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THESIS

**OPERATIONAL EFFECTIVENESS OF SMARTPHONES
AND APPS FOR HUMANITARIAN AID AND DISASTER
RELIEF (HADR) OPERATIONS—A SYSTEMS
ENGINEERING STUDY**

by

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September 2012

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HUMANITARIAN AID AND DISASTER RELIEF (HADR) OPERATIONS–
A SYSTEMS ENGINEERING STUDY**

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The revolution in wireless technology has made smartphones an integral part of people's lives. In today's hyper-connected world, smartphones could possibly help save hundreds of thousands of lives in the aftermath of a disaster or humanitarian crisis. Software developed by computer scientists could be used to quickly and accurately locate missing people, rapidly identify cases of malnutrition, and effectively point people towards safe zones—simply by checking their phones. From a systems engineering and analytical perspective, this study examines the feasibility of using smartphones, connected through commercial and private communication networks and coupled with different types of applications, to effectively assist in humanitarian aid and disaster relief (HADR) operations. The study analyzes the operational requirements and presents networking solutions and a list of applications that have proven useful in HADR operations. This study allows defense organizations to have a deeper appreciation of the possibilities of commercial smartphones and their applications in HADR operations. The study also highlights the problems associated with smartphone technology in HADR operations. Defense organizations may benefit from and implement the list of feasible and proven applications presented in the study.

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TABLE OF CONTENTS

I.	INTRODUCTION.....	1
A.	BACKGROUND.....	1
B.	THESIS OBJECTIVE AND RESEARCH QUESTIONS.....	1
II.	BACKGROUND INFORMATION	3
A.	THE INDONESIA TSUNAMI, 2004.....	3
1.	Overview	3
2.	Lessons Learned.....	3
B.	THE HAITIAN EARTHQUAKE, 2010.....	4
1.	Overview	4
2.	Lessons Learned.....	5
C.	EVOLUTION OF SMARTPHONES AND APPLICATIONS.....	5
III.	SYSTEMS ENGINEERING ANALYSIS.....	7
A.	ANALYSIS FRAMEWORK.....	7
B.	THE PROBLEM SPACE	8
1.	Problem Definition.....	8
2.	Challenges in HADR Operations.....	9
a.	<i>Physical Destruction</i>	9
b.	<i>Utilities and Communication Systems</i>	9
c.	<i>Hygiene and Sanitation</i>	10
d.	<i>Language and Literacy</i>	10
e.	<i>Limited Time and Resources</i>	10
f.	<i>Lack of Command and Control</i>	11
3.	Key Stakeholder and Needs Analysis.....	11
4.	Summary of Revised and Integrated Stakeholder Needs.....	14
a.	<i>Supplies</i>	14
b.	<i>Infrastructure</i>	14
c.	<i>Information</i>	14
d.	<i>Communication Links</i>	15
e.	<i>Services</i>	15
f.	<i>Security</i>	15
5.	Functional Analysis.....	15
6.	Operational Requirements and Metrics	18
7.	Requirements for Effective Communication.....	19
a.	<i>Quick Set-Up</i>	19
b.	<i>Tight-Loop, Frequent Communication</i>	20
c.	<i>Lightweight Equipment</i>	20
d.	<i>Scalability</i>	20
e.	<i>Battery</i>	20
8.	Conclusion for the Problem Space	21
C.	THE SOLUTION SPACE	21
1.	Networking Solutions.....	22

a.	<i>Hastily Formed Networks (HFN)</i>	22
b.	<i>Cloud Computing and Virtualization Technology</i>	23
c.	<i>SPARCCS</i>	26
d.	<i>Short Message Service (SMS)</i>	28
2.	Devices	29
a.	<i>BlackBerry</i>	30
b.	<i>MONAX iPhone System</i>	31
3.	Suitable Applications (Apps) for HADR Operations	32
a.	<i>Map-Books Replacement</i>	32
b.	<i>Infrastructure Damage</i>	33
c.	<i>Aid Tracking</i>	33
d.	<i>Field Level Operations Watch (FLOW)</i>	34
e.	<i>REUNITE</i>	35
f.	<i>Where's Safe</i>	36
g.	<i>Height Catcher</i>	36
h.	<i>The Army App Store</i>	37
4.	Conclusion for Solution Space	37
D.	FEASIBILITY ANALYSIS	37
1.	Solutions to Needs and Functional Mapping	37
a.	<i>Provide Supplies and Logistics</i>	38
b.	<i>Provide Security</i>	38
c.	<i>Exchange Information</i>	38
d.	<i>Setup Communication Links</i>	39
e.	<i>Provide Emergency Response</i>	39
f.	<i>Provide Infrastructure</i>	39
g.	<i>Provide Governance</i>	39
2.	Benefits and Tradeoffs Analysis	39
a.	<i>Cost</i>	40
b.	<i>Security</i>	40
c.	<i>Information</i>	41
3.	Lifecycle Management	41
a.	<i>Hardware</i>	42
b.	<i>Software</i>	42
c.	<i>During Operations</i>	43
d.	<i>Post-Operations</i>	43
IV.	CONCLUSIONS AND RECOMMENDATIONS	45
	LIST OF REFERENCES	47
	INITIAL DISTRIBUTION LIST	51

LIST OF FIGURES

Figure 1.	Smartphone and PCs Sales (From Zeininger, 2012).....	6
Figure 2.	Analysis Framework	8
Figure 3.	Functional Hierarchy for HADR Operations.....	17
Figure 4.	SPARCCS Architecture (From Gibson et al., 2012)	27
Figure 5.	Monax iPhone System (From Chernicoff, 2011).....	31
Figure 6.	New Smartphone Apps Available Per Day (From Gruener, 2012)	32

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LIST OF TABLES

Table 1.	Stakeholders and Needs Table	13
Table 2.	Operational Requirements Mapped to Functions	18

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LIST OF ACRONYMS AND ABBREVIATIONS

APP	Smartphone Applications
BGAN	Broadband Global Area Network
C2	Command and Control
COP	Common Operating Picture
COTS	Commercial Off-the-Shelf
FRS	Family Radio Service
HADR	Humanitarian Aid and Disaster Relief
HFN	Hastily Formed Networks
IGO	Inter-Governmental Organization
NAS	Network Attached Storage
NGO	Non-Governmental Organization
SA	Situational Awareness
SME	Subject Matter Expert
VSAT	Very Small Aperture Terminal
WiMAX	Worldwide Interoperability for Microwave Access

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EXECUTIVE SUMMARY

While traditional armed conflict still exists in today's post-911 environment, there is a shift in focus towards stability-based operations such as humanitarian aid and disaster relief (HADR) throughout the world. During the last decade, the world has seen a wide range of unexpected disasters. This compels neighboring countries to assist one another in times of need, often through the support of their military forces. Another emerging trend is the advance of smartphone technologies. Commercial smartphones today are just as powerful as, if not better than, personal desktop computers. With greater computing and networking capabilities, these lightweight mobile devices bring the power of computing to the user on the move. It is estimated that 70% of the entire world owns a cellphone (Saylor, 2012). The extensive reach of these mobile devices brings new possibilities and capabilities to the commercial and military paradigms, paving the way for a change in the conduct of military operations.

This thesis examines and integrates two emerging trends: the explosion of smartphone applications in the commercial and military realms and the growing requirement for military forces around the world to conduct humanitarian aid and disaster relief (HADR) operations. Two recent HADR operations (the Haitian earthquake of 2010 and the Indonesian tsunami of 2004) involving U.S. and Singaporean military forces, respectively, provide some background and lessons learned for analysis.

Using a systems-engineering analysis framework, a methodology is established to break down the problem and allow us to maximize the potential of smartphone solutions in HADR operations. The problem space first examines the challenges in the HADR environment, analyzes stakeholder needs, and translates these needs into functions and operational requirements. Literature reviews offers insight into current networking solutions, smartphones applications, and devices within the solution space. The problem space and solution space then come together by mapping the operational requirements with a wide array of available smartphone solutions and by analyzing the benefits, tradeoffs, and lifecycle issues involved. The system-engineering analysis framework

helps to fulfill the needs and operational requirements of HADR operations by using readily available commercial off-the-shelf (COTS) smartphone and networking technologies.

