergency Operations Center (NEOC), the Multi-National Military Coordination Center (MNMCC), the logistics cluster, and one unit as a backup. Mobile backup hard drives will also be required for additional mobile use if the network communications system is down. Figure 34 provides a high level diagram of the deployable hardware units that will be required at the primary operations centers, and the mobile hardware to support data collection for the COP by HADR Responders. The mobile hardware includes ruggedized smartphones (iPhone and Android operating systems), tablets, and smart watches. This hardware aids in communication and relaying of information from the field to include damage assessments, needs assessments, requests for additional resources, and geo-tracking of personnel. From the telecommunication standpoint, it is expected that the Telecommunications cluster will provide the necessary terrestrial and satellite communications hardware to maintain a communication point-of-presence (PoP) node for the platform in theater.

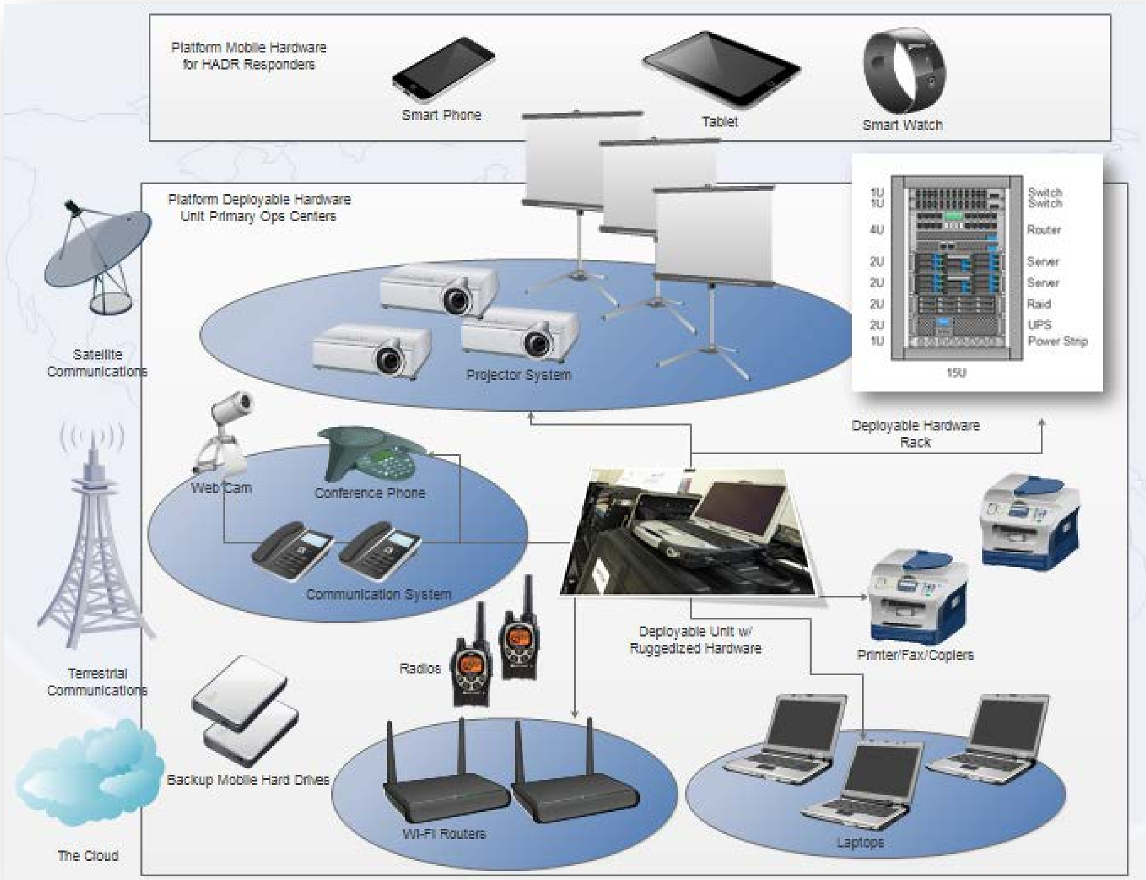

Figure 34. Deployable Hardware Units to Support the HADR OMP

2. Software Module and Service Decomposition

To support the various software applications components, a software architecture will need to be developed. The module decomposition architecture shown in Figure 35 was developed displaying the system boundaries and module decomposition to support the logical architecture for the HADR OMP. These modules decompose the solution into elements that provide the functions identified in the system requirements phase (Klein et al. 2016). A reference architecture initially introduced to support big data systems in the national security domain was used as a starting point due to the similarities in supporting the HADR OMP information management and analysis functions, such as collection, processing, analysis, visualization, and dissemination of information (Klein et al. 2016).

Table 9 provides a purpose description of the various modules necessary to support the functions of the platform. These module descriptions are slightly modified for application to the HADR OMP from a paper presented at the 2016 International Workshop on Big Data Software Engineering titled, "A Reference Architecture for Big Data Systems in the National Security Domain" (Klein et al. 2016).