The severe conditions of a disaster site present many challenges to first responders, aid agencies, local authorities, and victims, in terms of communication, operations, and survival. Some of the challenges faced in a HADR environment include massive physical destruction, the breakdown of basic utility and communication systems, deteriorating hygiene and sanitation, language and literacy barriers due to various actors from different places coming into proximity, limited time and resources, and a lack of command and control. Also, there are many stakeholders; and each has different concerns and plays a different role in the overall aid effort. Some of the effective needs of these stakeholders include basic supplies, safe infrastructure, timely information about the situation and the relatives of victims, working communication links, emergency services, and security.

By analyzing and understanding the functions needed for HADR operations, operational requirements can be developed. Some of the key functions of HADR operations include the provision of supplies, logistics, and security, exchanging information among the various stakeholders, setting up communication links, and providing emergency services, infrastructure, and overall governance of the situation. To effectively use smartphones in HADR operations, some of the requirements for robust communications include quick equipment setup; “tight-loop” frequent communications; lightweight equipment and scalability; and battery-management capabilities.

While there are many requirements, the fundamental function is to provide coherent and timely information to victims and aid organizations so that they can share a common operating picture. By staying connected, everyone in the HADR situation can work together and assist in relief efforts from their own perspective. Smartphones can provide the basis to fulfill this central function and, with innovative applications, can overcome many challenges in and improve the efficiency of HADR operations.

Based on literature reviews of networking solutions and smartphone applications, the solution space examines and highlights possible products that can be effectively used to aid HADR operations. Hastily formed networks (HFN), cloud computing, virtualization technology, SPARCCS, and SMS are some networking solutions to connect everyone in a HADR environment, assuming that land-based communication links are absent or weak. In terms of smartphones, three of the most common operating platforms are the Android OS, iPhone OS and the BlackBerry. Regardless of their capabilities, they have all been used in some way or another to assist HADR operations in recent times.

Currently, there are more than a million smartphone applications (“apps”) developed for various devices and serving different purposes, with the number growing at a staggering pace every day. These apps can range from games to business to daily utility tools. A quick search on the Internet reveals that many apps have also been developed for various types of military operations. The following are just some of the HADR-specific applications developed by aid agencies all over the world to assist operations. Beyond these mission-specific apps, the possibilities to design and modify apps to suit different needs and contexts are endless.

1. Map-Books Replacement—An app to replace paper map books, saving search time and printing costs
2. Infrastructure Damage—An app that includes 451 layers of infrastructure for first responders to identify and understand what existed in damaged locations before impact
3. Aid Tracking—An app that allows field teams to easily and quickly update records during aid distribution and register new beneficiaries in remote areas
4. Field-Level Operations Watch (FLOW)—An app that broadcasts immediate, instant reports about whether water and sanitation projects are working or failing
5. REUNITE—An app that records initial interviews with victims using a smartphone and uploads these onto a central server for workers to reunite lost family members

6. Where's Safe—An app that replaces the emergency radio-broadcast system, which does not reach a large number of people, by allowing refugees to find their nearest safe point simply by sending an SMS message

7. Height Catcher—An app that quickly measures the level of malnutrition and instantly calculates what food or fluids the victim needs

8. The Army App Store—An Army software marketplace that offers training applications for use on commercial smartphones and tablets

It is evident that the networking solutions, COTS devices, and the wide variety of apps available today bring many possibilities for use in HADR operations. However, most of these technologies are still in the early stages of widespread implementation for operations. This is due to security reasons, mindsets, or lack of a concerted effort to ensure interoperability among organizations. Nevertheless, organizations are often observed using these solutions within their communities in small doses, and the abundance of technological options should provide greater opportunities for wider application in the future. Some of the benefits and tradeoffs considered in this research include the cost savings derived from using smartphone technologies versus the cost of developing these technologies. Security and information control are other considerations when using smartphones for operations.

In terms of the lifecycle management of smartphone technologies, organizations have to think through the development and disposal of hardware and software and the control of their usage and distribution during and after operations.

HADR operations present various challenges on many fronts. The large number of stakeholders and urgency involved hinders interoperability and operations efficiency. Information exchange is often stifled due to lack of communication links, and this leads to further operational obstacles.

The advancement of smartphone technologies has reached a mature stage, and they are becoming an essential daily communication tool for many. Smartphones and applications thus provide alternatives to bridge the communication barriers between stakeholders and provide a common operating platform and environment for better

organization of HADR operations. Innovative applications can fulfill operational requirements and meet the needs of stakeholders in different ways.

While there are millions of smartphone applications on the market today, there are only a handful designed specifically for HADR operations. Despite this paucity, it is important to understand that smartphone applications are extremely flexible in terms of how they are used. Entertainment and daily utility applications can be easily modified and applied to all kinds of operations.

In an age where smartphones are slowly replacing traditional computers and ways of communicating, organizations need to examine their modes of operation and find ways to incorporate smartphone technologies. More importantly, there must be a centralized effort in using these smartphone technologies in order to bring together the various stakeholders in a HADR situation and bring about a greater effect.

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And lastly, to Hapi, my beloved companion who never fails to greet me with the biggest smile and a wagging tail every day I come home from school: sorry for the times you were left alone, I love you always.

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I. INTRODUCTION

A. BACKGROUND

While traditional armed conflict still exists in today's post-911 environment, there is a shift in focus towards stability-based operations such as humanitarian aid and disaster relief (HADR) throughout the world. During the last decade, the world has seen a wide range of unexpected disasters. This compels neighboring countries to assist one another in times of need, often through the support of their military forces. Military forces are also obliged to support reconstruction efforts in post-conflict nations, forcing greater interactions between the military and the population.

Commercial smartphones today are just as powerful as, if not better than, personal desktop computers. With greater computing and networking capabilities, these lightweight mobile devices bring the power of computing to the user on the move. It is estimated that 70% of the entire world owns a cellphone (Saylor, 2012). The extensive reach of these mobile devices brings new possibilities and capabilities to the commercial and military paradigms, paving the way for a change in the conduct of military operations.

This thesis examines and integrates two emerging trends: the explosion of smartphone applications in the commercial and military realms and the growing requirements for military forces around the world to conduct humanitarian aid and disaster relief (HADR) operations.

B. THESIS OBJECTIVE AND RESEARCH QUESTIONS

From a systems engineering and analytical perspective, this study examines the feasibility of using smartphones, connected through both commercial and private communication networks and coupled with different types of applications ("apps"), to effectively aid HADR operations. The study analyzes operational, connectivity, and application needs, and presents a list of apps that have demonstrated their utility in HADR operations for possible implementation. In order to fulfill these objectives, the following research questions are posed:

1. What are the functions and operational requirements for HADR operations, and how can these requirements be fulfilled through the use of smartphones applications?
2. What are some of the benefits and tradeoffs of using smartphones for HADR operations?
3. What are the critical factors that affect the lifecycle management of using smartphone applications for HADR operations?

II. BACKGROUND INFORMATION

It is clear that natural disasters bring severe damage to countries and people. From 1974 to 2003, there were about 6,367 natural disasters, resulting in more than two million deaths and damages of approximately \$1.38 trillion. Of the top ten disasters in 2010, ranked by number of deaths, six occurred in Asia, three in the Americas, and one in Africa. Alarmingly, Asia suffered almost 85% of natural-disaster deaths in the last decade (Guha-Sapir, Hargitt, & Hoyois, 2004).

This thesis examines two recent HADR operations (the Haitian earthquake of 2010 and the Indonesia tsunami of 2004) involving the U.S. and Singaporean military forces, respectively, to provide some background and lessons learned for analysis.

A. THE INDONESIA TSUNAMI, 2004

1. Overview

On 26 December 2004, a 9.3-magnitude earthquake hit Indonesia off the northwest coast of the island of Sumatra. The earthquake quickly caused the ocean floor to deform and triggered a series of devastating tsunamis along the coasts of most landmasses bordering the Indian Ocean (UNICEF, 2008). Coastal communities were destroyed by tsunami waves as high as 30 meters (98 feet) and over 230,000 people were killed across fourteen countries. The disaster was amongst the deadliest in history and affected Indonesia, Sri Lanka, India, and Thailand the most. Shortly after the disaster, more than \$14 billion in humanitarian aid resources were donated worldwide to assist in the affected countries (Jayasuriya & McCawley, 2010).

2. Lessons Learned

While there was an outpouring of assistance from the international community and neighboring countries, there were several areas for improvement in the management of the disaster, as documented by UNICEF (UNICEF, 2008).

The complexity of the large-scale emergency was clearly beyond any one agency's capacities, and the voluntary nature of the HADR operations led to uneven

coordination and long-standing gaps in response. There is manifestly a need for effective coordination, partnership, and stewardship among the various agencies and stakeholders to reach all persons affected by an emergency.