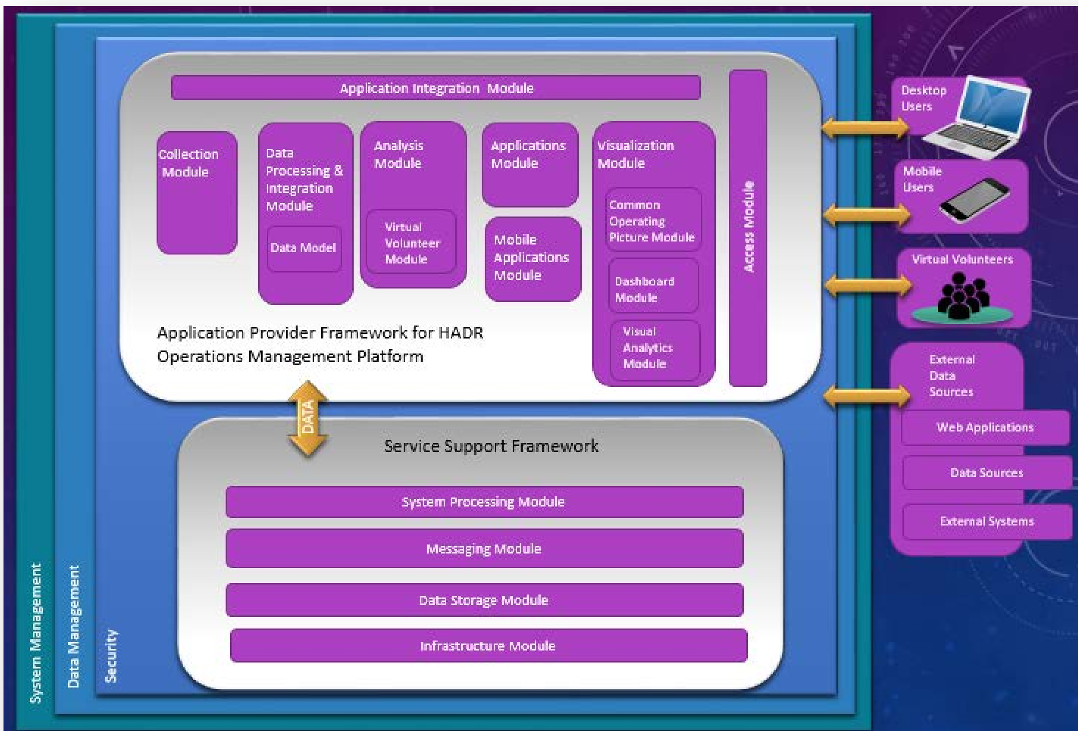

Figure 35. HADR OMP Software Module Decomposition. Adapted from Klein et al. (2016).

Table 9. Module Descriptions for the HADR OMP Based on Reference Architecture. Adapted from Klein et al. (2016).

Modules	Description
Application Framework	
Application Integration Module	Application Integration configures and combines other modules in the application provider, integrating activities into a cohesive application platform. An application is the end-to-end data processing through the system to perform specific tasks determined by the use cases.
Collection Module	The collection module interfaces with the external data providers, and ensures that the data coming in is managed appropriately by an established data model, ensuring the characteristics and constraints of the data is managed appropriately to prevent data loss. For this module work effectively. Standardization of data inputs will be necessary, and/or the ability to translate data in-line with the data model.
Data Processing & Integration Module	The main purpose of the external data processing (EDP) module is transforming data to make it useful for the other modules downstream. It performs the transformation portion of the traditional Extract, Transform Load (ETL) cycle, including tasks such as: • Data validation (e.g., checksum validation); • Cleansing (e.g., removing or correcting bad records); • Optimization (e.g., de-duplication); • Schema transformation and standardization; • Indexing to support fast lookup. The EDP module may perform basic enrichment, which adds information from other sources to a data record. Later, the Data Exploitation & Analysis Module can perform more sophisticated enrichment, for example, using a recommendation engine to create new associations to other records.
Data Analysis Module	The data analysis module works to extract relevant information from the data to be provided for exploitation and analysis. Within this module there is also a sub-module. The virtual volunteer sub-module is responsible for providing data sources to be analysed and exploited by the virtual volunteer community. This data includes social media information (Tweets, Facebook, SMS messages, etc.), satellite imagery, drone footage, etc. Initially, a human-in the loop, will be required to perform the overall analysis, exploitation, and validation within the platform by utilizing analysis tools, however, the goal should be to automate as much as possible to ensure timeliness of information dissemination.
Applications Module	This module provides the internal and external applications that are required to meet the functional requirements of the platform, and are broken down into application components. These applications are shown in the logical architecture diagram.
Mobile Applications Module	This module provides the mobile applications that are required to meet the functional requirements.
Visualization Module	The visualization module provides the graphical user interfaces (GUIs) from processed data, the outputs of the analytics, and internal/external applications to the user. Within this module there are three sub-modules: Common Operating

Modules	Description
Application Framework	
	Picture (COP), dashboard, and visual analytics. The COP module provides the GUIs responsible for creating the dynamic, on-demand generation, and interactive COP map with layers of information that can be shown or removed with a click of a button. The dashboard sub-module will provide GUIs of various dashboards, which includes various tools and applications that can be used by the users. The visual analytics module will provide the GUIs necessary to perform analysis and validation on the data collected.
Access Module	The access module allows various stakeholders to gain access to the HADR OMP, and provides access to various GUIs and information based on the user profile. This module is also the go-between with external systems, and is used to enforce the security rule-sets and permission determined in the security management module.
Service Support Framework	
System Processing Module	The Processing module ensures efficient, scalable, and reliable execution of analytics. It provides the processing hardware necessary to support the system. The HADR OMP will distribute the processing logic and execute it locally on the same nodes where data is stored, transferring only the results of processing over the network. The system processing module will also need the ability to not lose data in the event of a process or node failure within the framework (ability to recover).
Messaging Module	The messaging module provides reliable queuing, transmission, and delivery of data and control functions between application components.
Data Storage Module	The data storage provides reliable and efficient access to the data. This includes the logical data organization, data distribution and access methods, and data discovery (using e.g., metadata services, registries and indexes). The data organization and access methods will be concerned with the data storage format (e.g., flat files, relational data, structured/unstructured data) and the type of data access required. The data storage module will ensure the availability and consistency of the data over a distributed system.
Infrastructure Module	The infrastructure module provides the infrastructure resources necessary to host and execute the activities of the HADR OMP. A physical architecture will be proposed in the proceeding section.
Cross-Cutting Modules	
System Management Module	The system management module includes the monitoring, configuration, provisioning and control of infrastructure and applications.
Data Management Module	Data organization is very important with high volumes of data inputs. If done incorrectly, it can significantly impact the performance of the platform. Data Management is involved in all the activities of the life cycle to include collection, data processing, integration, analytics, visualization, and access to the system. Standardization of data will help aid in the management.
Security Module	The security module is responsible for controlling access to the data and applications within the platform, and is responsible for enforcement of access rules and restricting access based on user profiles. This modules is also responsible for protection against intrusion from hacking or other nefarious activities.