It was noted that the government did not have a robust preparedness system and did not adopt a comprehensive and systematic view of risk management towards natural disasters. Communities should be provided with the knowledge and skills needed to identify warning signs and prepare for and better cope with impending disasters. Governments also need to develop a more consistent risk-reduction strategy.

There is a need to expand emergency surge-capacity of staffing, as effective emergency response requires the right person at the right place at the right time. Similarly, providing the right supplies in the right place and right time means that supplies be delivered to the most appropriate location and people when needed.

In UNICEF's assessment, it was pointed out that, in general, programming decisions and reports were not sufficiently based on objective assessment evidence and regular monitoring and evaluation. Reliable information is essential in order to identify and prioritize the crucial operations, and plan, monitor, coordinate these missions and be accountable to stakeholders.

B. THE HAITIAN EARTHQUAKE, 2010

1. Overview

On 12 January 2010, a 7.0-magnitude earthquake struck Port-au-Prince, Haiti's capital, killing an estimated 230,000 people, injuring 300,000, and rendering 1,000,000 homeless. Public infrastructure, utilities, roads, and communication networks were severely degraded (The Economist, 2010). Before the earthquake, Haiti was already home to a United Nations peacekeeping mission, and a disaster of such magnitude crippled Haiti further in taking care of its citizens. The international community quickly responded with different kinds of aid, and a wave of support soon flowed into Haiti.

2. Lessons Learned

While there was a surge of aid provided to the situation, it did not include communications technology, and some non-governmental organizations (NGOs) did not have a dependable communication system. Most relied on temporally asymmetrical and Internet-access-reliant e-mail to carry out operations (Meyer, 2011). The lack of widespread Internet access slowed down relief operations and hindered first responders' ability to convey important information. The problem was further magnified when different groups with different operating procedures and languages came into play.

The Haitian disaster was characterized by a complex urban landscape with high crime rates and inadequate infrastructure. This led to challenges in establishing effective security measures to stabilize the situation. It was noted that the weakness of the Haitian government contributed to the problem of conducting aid operations efficiently (Humanitarian Practice Network, 2010).

Other problems in Haiti included poor land management and relief-camp organization in terms of citizen and cargo-capacity control (Murphy, 2011). The delivery of food was challenging on many fronts. Roads were impassable, electricity was sporadic, weather was frequently bad, and beneficiaries had to travel long distances by foot to get to distribution sites. These hurdles also made it difficult to track aid and ensure that people were getting the food and health guidance they needed.

C. EVOLUTION OF SMARTPHONES AND APPLICATIONS

Smartphones today are just as powerful as regular desktop computers were a few years ago. They are no longer just phones that are used for basic vocal and text communications. Smartphones today contain powerful processors, large memories, and an unlimited expandable storage capacity (Abuan, 2009). Furthermore, smartphones exceeded the content-capture capabilities of desktop computers a few years ago. Most smartphones are pre-equipped with cameras and microphones, allowing users to capture important information such as pictures, video, and sound on the go. While the desktop computer has similar functions, its lack of portability makes the smartphone a better vehicle for mobile computing and information processing (Singh & Ableiter, 2008). It is

suggested that by the end of 2012, the sales of smartphones will have overtaken that of personal computers, as shown in Figure 1 (Zeininger, 2012).

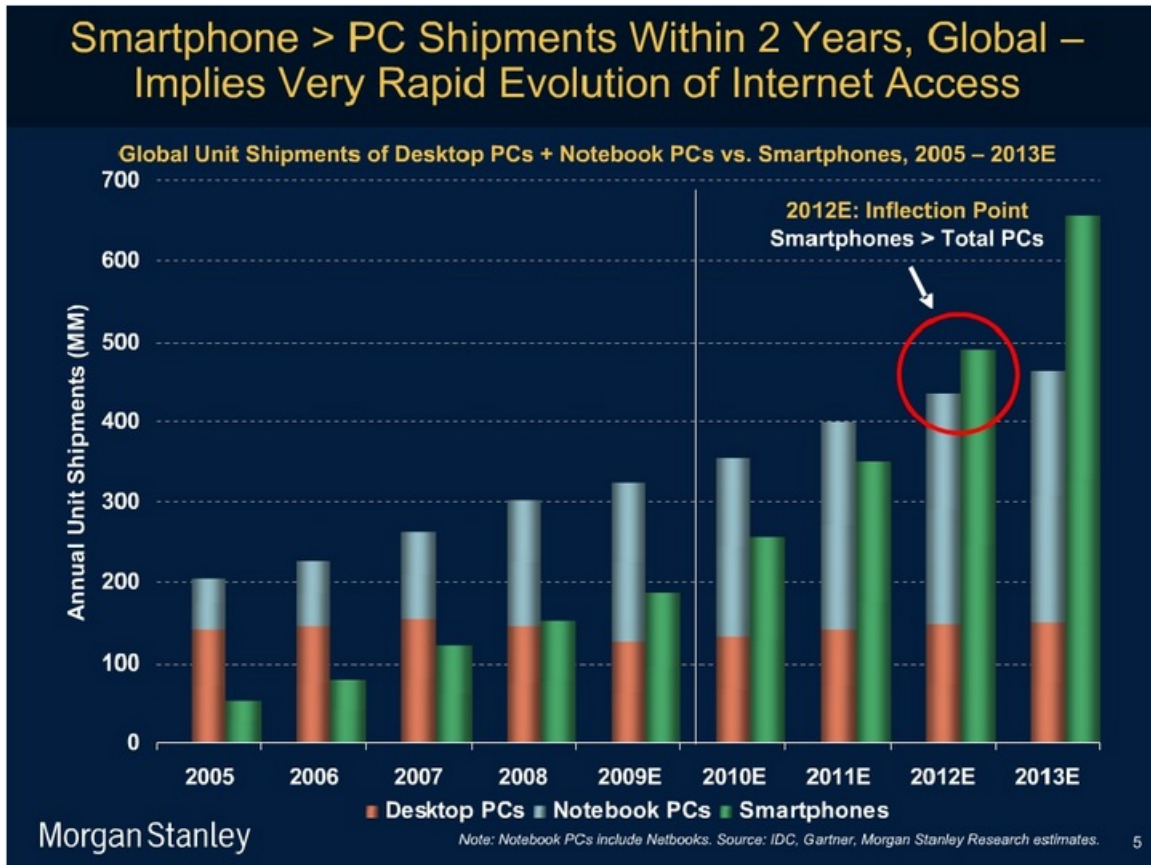


Figure 1. Smartphone and PCs Sales (From Zeininger, 2012)

III. SYSTEMS ENGINEERING ANALYSIS

A. ANALYSIS FRAMEWORK

Blanchard and Fabrycky discuss that while there is a general agreement regarding the principles and objectives of systems engineering, its actual implementation will vary from one system and engineering team to the next. A newly identified need, or an evolving need, reveals a new system or operational requirement. In this case, the overall need would be to improve on the way HADR operations are conducted. After the definition of need and conceptual design, the systems engineering process is followed by the preliminary design, detailed design and development, production, utilization and support, and phase-out and disposal stages (Blanchard & Fabrycky, 2011). However, in this case, since it is decided that the solution would be to use smartphone applications, a modified analysis framework is used to evaluate the problem, synthesize the available solution for usage and analyze the benefits of the solution.

The analysis framework, as shown in Figure 2, establishes a methodology to break down the problems in HADR operations and allows us to maximize the potential of smartphone solutions for use in HADR operations. The problem space first examines the challenges of the HADR environment, analyzes stakeholder needs, and translates the needs into functions and operational requirements. Literature reviews and research then offer networking solutions, smartphones applications, and devices within the solution space. The problem space and solution space come together by mapping the operational requirements with the wide array of available smartphone solutions and analyzing the benefits, tradeoffs, and lifecycle issues involved. This system-engineering analysis framework thereby helps to define the needs and operational requirements of HADR operations by using readily available commercial off-the-shelf (COTS) smartphone and networking technologies.