3. Distributed Computing and Network Architecture

The platform's networking architecture must be dynamic, manageable, cost-effective, and adaptable to meet the mission and stakeholder requirements. The platform must also have the ability to adapt to new applications and data sources as the system grows. For this reason a software-defined networking (SDN) architecture with distributed computing is proposed to support the HADR OMP (Cisco 2016).

Distributed computing will be necessary to aid in the vast amounts of processing that will be required. Some of these data processing servers may already exist and can be utilized with partnerships between governments, UN-OCHA, IGOs, and NGOs. It's possible that the majority of data processing can take place in a location outside of the HADR zone with processed data provided infield for fusion into the COP and local data repository to support the platform applications. This allows for the hardware units being deployed into theater to be smaller and more easily transportable, allows for additional reliability of the platform due to the unpredictability of communications and power in a HADR zone. The systems will also need to function when telecommunications are down due to this unreliability, thus backup offline systems will be part of the deployable hardware necessary to support the platform. Figure 36 provides a proposed Network Architecture for the HADR OMP. However, as part of the follow-on effort a more thorough trade-space analysis should be conducted with a networking team to ensure that the best solution is implemented.

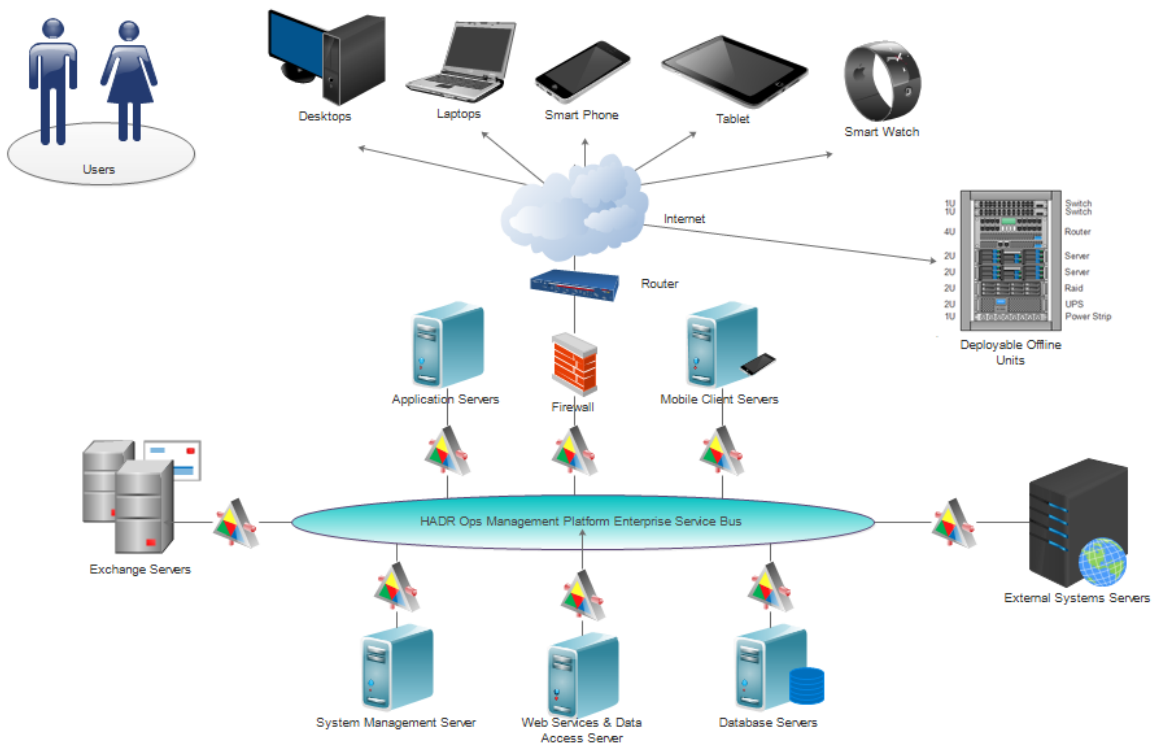

Figure 36. HADR OMP Distributed Computing Network Architecture. Adapted from Microsoft (2016).

VI. CONCLUSION AND RECOMMENDATIONS

This thesis addressed the initial concept development and system definition of a HADR Operational Management Platform (OMP) to be used by various stakeholders involved in time critical humanitarian response efforts. It includes inputs from multiple sources of information, and explores ways to provide information and tools to more effectively manage HADR efforts. The HADR OMP includes a common operating picture for better situational awareness, collection management and analysis, information sharing and data management, along with software based collaboration and functional tools to support the various modes of HADR operation.

During the writing of this thesis three primary research questions were addressed. The first question asked, "What are the functions and operational requirements for HADR operations, and how can these requirements be managed more efficiently through the use of a HADR OMP?" This question was addressed, first, by using system engineering processes and tools during the mission analysis phase to create a mission scenario, identifying the problem space, developing an operational concept, and identifying key stakeholders' needs. This led to the HADR OMP MOEs, which are the initial operational requirements for the system. From there, the functions of the HADR OMP were identified and decomposed with traceability back to the MOEs.

The second question asked, "What type of data and technologies can be utilized to support a management platform?" This question was addressed in the system definition phase. High level functions of the HADR OMP were developed along with a proposed logical and physical architecture. This allows for the identification of existing technology to include new data sources and software based applications that have the potential be incorporated into the HADR OMP to meet the functional requirements necessary for the platform.

The third question asked, "How can "virtual volunteers" most effectively be utilized to help in HADR operations?" For the purposes of this thesis, virtual volunteers are defined as people volunteering their time to conduct tasks to support the HADR response effort via their computers over an internet connection. This question was addressed by exploring the functions and roles that virtual volunteers can have to support a HADR event, and incorporating the ability for these virtual volunteers to be incorporated into the HADR OMP.

The next step is to refine the concept and system definition by receiving feedback from stakeholders involved in HADR operations to ensure all necessary requirements are captured appropriately and that the proposed solution meets the needs as expected. In addition, partnerships will need to be made between many humanitarian organizations with agreements for sharing data. UN-OCHA would need to endorse and lead the effort on creating the platform as well as advocacy from multiple humanitarian response stakeholders. Standards for data sharing will need to be agreed upon with externals starting with the Humanitarian Exchange Language (HXL) standard as the baseline.

In addition, with the potential for new technologies to aid in HADR operations there are also concerns and new challenges that are faced. When utilizing open source technologies such as crisis mapping and crowdsourcing for HADR operations many questions need to be considered. For example, the "Humanitarianism in the Network Age," OCHA Policy and Studies Series, asks the following questions:

- How do you know how accurate the information is?
    - ✓ What is the confidence level of the information being provided?
    - ✓ How subjective vs. objective is the interpretation of the data?
    - ✓ How do you know if the data hasn't been manipulated?
- If the data is shared, can it negatively impact the population at risk due to local conflicts?
- How do you ensure that biases are not made in decision making to help those who have higher level access to mobile and network technology?
- Is the HADR operations platform secure from hackers or malware (UN-OCHA 2013, 8)?

This thesis touched on these areas indirectly, but did not address them specifically. More detailed design should be completed to ensure that these questions are thoroughly answered.

Engineering teams will need to be created to further define the solution for the platform. This includes further development and detailed design of the platform applications, application interfaces, visualizations, data management (including "big data"), network architecting, network management, software management services, training programs, and deployment hardware. Follow-on research and trade-space analysis should be conducted to more thoroughly assess the existing platforms, new data sources and software based applications that can be incorporated into the HADR OMP. During the writing of this thesis, many new software applications to support HADR operations are still in development.

Finally, the system definition should include an agile software development process that allows for expandability, flexibility, and adaptability with open source software, and should meet other pre-defined quality attributes. A listing of the quality attributes can be found in Appendix B. The outputs of the system definition phase are used moving forward into the system realization phase and include the implementation, integration, verification, and validation of the system prior to deployment. A prototype should be created to aid in the development of the platform, and allow for applications to be added easily for testing for functionality and interoperability with already existing applications. The development of training courses and IT support teams will need to be in included in this development.

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APPENDIX A: TECHNOLOGY AND DATA SOURCE ASSESSMENT

Survivors and disaster relief responders now use social media and electronic communications during crises to save lives. The increased prevalence of socially-sourced information has led to interactive "LIVE" mapping during humanitarian aid and disaster relief efforts. For instance, the 2010 Haiti Earthquake was one of the first crises where crisis mapping was used to support rescue and recovery operations. After the earthquake, text messages were translated and placed on maps by "virtual volunteers" to help aid in the relief effort.

Social media has also grown at an exponential rate in the past five years. As of 2015, over +1.71 billion people have Facebook accounts (Facebook 2016) and 313 million have active Twitter accounts (Twitter 2016). In addition to its role in people's daily lives, social media can communicate crisis-relevant information, such as victim locations and infrastructure damage (UN-OCHA 2013). Figure 37 shows the most popular social networking sites by country (Cosenza 2016).

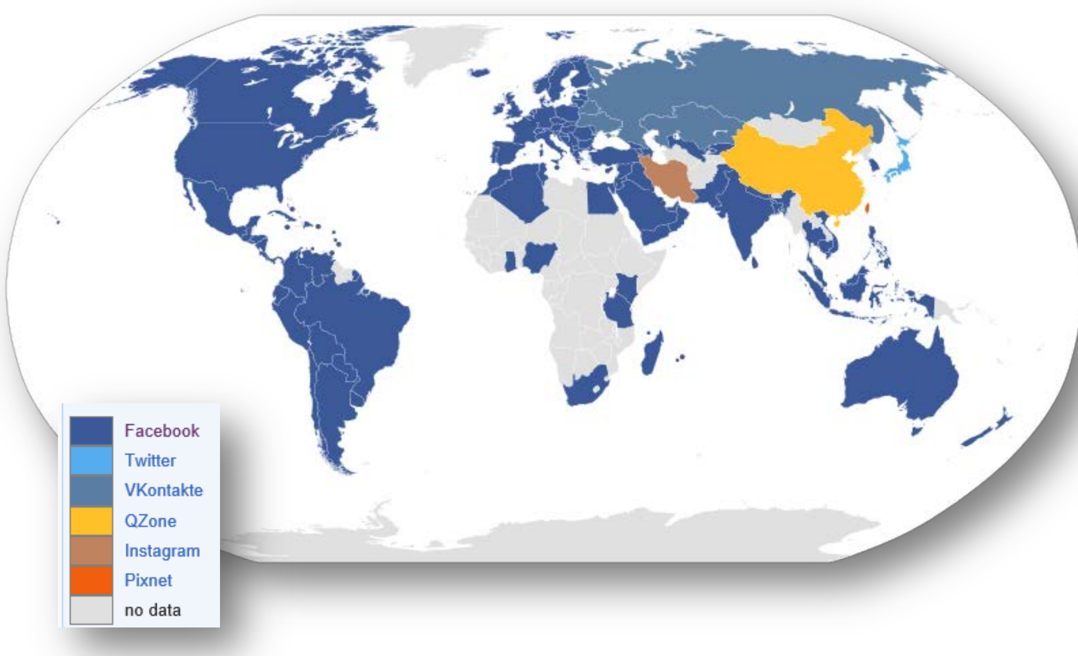

Figure 37. Most Popular Social Networking Sites by Country.
Adapted from Cosenza (2016).

Humanitarian agencies are finding new ways to aggregate and display information for decision makers. They are searching for rapid, low-cost, and accurate solutions to dynamic situations by incorporating new applications, like crowd sourcing and crisis mapping, into their operations. According to "Humanitarianism in the Network Age," OCHA Policy and Studies Series, 2012, "either organizations adapt to the network age, or they grow increasingly out of touch with the people they were established to serve" (UN-OCHA 2013, 11).

A. CRISIS MAPPING

According to Patrick Meier, an internationally recognized leader in applications of new technologies for crisis mapping, Crisis Mapping is "live mapping focused on crises (purposely broad because it can be applied to many types of crises) to include political, social, and environmental" (Meier 2009). Crisis Mapping is where "scholars, practitioners, and communities alike work together to create, analyse, visualize and use real-time data for humanitarian response and post-conflict reconstruction and development" (Meier 2009).