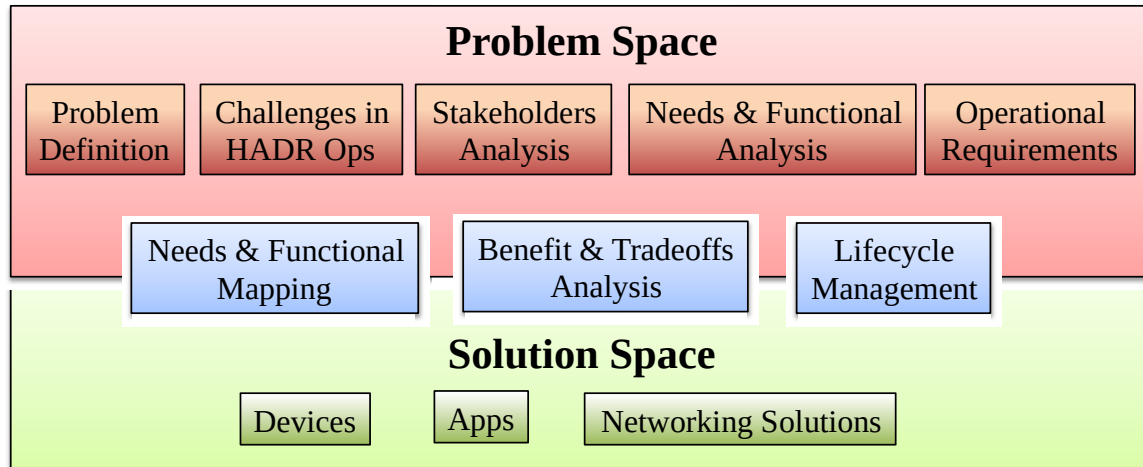


Figure 2. Analysis Framework

B. THE PROBLEM SPACE

The problem space discusses the issues involved in HADR operations, analyzes stakeholder needs and operational requirements, and examines the requirements for effective communication in a HADR environment.

1. Problem Definition

It is hard to predict when the next natural disaster might occur. The uncertainty of HADR operations and each disaster's unique geographical and sociological environment make operations even more challenging. Significant problems that first responders and various agencies face in HADR operations are the chaotic environment they must operate in and the lack of an organized manner in which help is provided. At the same time, there is a need to meet the various demands and expectations of the different stakeholders and organize them to work together effectively towards the common goal of providing aid for the affected nation. With these initial insights, the primitive need is to provide a common working environment and overcome communication barriers for stakeholders and impromptu agencies in order to improve the overall effectiveness of HADR operations.

2. Challenges in HADR Operations

The severe conditions in a disaster site present many challenges to first responders, aid agencies, local authorities, and victims in terms of communication, operations, and survival. The following key issues allow us to understand the challenges involved so that we can subsequently examine the possibility of using smartphone solutions for HADR operations.

a. Physical Destruction

The most apparent effect of any disaster is the massive physical destruction of the site. Depending on the magnitude of the disaster, physical structures such as apartments, buildings, businesses, hospitals, and government buildings might no longer be safe for shelter. Earthquakes might cause structures to be unstable, and flooded locations make buildings inaccessible and uninhabitable. Roads may become impassable, and access to safe locations and aid support becomes a challenge for both the aid provider and the victim. When using physical means of travel such as walking, long distances make it extremely difficult to track aid resources and ensure that people are getting food and guidance (Murphy, 2010).

b. Utilities and Communication Systems

Basic and vital utilities are often severely degraded or completely ruined. Electrical power might be sporadic and telephone landlines might not work if cables and communication towers are destroyed. In the case of floods and tsunamis, the vast quantity of water damages electrical and communication equipment, which need to be replaced completely in order to restore communications. Sometimes, even the most reliable systems, such as the voice radio networks used by police and emergency services, are knocked offline. These systems rely on terrestrial radio repeaters that are vulnerable to sundry disasters, and when they are online, the radio systems of different agencies are often not interoperable, meaning cross-organizational communication is difficult (Meyer, 2011). Most of the time, different agencies have to swap radios or rely on device or network-dependent methods such as telephone and e-mail. During the Haitian earthquake, the informational infrastructure of the Haitian technological-information

network was totally nonexistent. In addition, the only fiber-optic cable connected to Haiti was severed (Morris, 2011). Engineers had to rush to restore land communication to ensure that aid agencies had a reliable communication means. It is important to note that wireless networks might generally be less affected, as base stations are usually farther distributed and satellite networks are not impacted.

c. *Hygiene and Sanitation*

In floods and tsunamis, sanitary problems become even more pronounced and problematic as waste products and debris are washed through city streets and into buildings. Maintaining a hygienic and safe working and living environment for responders and victims becomes a challenge, as massive cleanup is necessary to decontaminate the area. Sanitary problems begin to manifest themselves in terms of rapid spread of disease and increased medical requirements for both aid workers and victims.

d. *Language and Literacy*

When disasters happen in nations where English is not the main spoken or written language, simple communication becomes a big obstacle and can slow down HADR operations severely. The situation becomes worse if the literacy rate is low and aid agencies have difficulty communicating with the victims. In these instances, translators are urgently required, but they are often scarce in HADR operations. At the same time, because aid agencies come from all parts of the world, there might also be language problems between first responders, too.

e. *Limited Time and Resources*

HADR operations are extremely time critical and resource intensive. Rescue missions and medical emergencies demand immediate attention from aid agencies, and with limited resources, they are often working under the pressure of time. Usually, the affected city is unable to cope with the magnitude of the problem after the

disaster has crippled its resources, and can only wait for external aid to arrive. The burden is on the affected city to maximize its current aid capacity and on external agencies to deploy rapidly.

f. Lack of Command and Control

An extreme outpouring of aid and support, both internally and externally, often creates a chaotic working environment. Aid agencies often depend on the host nation's support and guidance in order to conduct their operations effectively. This can be in the form of area allocations, communications setup, resource management, and direction for the aid effort. However, because there are so many different stakeholders in HADR operations, the command and control of all agencies becomes a challenge, especially if the local government is not resilient and stable in the first place.

3. Key Stakeholder and Needs Analysis

In a disaster, there are many stakeholders, and each has different concerns and plays different roles in the overall aid effort. Based on literature research, interactions with subject matter experts (SME) who have operated in a HADR environment and personal assessment, the stakeholder needs are formulated in Table 1. To understand stakeholder needs and relate them to the overall aid operation, stakeholders can be broadly divided according to locational boundaries: those within the disaster site, those outside the physical site, and those that are approaching the disaster area. In relation to these divisions, stakeholders can also be categorized by how much they are affected by the disaster. The key stakeholders and their essential needs are shown in Table 1.

STAKEHOLDER	PROXIMITY	PRIMITIVE NEEDS	EFFECTIVE NEEDS	GOALS	CONCERNS
Affected general civilian population	Within the disaster site	Basic needs such as water, food, shelter, warmth and safety	Safe locations with basic amenities, and information about the local situation	To return to normalcy	Personal survival and information about families
Local businesses, communities and building owners	Within the disaster site	Security for their businesses and buildings	Swift law enforcement responses and reconstructions	Restoration of business operations	Looting, compensation for businesses and building restorations
Local leaders and government	Within the disaster site	Updates on situation for quick and effective decision making	Strong communications and links with agencies on the ground	To ensure a quick and smooth recovery process	Cooperation with external agencies and time constraints
Local emergency services: Fire, medical, police, military and civil agencies	Within the disaster site	Clear instructions and situational updates for effective recovery operations	Robust communications and links with affected areas and population	To conduct recovery and security operations efficiently	Chaotic working environments and information overload
External aid agencies such as military forces and Red Cross	Incoming to disaster location	Well-defined instructions from local authorities as to where and how they can assist, and information about the situation	Guidance and information from local authorities	To assist in the aid and security operations	Information overload or blockade, creating an overt presence, lack of support from host nation and lack of cooperation amongst agencies
External media	Incoming to disaster location	Newsworthy information	News, information and media (pictures, videos and texts) about the situation from various	To seek information about the situation from	Lack of guidance and support from the local authorities, information overload

			sources	all possible sources and broadcast the information	or blockade, and the lack of news sources
Host nation's government	Outside of disaster site	Updates on situation for quick and effective decision making from local agencies	Strong communications and links with the governmental authorities from the affected areas	To restore the disaster sites to normalcy	Untimely and inaccurate information due to time and distance differences
Relatives	Outside of disaster site	Well-being of affected relatives	Information and updates from all possible sources about their relatives	To know that their relatives are safe and be informed about their latest situations	Inaccurate or the lack of information about the situation and their relatives
Host nation's network and communications agencies	Outside of disaster site	Working communication systems and networks	Updates and feedback from affected areas	To ensure that networks and communication systems are working	Lack of information and details about the damages that hinders repairs
External authorities such as United Nations and other countries	Outside of disaster site	Official updates from affected nation	Official information sent from affected nation and verification of information	To ensure that affected nation is coping with the situation well	Lack of information and transparency from affected nation and spill-over effects if situation is mishandled