Crisis mapping utilizes social media, texting, and other data sources to help show the most up-to-date information on a dynamic map that can be continuously updated. Crisis mapping relies on crowd sourcing, in which, in broad terms, is defined as the "practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people, and especially from an online community, rather than from traditional employees or suppliers" (*Merriam-Webster Dictionary* 2014). Crowd sourced information comes from two primary sources, the populace in the affected community and trusted individuals like humanitarian aid workers and registered volunteers. This latter, more specific, form of crowdsourcing is known as crowd seeding.

MicroMappers is a joint initiative between UN-OCHA, Qatar Computing Research Institute (HBKU), and the Standby Task Force. According to their website, MicroMappers "is a crowdsourcing platform for consuming & classifying news, images, YouTube, aerial imagery, satellite imagery" (Meier 2014).They have activated crisis maps in recent natural disasters such as the Ecuador Earthquake in April 2016, the Nepal Earthquake in April 2015, and the Vanuatu Cyclone Pam in March 2015.

B. HUMANITARIAN ID

Humanitarian ID is a contact management application created by UN-OCHA and provides tools for humanitarian responders be to find, connect, and collaborate at the onset of a major disaster. It allows responders to develop a personal profile, provide contact details, and prepare to support a crisis ahead of time. Once registered, responders can check into the country/emergency. Responders can also develop a local profile when they support a specific humanitarian effort, join groups that are associated with the effort, check-in once they reach the disaster location, and receive relevant information related to the coordination of the disaster. If security risks are high, only verified users can view other profile and contact information (*Humanitarian ID* 2015).

Humanitarian ID also helps coordinators find responders that are working in their sector, and can manage their contact lists. Managers can also better understand the capacity and personnel gaps within the various sectors in the disaster region (*Humanitarian ID* 2015). Humanitarian ID is a possible solution to support personnel and administration management within the HADR OMP.

C. BIG DATA ANALYSIS

Big Data analysis provides correlation and analysis of large quantities of data, which can provide surprising insights into the HADR operations environment (UN-OCHA 2013, 7). The challenge with Big Data is how to take massive datasets useful to decision makers in near-real-time situations while avoiding information overload. (UN-OCHA 2013, 26). The issue of managing information overload is out of scope to this thesis; however, it is important to understand that Big Data will play a greater role in HADR operations than ever before now and into the future. The software decomposition of the HADR OMP is based on a Big Data reference architecture initially introduced to support big data systems in the national security domain (Klein, et al. 2016). Future development of the HADR OMP should include Big Data analysis.

D. HUMANITARIAN DATA EXCHANGE

The Humanitarian Data Exchange (HDX) is a database developed by UN-OCHA as an open repository for sharing information related to humanitarian and disaster relief efforts, and is searchable by the public. As of July 2016, the HDX included over 4,057 datasets from 244 locations worldwide with over 769 sources of information (UN-OCHA 2016). The HDX has many uses from a global strategic standpoint in planning and advocating for humanitarian efforts.

The HDX project is working towards providing humanitarian data real-time to governments, aid agencies, and affected people (Kobylinski 2014). However, it is unclear how this information will be effectively used to aid HADR efforts at the operational level. Future development of the HADR OMP should explore tradeoffs for including the HDX into the overall architecture or as a data source.

E. HUMANITARIAN DATA EXCHANGE STANDARDS

In 2015, UN-OCHA released their 1.0 Beta of the Humanitarian Exchange Language (HXL) standard. HXL helps various humanitarian organizations by creating a data standard for automation and interoperability. This standard helps data to be recognized and merged with other sources of data more efficiently. Figure 38 shows examples of the various hashtags, tagging, and attributes that can help support the consolidation of data between humanitarian agencies (Megginson 2015). The HADR OMP can incorporate the HXL standard into the architecture design and requirements to ensure that data is more easily, collected, processed and shared with external data sources.

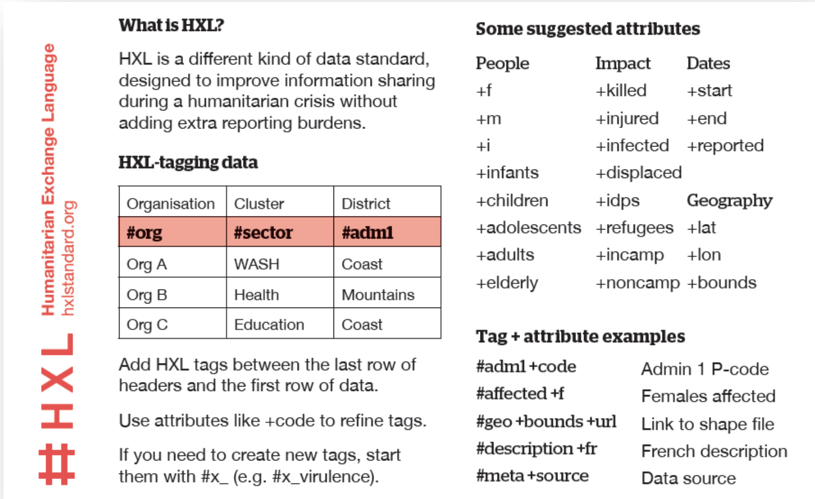

Figure 38. HXL Beta 1.0 Release – Tagging and Attributes. Source: Megginson (2015).

F. GDACS AND THE VOSOCC

The Global Disaster Alert and Coordination System (GDACS) is a framework developed in a partnership between the United Nations, the European Commission, and other disaster relief organizations. The system was developed to improve alerts, information exchange, and coordination during the initial phase after a major disaster. (GDACS 2015). The GDACS includes the Virtual On-Site Operations Coordination Center (VOSOCC) to help with collaboration and coordination of activities. In contrast, the On-Site Operations Coordination Center (OSOCC) is a local rapid response center used for coordination and facilitation of international relief, and also supports and coordinates with the Host Nation. The OSOCC is a focal point for the HADR OMP, and is described in greater detail in the operation concept section.

The VOSOCC is a computer based real-time online coordination platform that exchanges information between stakeholders in the initial phase of a disaster. This information includes: baseline country information, socio-economic background, demographics, logistical support data, relief team status, cluster activities, assessment information, Civil-Military coordination status, environmental concerns, and security risks (UN-OCHA, FCSS 2014).

Although the VOSOCC has been used in HADR operations, the system is still fairly new with room for enhancements. It is setup similar to a SharePoint site with access to information, but does not provide an overall common operating picture (COP) with all the necessary tools to manage, coordinate, and operate a humanitarian response. This results in a need for a more interactive HADR OMP to integrate these necessary capabilities. The VOSSOC is an existing platform that could potentially be incorporated into the HADR OMP.

G. GDACS LIVE MAPPING

Included in the GDACS is an interactive live crisis map that includes geo-spatial data from multiple sources. The Live Map GDACS system works to integrate satellite imagery and field data to support HADR operations by providing damage assessment information on a live interactive map. Location tagged photos are automatically uploaded from the UN-ASIGN smartphone app (UNOSAT 2015). Figure 39 provides an example of the Live Map GDACS system. The downside to the Live Map GDACS system is that other organizations are creating their own crisis maps that don't necessary talk to GDACS leaving gaps in data collection. The Live Map GDACS is an existing platform that should be considered for incorporation into the HADR OMP or as a data source. Other crisis map platforms should also be considered such as MicroMappers (MicroMappers 2014).

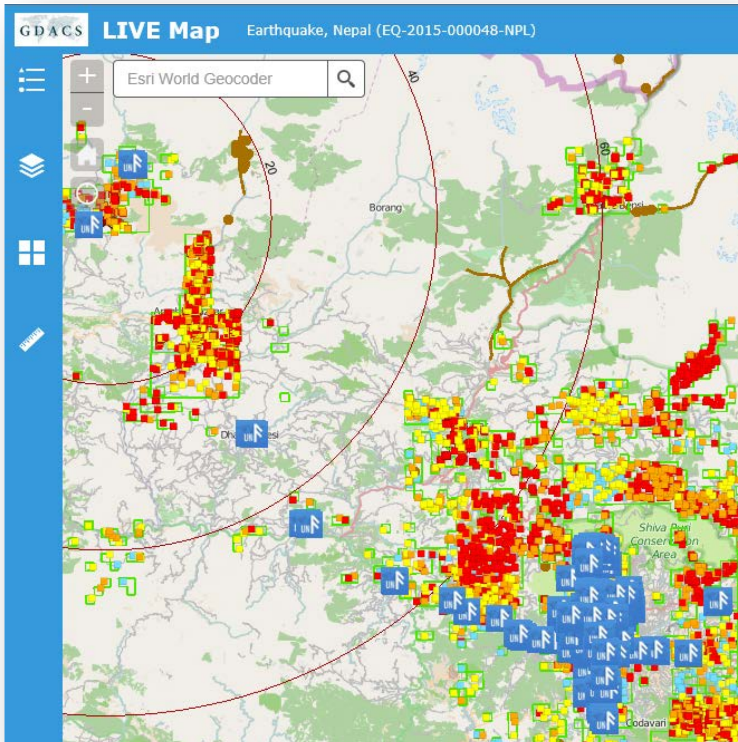

Figure 39. GDACS Live Mapping UNOSAT (2015).

H. GOOGLE CRISIS RESPONSE

Google Crisis Response is a branch within Google.org that works to utilize the capabilities available at Google to support humanitarian efforts. Some of these efforts include information flow, crisis mapping, data sharing, and donation support for humanitarian organizations. Some of the tools that Google has developed include: Google Person Finder, Google Crisis Mapping, and Google Public (Google 2015).

Google has been known to set up 24/7 support centers after major disasters to aid in response efforts. According to Joint Publication 3-29, after the 2011 Fukushima nuclear power plant crisis in Japan, Google engineers provided free training, analysis, crowd sourcing tools, and overhead imagery tools to operational planners responsible for maintaining the nuclear facility (Joint Publication 3-29 2014).

One of the notable tools that Google developed is the Google Person Finder, which enables disaster victims to reestablish communication with their family members and friends following a HADR event. This tool was initially developed by Google after the 2010 Haiti earthquake. The source code available at github.com for outside developers to improve the tool. government and nonprofit organizations can download data into Google Person Finder or synchronize with existing databases (Google 2015).

I. THE MOBILE GDACS

Mobile smartphone applications were developed to disseminate GDACS HADR information to responders as fast as possible. "iGDACS" is a mobile app that allows responders to get the latest alert and key statistical information on their iPhone. It also allows feedback to be provided on HADR events to be sent to others in the GDACS community. UN-ASIGN is one of the applications produced, and is available on both Android and iPhones. It is a fully operational crowd-source application that is used to provide geo-located photos and text messages back to the Live GDACS map. The application is designed to work over low bandwidths and in offline conditions for areas that have unstable access to internet connections (GDACS 2015).

J. DRONE TECHNOLOGY

Unmanned Aerial Vehicles (UAVs), also known as "drones," played a major role in the Nepal 2015 earthquake HADR response effort. With a shortage of available helicopters, drones were used to collect damage assessment information, which allowed helicopters to focus on critical rescue missions. It is expected that drones will be used in increasing numbers into the future. They can provide comprehensive data collection and mapping capabilities. Drones can cover as much as 5 to 10 square km in a few hours, complementing slower ground-based field surveys. They are also deployed below cloud cover that can hamper satellite imagery collection (Team Rubicon 2015).

APPENDIX B: QUALITY ATTRIBUTES AND DEFINITIONS

Supportability is an important element in the design process, and is typically the most significant element impacting the operations and support costs. These costs are typically the largest contributor to the total life-cycle costs of a system. According to the 2009 PHD NSWC MSSE/MSSEM Cohort 6 Capstone Project Report, supportability includes the "provision of maintenance, training, test equipment, technical documentation, supply support, facilities, transportability, human systems interfaces, and other non-functional requirements" (Capstone Project Report, PHD NSWC MSSE/ MSSEM Cohort 6 2009, 10). These requirements help to ensure the system in development is usable, reliable, and maintainable throughout its life cycle. Supportability requirements will need to be developed for the HADR operations management platform, and will focus on ensuring the system can be supported in a cost effective manner (Capstone Project Report, PHD NSWC MSSE/MSSEM Cohort 6 2009).