Table 1. Stakeholders and Needs Table

4. Summary of Revised and Integrated Stakeholder Needs

After evaluating, analyzing and integrating the various needs of stakeholders, the following revised needs are deemed to be vital for HADR success, from both the aid organization's and victim's perspective.

a. Supplies

Basic survival supplies such as clean water, food, and medical supplies are crucial in ensuring that the victims can overcome their situation and aid workers can sustain their operations in the harsh environment. These essentials are time critical and must be provided as quickly as possible to the disaster site.

b. Infrastructure

Safe locations that provide shelter and warmth are needed to ensure the safety and survival of victims. At the same time, infrastructure is required for all agencies to organize themselves and conduct their relief efforts efficiently. In a chaotic and uncertain work setting, the identification and organization of safe and suitable infrastructure is paramount.

c. Information

There must be a two-way exchange of information between ground zero and all authorities and agencies in the HADR operation. The timeliness of information is crucial for swift and effectual decision making. Accurate and timely situational updates from both ends ensure that victims, relatives, aid agencies, and authorities share the same correct picture, and this can provide a form of psychological assurance to all affected parties. The control of information is equally significant in preventing information overload and ensuring that only the right, required material is communicated to the appropriate stakeholder. This requires proper organization and transparency in the sharing of information.

d. Communication Links

For information to be transmitted to and from a disaster site, strong communication links must be present in either land or wireless form. Without a robust communication means, information becomes outdated and worthless, since it cannot be shared in time.

e. Services

HADR operations require a wide range of services from various aid agencies, both local and external. These include firefighting, medical assistance, ambulance transportation, debris removal, supply and logistical transportation, and search and rescue. These services are imperative in a HADR operation and must be provided in a well-timed manner to prevent overcrowding and chaos. More importantly, they must be organized to ensure efficiency in resource allocation and promptness in response.

f. Security

When a disaster happens, the security of the location is often compromised, because security forces are likewise affected and distracted by the disaster. In order for HADR operations to be conducted well, there must be strong security within the disaster location and all other operating environments. Aid operations are hampered when security problems take control of the situation. As such, policing and military action need to be established quickly to contain lawlessness and unrest and must be performed concurrently with aid operations. This will safeguard the victims and aid workers from potential obstacles to restoring normalcy.

5. Functional Analysis

While there are many functions required in HADR operations, this functional analysis will be focused towards those that might possibly be fulfilled by the employment of smartphones. In reviewing the documents such as the Systems Engineering Analysis Cohort 17 Team A's Report, Influence of Foreign Humanitarian Assistance/ Disaster

Relief in a Coastal Nation (Alexander, Beery, Brinkley, et al., 2011), and analyzing the stakeholder needs discussed above, the top-level functions and their sub-functions are derived.

Figure 3 shows the top-level functional hierarchy for HADR operations and its sub-functions, which may have potential for smartphone applications. The sub-functions describe the aspects that can be improved by smartphone applications through enhanced communications and information dissemination. In the next section, these sub-functions will be linked to operational requirements that specify the services and resources that are required for these functions.

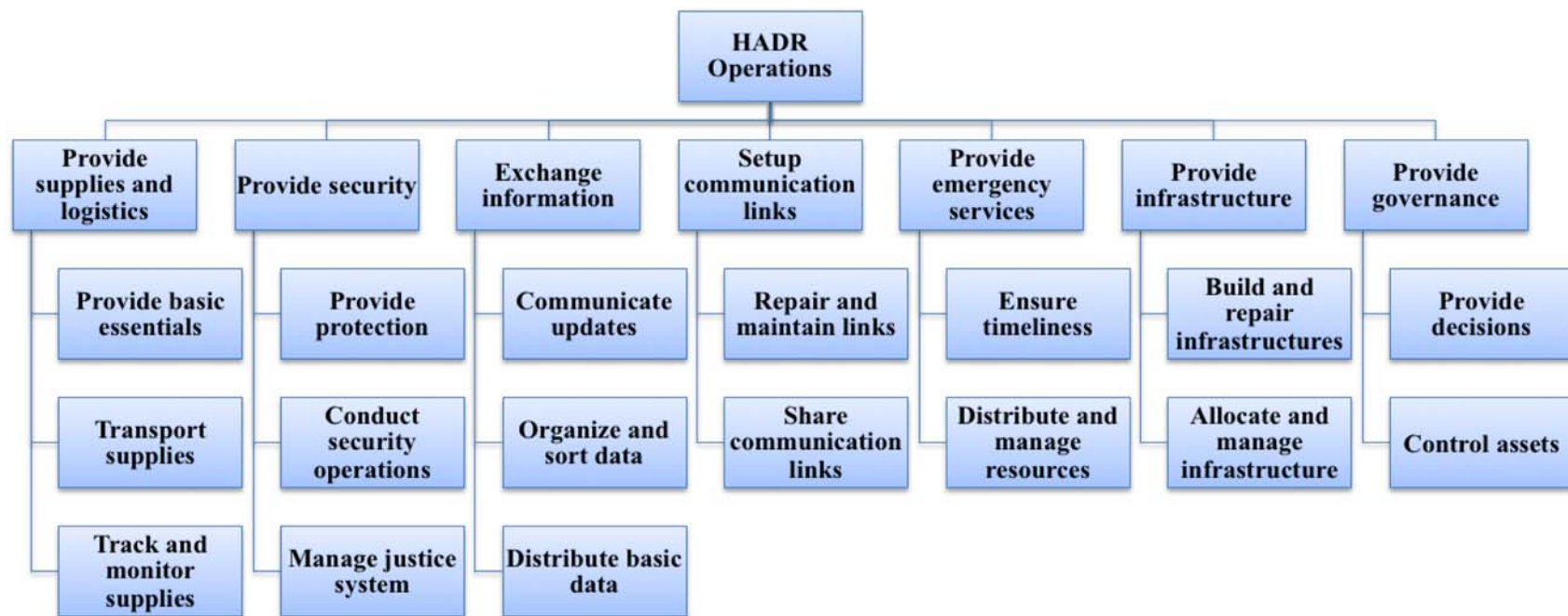


Figure 3. Functional Hierarchy for HADR Operations

6. Operational Requirements and Metrics

By analyzing and understanding the functions needed for HADR operations, we can map them and develop the operational requirements. This assessment identifies the key resources and services needed to respond effectively to a HADR situation. Table 2 shows how the functional requirements translate into operational requirements in terms of services and resources needed for HADR operations.

Top-Level Functions	Sub-Level Functions	Operational Requirements (Service & Resources)
Provide Supplies And Logistics	Provide Basic Essentials	Food, water, warmth, hygiene and living commodities
	Transport Supplies	Transportation system in terms of vehicles, roads, and maps
	Track And Monitor Supplies	Stock-taking system, tracking system, system to monitor beneficiaries
Provide Security	Provide Protection	Police and military forces, helpline system
	Conduct Security Operations	Blue-force tracking system, crime-monitoring system, transportation for forces
	Manage Justice System	Crime information, court and jail infrastructure
Exchange Information	Communicate Updates	Communication system, access system
	Organize And Sort Data	Central database, sorting system, authorization system, filtering system
	Distribute Data	Distribution system, monitoring system
Setup Communication Links	Repair And Maintain Links	Updates of damages and repair statuses, repair resources, transportation system
	Share Communication Links	Device and network distribution system, authentication system
Provide Emergency Services	Ensure Timeliness	Helpline system, updating system, monitoring system
	Distribute And Manage Resources	Resource management system
Provide Infrastructure	Build And Repair Infrastructures	Update of damages and repair statuses, repair resources, transportation system
	Allocate And Manage Infrastructure	Infrastructure overview system, resource allocation system
Provide Governance	Provide Decision	Updates of situations and resources, communication links with ground agencies
	Control Assets	Resource monitoring system

Table 2. Operational Requirements Mapped to Functions

The operational requirements described above provide a basis where improved communications can increase the efficiency and effectiveness of HADR operations. Improved communications leads to heightened situational awareness for all stakeholders in a HADR environment and the metrics that can be used to measure the improvement include speed, timeliness, accuracy and persistence of information. As information is transmitted more rapidly, decisions can be made more quickly and this enables a higher throughput in terms of supplies, aid and assets. The timeliness of information ensures that everyone is up to date with the latest development within the disaster situation, and allows for better informed decision-making. The accuracy of information ensures that assets and resources are deployed effectively and efficiently, and minimizes the loss due to erroneous decisions. The persistence of information allows for better tracking of resources and the situation, providing all stakeholders with more feedback and details about the ground picture.