Functional properties of the system itself such as modifiability, reusability, testability, etc are known as quality attributes. These quality attributed effect the supportability and performance of the system. Figure 40 shows the HADR OMP objective hierarchy with quantified quality attributes. Table 10 lists the quality attributes and definitions as defined by the 2009 PHD NSWC MSSE/MSSEM Cohort 6 Capstone Project Report, with slight modification for application to this thesis (Capstone Project Report, PHD NSWC MSSE/MSSEM Cohort 6 2009, 484).

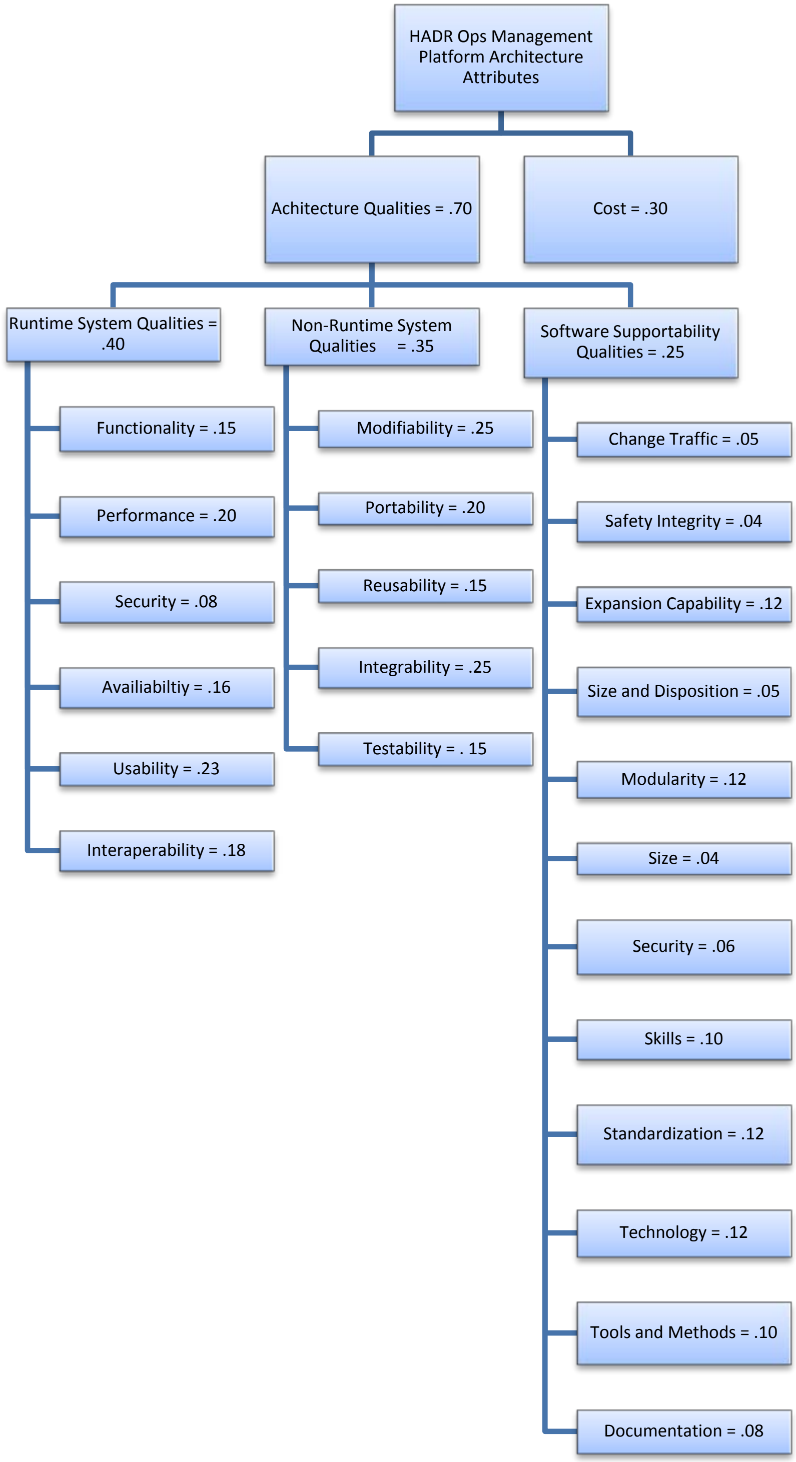

Figure 40. HADR Operations Management Platform Quality Attributes Objective Hierarchy. Adapted from Capstone Project Report, PHD NSWC MSSE/MSSEM Cohort 6 (2009).

Table 10. Quality Attribute Definitions. Adapted from Capstone Project Report, PHD NSWC MSSE/MSSEM Cohort 6 (2009).

Quality Attributes	Definition
Functionality	The ability of the system to do the work for which it was intended.
Performance	The response time, utilization, and throughput behavior of the system.
Security	A measure of system's ability to resist unauthorized attempts at usage or behavior modification, while still providing service to legitimate users.
Availability	The measure of time that the system is up and running correctly; the length of time between failures and the length of time needed to resume operation after a failure.
Usability	The ease of use and of training the end users of the system. Interoperability The ability of two or more systems to cooperate at runtime.
Modifiability	The ease with which a software system can accommodate changes to its software.
Portability	The ability of a system to run under different computing environments. The environment types can be either hardware or software, but is usually a combination of the two.
Reusability	The degree to which existing applications can be reused in new applications.
Integrability	The ability to make the separately developed components of the system work correctly together.
Testability	The ease with which software can be made to demonstrate its faults
Conceptual Integrity	The integrity of the overall structure that is composed from a number of small architectural structures.
Correctness	Accountability for satisfying all requirements of the system. Sensitivity The degree to which a system component can pick up something being measured.