7. Requirements for Effective Communication

Other than the operational requirements and metrics discussed above, there are some considerations and requirements for effective communications in HADR missions. With the introduction of multiple agencies in a crisis situation, interoperability becomes a significant issue, preventing interagency cooperation (Gibson, Crewes, Asche, & Singh, 2012). Often, each agency has developed its own methodology and corresponding systems for achieving communications capabilities. These individual systems and databases are often unable to communicate with each other. As a consequence, information dissemination across agencies becomes almost impossible in real time, leaving decision makers in a precarious position of having to make important decisions with stale and possibly inaccurate information (Singh & Ableiter, 2008).

a. Quick Set-Up

A key requirement of first responders, especially immediately after a disaster has struck, is to initiate their mission as fast as possible. This means little time to setup. Equipment must be easy to set up and aid agencies must be familiar with them.

Applications must be designed to work with COTS smartphones, and the process of using them must be simplified, so that they can be used for the mission rapidly and easily.

b. Tight-Loop, Frequent Communication

An important task of first responders is to convey the ground reality to their coworkers and the control room. This needs to be done frequently and in real time, but without taking too much time and attention lest it start affecting their mission performance. To support this requirement, the solution device must produce images, videos, and text that are tagged automatically on capture. As the content is produced, it can be automatically shared within the team.

c. Lightweight Equipment

Due to the nature of their work, first responders' equipment needs to be as light as possible. Additional weight slows down the aid process in terms of setup and transportation. Smartphones, which are lightweight and small but still provide great computational, networking, storage, and content-capture power, can be very effective in enhancing mission success.

d. Scalability

Apps and networking solutions must be scalable so that they can easily and rapidly be configured to start supporting a mission as need arises. As the mission evolves, additional equipment, users, and features can be added to the configuration to support the expanded team.

e. Battery

Due to their short charge life and weight, smartphone batteries are an important issue. Often first responders have to carry spare batteries, which increases the weight they have to support. This problem can be addressed by implementing smart energy-management techniques, quick recharging technologies or battery exchange

procedures. Energy-management techniques can look at the equipment-usage patterns and make decisions in real time as to the most effective strategy for minimizing energy use.

8. Conclusion for the Problem Space

This study of the problem space provides a clearer insight into the intricacies of HADR operations and allows us to formulate the operational requirements. While there are many requirements, the fundamental function would be to provide coherent and timely information to victims and aid organizations so that they can share a common operating picture, and the measure of performance would be the speed, timeliness, accuracy and persistence of information. By staying connected, everyone involved in HADR can work together and assist in relief efforts from their own perspective. In the solution space, the thesis examines how smartphones can provide the basis to fulfill this central function and determine how it can overcome the challenges and improve efficiency of HADR operations with innovative applications.

C. THE SOLUTION SPACE

In order to improve communications and increase the situational awareness of aid agencies in a HADR environment, networking solutions and smartphone applications can be used to this end. Based on literature reviews about networking solutions and smartphone applications, the solution space examines and highlights possible products that can be effectively used to aid in HADR operations. The list is not exhaustive, and constant changes in technology allow more advanced and inventive ideas to be developed over time to suit HADR needs. The networking solutions highlighted provide the foundations to connect everyone when communication links are absent or weak. A section on smartphone devices briefly discusses the COTS available for use today, and a list of innovative applications developed by private and commercial parties is presented.

1. Networking Solutions

Land-based communication links in a HADR environment are often compromised during a disaster, and wireless-networking solutions are usually used before land links are restored. Below are some networking solutions that can connect everyone wirelessly in a HADR environment.

a. Hastily Formed Networks (HFN)

In essence, hastily formed networks (HFN) occur when several groups come together to form a communicative bond that enhances their collective capabilities, and this bond can be represented by many types of communication, such as word of mouth, technologically enhanced communications, or hand-delivered messages. The bond can also be formed through interaction with outside agencies not within the geographical region, via the Internet, radio, and phone services, among many other technological means (Morris, 2011).

Hastily formed networks are used to create nodes in areas where there is no network connectivity. HFNs act as an extension of the enterprise network and can facilitate aid to HADR missions. An important feature of an HFN node is that it must have “reach-back” capability, which is the ability to obtain products, services, and applications that are not forward deployed.

The Naval Postgraduate School (NPS) has designed and created its own HFN capability and has deployed it to several HADR missions such as the Southeast Asian tsunami (2004), Hurricane Katrina (2005) and the Haitian earthquake (2010) (Steckler & Meyer, 2010). The technology comprises lightweight, portable, self-sustaining, and rapidly deployable “flyaway” kits (FLAKs) that are assembled from various communications equipment (Lancaster, 2005).

The FLAK is a rapidly deployable communications package, or backpack, capable of establishing communications quickly in any environment. This case can be altered to fit the needs of the team or environment. However, the essential equipment covers satellite connection, network meshing, energy requirements, and handheld communications. These four areas are essential in establishing a first-response

communications network capable of supporting a small team. These kits consist of rack-mounted network gear, Worldwide Interoperability for Microwave Access (WiMAX) antenna, meshed wireless fidelity (Wi-Fi) access points, broadband global-area network (BGAN) satellite-data unit, laptops, satellite phones, Family Radio Service (FRS) radios, generators, solar panels and wind turbines, batteries, inverters, and transformers.

HFNs are a relatively simple concept when initially introduced into a system. Natural disasters occur; equipment is introduced; and after initial set-up, a point-to-point connection is established via BGAN or Very-Small-Aperture Terminal (VSAT) satellite connections to initially develop a node. Other players are introduced into the system, such as non-governmental organizations (NGOs), inter-governmental organizations (IGOs), and other entities needing a network established in the form of a cluster system. Over time, the system can become more and more complex, depending upon the circumstances and available resources. Yet, the HFN is continually evolving into whatever temporary infrastructure is needed by end users as stability returns to the region.

b. Cloud Computing and Virtualization Technology

Cloud computing is a viable solution that helps fulfill the need to create a fast and efficient network able to support various aid agencies working together in a HADR environment (Denning, 2006). Morris discussed the possibilities of adding virtualization technology to HFNs to create a virtual cloud-computing environment, in order to improve the command-and-control (C2) capabilities of the military and aid agencies in HADR missions (Morris, 2011).

Military and aid-agency C2 capabilities, though adequate in some settings, can be enhanced using virtual applications. HFNs are generally deployed to a tactical environment to accomplish and meet real-world demands. Virtualization technology could enhance the command and control of any communication system because of its ability to decrease the overall equipment footprint and increase C2 capabilities. The additional technologies applied to HFN systems may aid in the speed of connectivity to

the World Wide Web and other mission-critical resources, thus promoting an enhanced C2 capability, and in turn, saving lives during HADR missions.

Virtualization technology is a means for multiple operating systems to be installed and used in specific hardware such as a server, laptop, etc. Virtual technology consolidates hardware and instantly builds an environment that is easily accessible remotely (Ryan & Helmke, 2010). VMWare, Inc., is currently leading the industry in server and desktop virtualization and is a major contributor to cloud-computing design and standardization. Other manufacturers such as Google and Apple have recently introduced their own cloud computing for users of their products.

When virtualization is introduced into a system, it reduces the hardware complexity (Morris, 2011). The system needs less hardware and leaves a smaller footprint, and the network becomes easier to manage. End users are able to use application-specific software through reach-back capabilities, and the system is enhanced even further. System virtualization allows organizations to run multiple operating systems and applications on their existing hardware, and this optimizes hardware usage and minimizes network bandwidth requirements, thus increasing capabilities.

Virtualization technology can aid in the reach-back capabilities of an HFN and components can easily be added to the rapid-response kit (RRK) of a first responder. The RRK is the gear initially taken by the responder into a disaster area. Ideally, the RRK would have the capabilities associated with an internal virtual, hastily formed network supported by a regional cloud for reach-back capabilities. The bandwidth needed to properly maintain a point-to-point conduit for reach-back to a database would be difficult. However, with virtualization technology, the bandwidth needed for reach-back capabilities should be less. The reason less bandwidth is needed with virtualization technology is that only selected individuals that need information from the enterprise would be allowed the reach-back capability. Virtualization technology can also be taken advantage of by taking the virtual system to the HADR area to set up a local cloud that can be accessed within a defined area by several individuals. Consequently, the network manager would be better capable of controlling the flow of traffic through the gateway.

A virtual HFN is smart and dynamic in nature and has the ability to provide services to many more users because of its lower bandwidth use and smaller footprint. To apply the virtual concept to the HFN, a server and a storage device with redundant capability will be needed to back up all the data for the system. This is the most ideal virtual system for the initial stages of a HADR mission that has little to no infrastructure already set up. For example, when a team flies into a natural-disaster area, they will set up the virtual system in a systematic method. All the data used for this setup will be stored in a memory bank such as a network-attached storage (NAS) device or something similar and lightweight. Solid-state hard drives could be used, as they require less power and have no moving parts, which improves their survivability in a mobile environment and has the added benefit of much higher performance than traditional spindle drives.

Applying this methodology to a real-world situation helps illustrate the complexity of a virtual HFN. Placing it in an environment that is representative of a disaster area aids in understanding the impact of virtualization technology in this scenario. For example, if a hurricane reaches a city, the resultant floods will presumably destroy all communications lines and infrastructure in the area. In this scenario, a team would be dispatched with HFN equipment to make a base camp at an airport. The team establishes a link to the satellite within less than an hour, with a VSAT such as a Tachyon or Cheetah earth terminal. IP addresses are input into the terminal and the team establishes connectivity with the World Wide Web (WWW). The internal network setup begins by connecting the server, switch, 802.11 wireless port, and as many 802.3 connections as needed for the end nodes that have been brought down with the team.

Once the equipment has been set up, the users begin to access applications from the virtualized server operating systems' application servers. These applications will be preloaded onto the virtualized desktop operating system of each virtual desktop to fit the needs of the mission. Applications such as Skype, Google +, and other programs use less bandwidth because of their virtual architecture and will be less likely to cause a bottleneck in the system.

Handheld devices carried by military personnel and aid workers enhanced by virtualization technology could be used to give instant access to pertinent data. The user's access to the same system the command center uses facilitates easy communication with higher officials to let them know the circumstances they currently face. Also, the command center would better inform the ground workers by pushing programs and data to them more easily and quickly. If we view ground workers as a singular node attached to the command center, the virtual concept is very similar to that of a virtualized HFN. Virtualized Wi-Fi devices such as smart phones or tablets will have instant connections to the command center and have many of the same capabilities as the command center.

The virtual HFN concept can also be deployed into combat areas with little to no communication networking already in place. The virtual HFN could support troops on the ground with very small equipment that requires little time to load and has instant access to data pertinent to the warfighter. Also, if the user needs a specific program, they would have access to the manager, who could download any program needed and make it available on the virtual operating system instantaneously.

Aviation technology is another tactical field that may benefit from further enhanced virtualization technology. If a pilot has virtual technology in the cockpit, the control towers might be able to manage the jet's systems from a distant location. Also, the control towers would be able to push any programs or software to the pilot as needed, on a case-by-case basis. The pilot might be able to get real-time information analyzed and make more informed decisions on further courses of action. The pilot and control tower could work more efficiently when carrying out missions.

c. SPARCCS

Maintaining an accurate common operating picture (COP) is important for efficient and successful missions in both disaster response and battlefield scenarios (Gibson et al., 2012). Past practices include using cellular, radio, and computer-based communication methods and updating individual maps. A drawback of these practices has been lack of interoperability of these devices, as well as inaccurate reporting and documentation among different entities. Recent advances in technology have led to the

use of collaborative maps for maintaining a COP among command centers. Despite the advantages this technique offers, it does not address the difficulties presented in receiving reports from field entities or ensuring that these entities have good situational awareness.

The Smartphone-Assisted Readiness, Command and Control System (SPARCCS) is being developed to address these issues. SPARCCS is an ongoing project at NPS that uses smartphones in conjunction with cloud computing to extend the benefits of collaborative maps to mobile users while simultaneously ensuring that the command centers receive accurate, up-to-date reports from the field. SPARCCS is implemented in a highly distributed fashion, where smartphones act as the primary device used by first responders and a cloud-based database system aggregates information provided by first responders for the command posts. Figure 4 illustrates a high-level architecture of SPARCCS.

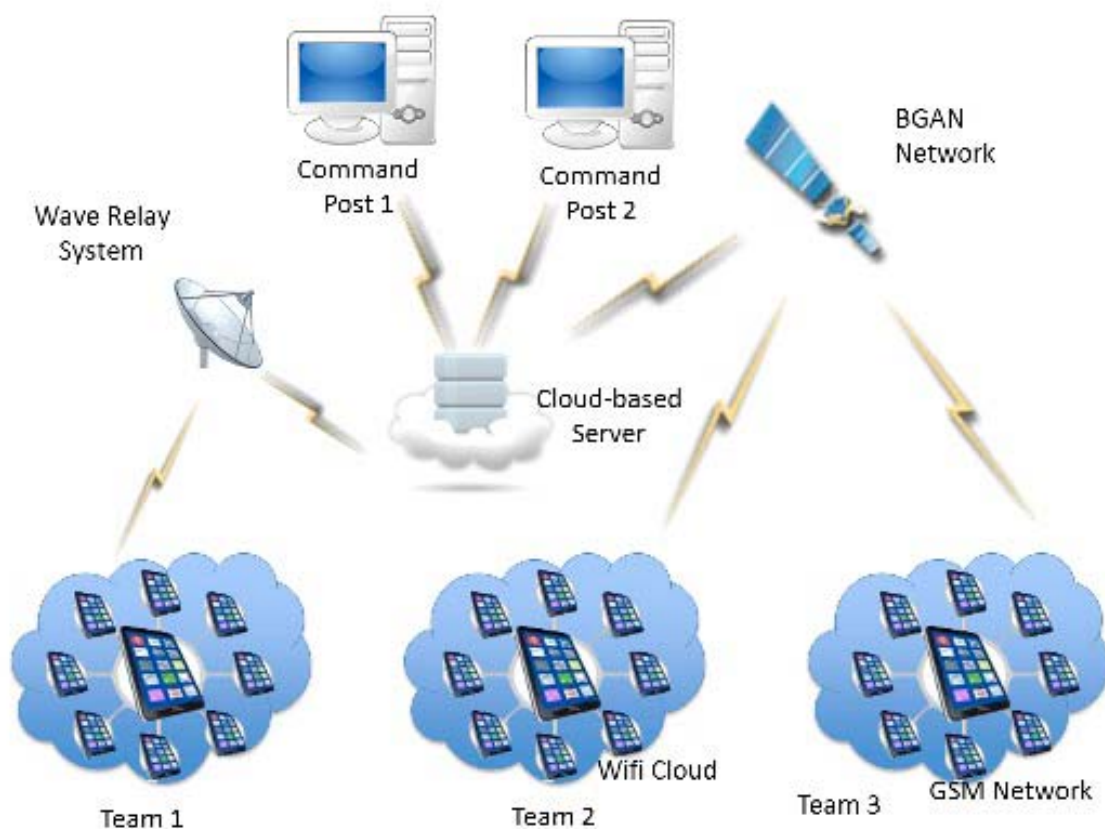


Figure 4. SPARCCS Architecture (From Gibson et al., 2012)

A mission in SPARCCS is typically spread across multiple small teams of first responders. Each responder is equipped with a smartphone, which is provisioned with SPARCCS mobile application. The responder uses this device to capture and share situational information as a content feed (made up of pictures, video, location, and messages) with the team leader's device, which can be another smartphone or a heavier-duty device, depending on the need of the mission. This content feed is maintained in a database running in the team leader's device. The team leader can share this information with other first responders and forward the aggregated feed from all team members to the SPARCCS server located in the cloud.

The SPARCCS server runs in the cloud and receives feeds from multiple teams participating in the mission. All of the content is maintained in the SPARCCS server and made available to local and remote command posts. A command post can view all participants and teams on the map as well as aggregated and individual content from first responders on the ground.