Quality Attributes	Definition
Change Traffic	Change traffic is a measure of the rate at which software modification is required. It is a complex function of requirements stability, software integrity and system operation. Change traffic will affect the volume of software support activity. Higher change traffic will require more software modification work. Change traffic may only be measured during actual use of the system. Before the software is in use, estimates may be made by comparison with similar applications and projections from requirements change and fault detection rate metrics taken during the software and system testing and trials. Any data available from comparable in-service systems on change traffic and effort will also be of significant value.
Safety Integrity	The safety integrity required of a software item will be determined by consideration of the safety criticality of the functions that it provides. Safety criticality relates to the likelihood of anomalies in the system causing accidents of varying severity. The overall safety criticality of a system should be established by the application of an appropriate hazard analysis technique. The criticality of particular software items will be consequent upon the partitioning of system functions in the system design. Designs should aim to minimize and isolate software, which implements highly critical functions. System requirements should define safety criticality categories and specify appropriate software safety integrity levels. Various constraints and requirements for software development, testing and modification will be associated with each safety integrity level.
Expansion Capability	Expansion capability is an attribute of system design. It is concerned with the degree to which software may be modified without being limited by constraints on computing resources. Associated physical limitations, such as space, are to be addressed in the context of the parent system. Examples of constraints on computing resources are:

Quality Attributes	Definition
	(a) Available memory. (b) Processor performance. (c) Mass storage capacity. (d) Input/Output bandwidth. Inadequate expansion capability might limit the scope for software modification or significantly impact on modification costs. Even simple changes might involve significant amounts of rework to overcome system limitations. Limited expansion capability is of particular relevance in the case of embedded, real-time applications. In such cases it is normal to state spare capacity requirements as part of any procurement specification.
Size and Disposition	The number of equipment in use, and locations at which software support is conducted, will have an impact on software supportability requirements and support costs. Significant sub-groups of users might generate requirements for variations of the software to suit their specific needs. The number and distribution of equipment will influence the magnitude of the software support task and the optimum location of the software support facilities. Moreover, large operational units are more likely to accumulate higher levels of equipment usage, thereby increasing the probability of fault detection and the identification of corrective change requirements.
Modularity	Modularity is an attribute of the low-level structure of a software design, and relates to the extent to which processes and functions are represented as discrete design elements. The modularity exhibited by a particular design will be a function of the engineering practices applied by the developer, and factors determined by the choice of design method, tools and programming language. However, in general the optimum approach to modularity will be one that balances functional and performance requirements against the need to provide an understandable and supportable design. Poor modularity might result in increased modification costs owing to the need to implement consequential changes in other parts of the software.

Quality Attributes	Definition
	Requirements for interface control and standardization might be used to influence the modularity of a system design.
Size	A number of metrics are available to quantify software size. The size of a software item might influence its supportability, both in terms of the level of change traffic expected and the resources required to implement a change. The size of the software within a system is dependent upon the application and the design solution Software requirements should state any constraints on the size of run-time software imposed by the system design. Many software support and supportability projections will be based on estimates of software size and complexity. Software development requirements should specify requirements for data collection and analysis to measure software size, and to verify any models or estimates of supportability parameters that depend on software size.
Security	The security classification of data, executable code and documentation might impose constraints and demands on the software support activities and/or the Project Support Environment (PSE). The main influence on a prime equipment will be to impose special handling requirements. These might limit access to the software and introduce design requirements, which give rise to specific software support tasks and equipment. The security classification of a software item will be dependent upon the application and the equipment design. Wherever possible systems should be designed such that highly classified software is physically segregated from all other software within a system. System security requirements should provide criteria for security classification of software items and should specify modification and handling constraints associated with such classifications.
Skills	Software modification will require personnel with appropriate software engineering skills. Requirements for particular skills might be associated with the application domain, the technology or the methods used. Skill requirements will be determined by the system design, the software design and the chosen software support policy. Skill requirements will have an impact on personnel and training needs.

Quality Attributes	Definition
Standardization	Standardization may be applied to the computing environment within which the software executes, and to the technologies and engineering processes used to develop the software and the associated software documentation. Standardization will benefit software supportability by reducing the diversity of tools, skills and facilities required. The scope for standardization across a system might be constrained by the overall architectural design. Standardization requirements should be included within system and software requirements. Software standardization requirements might be less rigorously applied to software, which will only be supported by the original developer utilizing existing facilities, personnel and equipment. Software standardization requirements should avoid constraining the design to software technology, which has limited life expectancy or no clear evolutionary path.
Technology	Technology should be considered in respect of the software engineering methods and tools used in development and implementation together with the hardware and software aspects of both the host and target platforms. Technology issues might include: specification and software design methods and supporting tools; operating systems, programming languages and compilers; software test methods and environments; project specific tools and techniques; processing architectures. Requirements for the use of specific technologies might impose constraints on the system and software design solutions; they will also affect software engineering productivity and integrity.
Tools and Methods	The selection of tools and methods is dependent on the technologies used to develop and implement the system. The use of particular tools or methods might influence the software productivity and integrity achieved during software modification. The cost of acquiring and supporting tools should be carefully considered, since it might influence the selection of the software support policy. Depending on the level of standardization achieved, the same tools and facilities might be used to support software items from one or more systems. Selection of the tools and methods to be used during

Quality Attributes	Definition
	software development is a design decision and will form part of the design solution. The selected toolset will normally be incorporated in a PSE, which would also provide, depending on the chosen support policy, the basis for the post-delivery support environment for the software. The tools within a PSE will require support throughout the life of the prime system to which they relate, since the tools themselves will experience change, upgrade and obsolescence. System developers should have a strategy for considering these issues in their initial toolset selection and for on-going management of overall toolset effectiveness and integrity during the system life cycle. Aspects which should be considered in respect of each potential tool supplier include the following: (a) Commercial viability and track record. (b) Quality of customer service arrangements. (c) Product upgrade policy, particularly in respect of the maintenance of functional compatibility between succeeding software versions and the continued provision of support for preceding versions.
Documentation	The term documentation refers to all records, electronic or hardcopy, that relate to the requirements, specification, analysis, design, implementation, testing and operation of a software item. In order to ensure software supportability the documentation must be produced to an agreed standard and it must be available to the organization charged with delivering software support. Any software tools used in the creation of documentation must be included in the support facility and arrangements must be defined for their through-life support.

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