The number of teams and members in a team are variable and can be dynamically configured based on mission needs. It is possible for a single team or multiple, geographically dispersed teams to handle a mission. The network connectivity among team members and their leader and the SPARCCS servers can be realized in several ways. For example, it is possible to have a local Wi-Fi cloud to support connectivity among the team members, and from the team leader's server to the main SPARCCS server, one may use a BGAN or wave relay. There is considerable flexibility in the SPARCCS architecture, enabling the team to work with the most convenient technologies available for the mission.

d. Short Message Service (SMS)

Beyond the advanced networking solutions discussed above, Hall proposes the use of the common technology of short message service (SMS) to improve on the ways HADR operations are conducted. In our current hyper-connected world, it is estimated that from 1990 to 2011, worldwide mobile-phone subscriptions grew from 12.4 million to over 5.6 billion, penetrating about 70% of the global population and

reaching the bottom of the economic pyramid (Saylor, 2012). While not all these mobile phones are smartphones, all phone users can still be connected by simple SMS technology. In view of the high penetration of simple mobile-phone devices and the high reliability of GSM networks, simple SMS is an effective communication tool to improve in HADR operations.

In a recent example, although Haiti is one of the poorest countries in the world, 80% of the people of Haiti have mobile devices. During the Haitian disaster, victims were desperately using SMS to signal distress (six million SMSs were sent during the first seven days), and along the streets, entrepreneurs were providing charging services to victims' mobile phones. In addition, 1.1 million early warning SMSs were sent ahead of Hurricane Tomas, 2.1 million public-health SMSs were sent for public-health awareness for cholera, and 1 million SMSs were delivered for other issues, such as sexual violence. Based on research, 74% received the data intended for them, 96% of them found it useful, 83% took action, and 73% shared these SMS (Hall, 2012).

SMS technology is prevalent, cheaper than smartphone and advanced-networking solutions, and faster for deployment, due to its simplicity. SMS is therefore a user-appropriate technology that can be used for HADR operations to great effect. It creates a connected community where information can be rapidly disseminated: for example, in a refugee camp, where victims can be updated on information such as security, food, water, incidents, news, and safe locations. Hall proposes working with big data companies such as Amazon and Google to develop technologies that harness the potential of SMS in terms of information filtering and improve results accuracy.

2. Devices

Mobile phones can generally be classified into traditional, simple mobile phones with low computing capabilities that are mainly used for calls and text messaging, and smartphones with computing powers comparable to desktop computers. However, even simple mobile phones are nowadays equipped with functions such as camera and Internet access. In terms of smartphones, three of the most common smartphones operating platforms are the Android OS, iPhone OS, and the BlackBerry. Regardless of the

capabilities of these phones, they have all been used in some way or another to assist HADR operations in recent times. The following are two examples where the BlackBerry has been effectively used in HADR missions and the iPhone has been modified for military usage.

a. *BlackBerry*

The International Medical Corps recognized Research In Motion (RIM), Ltd., at its 2011 annual awards celebration for the role of BlackBerry smartphones in assisting disaster-recovery efforts around the world (N4BB (News for BlackBerry), 2011). International Medical Corps is a global, humanitarian, nonprofit organization that is a leading first responder, providing medical assistance and healthcare to populations distressed by natural disaster, conflict, and disease.

As part of the disaster-relief efforts following the earthquake in Haiti and the earthquake and tsunami in Japan, Dr. Joyce (an aid worker) arrived with a BlackBerry device in hand as a first responder. Although cellphones were not working, he was able to send messages with his BlackBerry smartphone. He used it to coordinate the setup of mobile medical centers, organize physicians, communicate with the central hospital, and direct material and equipment to where it was needed. On several occasions in Haiti, he and the team used their BlackBerry smartphones to coordinate with pilots bringing relief supplies and direct them to functioning airstrips.

Margaret Aguirre, the director of global communications for International Medical Corps, was part of the first emergency response team that arrived in Haiti hours after the earthquake. She also had a BlackBerry smartphone in hand. Doctors and nurses treating patients amid rubble and under trees were able to communicate with each other about patients needing immediate surgery and to coordinate the urgent transportation of blood supplies. Their BlackBerry phones helped them communicate to get materials to where they were needed and find where things were in the moment of crisis. Aguirre also used her BlackBerry handset to take photos and send updates to headquarters, as well as to post images and information to Facebook and Twitter. These social-media posts in the

early days of the mission enabled military personnel to know the needs of various humanitarian groups on the ground and where to direct assets.

b. MONAX iPhone System

Lockheed Martin developed the MONAX system by combining off-the-shelf smartphones and a modified commercial, 3G wireless technology (Chernicoff, 2011). By using nontraditional frequencies and wireless technology, the system delivers a secure, encrypted connection between a base station and hundreds of users, with enhanced data rates.

By inserting an iPhone into a Lynx sleeve, users can securely take advantage of a commercial smartphone to access the military's own round-the-clock app store that includes military applications ranging from mission reporting to facial recognition to enterprise intelligence, surveillance, and reconnaissance.

The system has been purchased by the Office of Naval Research and issued to the Marine Corps Pacific Experimentation Center to support their disaster relief and humanitarian aid missions, and it is still being evaluated before it receives broad deployment to actual combat zones or wide implementation in humanitarian relief missions.



Figure 5. Monax iPhone System (From Chernicoff, 2011)

3. Suitable Applications (Apps) for HADR Operations

Currently, there are more than a million smartphone apps developed for various devices, serving different purposes, and the numbers are growing at a staggering pace every day, as seen in Figure 6 (Gruener, 2012). These apps range from games to business and daily utility tools. A quick search on the Internet reveals that many apps have also been developed for various types of military operations. The following are just some of the HADR-specific applications developed by aid agencies all over the world to assist operations. Beyond these mission-specific apps, the possibilities for designing and modifying apps to suit different needs and contexts are endless.

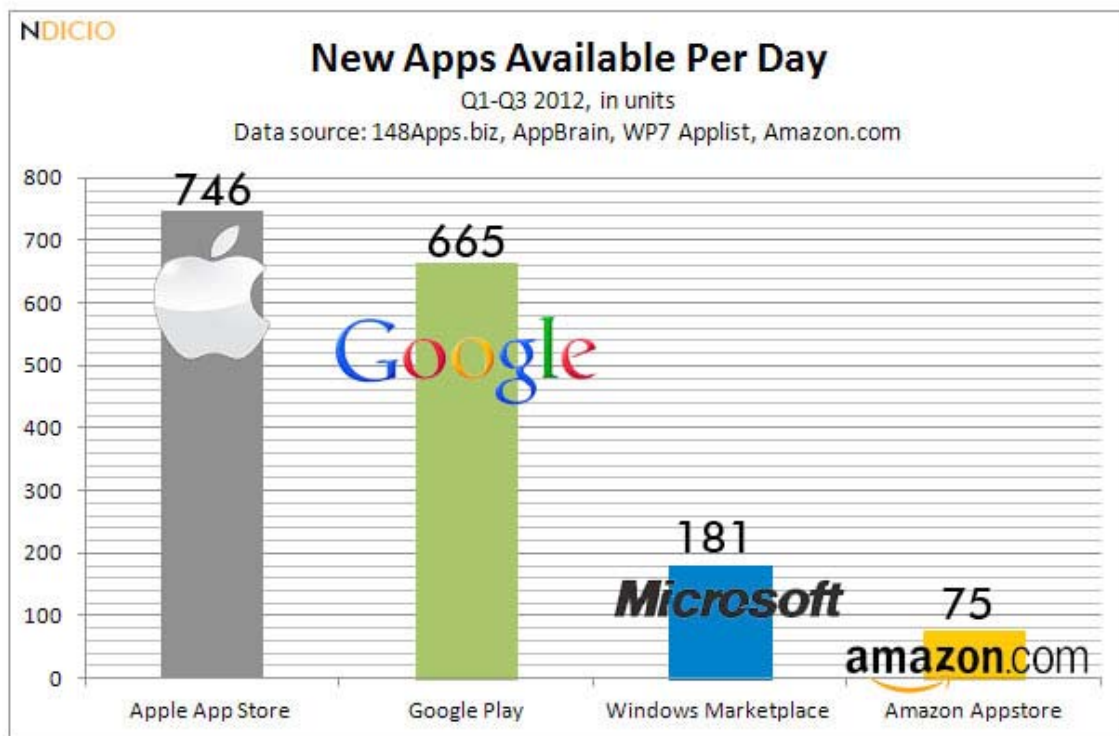


Figure 6. New Smartphone Apps Available Per Day (From Gruener, 2012)

a. *Map-Books Replacement*

Often, first responders just need a few pages from map-books (which typically run up to about 200,000 pages for a disaster) for the area they will be working in. The National Geospatial-Information Agency has developed an application to replace

these paper-map books (Ball, 2011). With the application, the first responder can zoom into the area of interest and see before and after imagery. The application can serve the equivalent of 6,000 pages per hour on the mobile device.

The move to digital map replacement is also applied to the military by making their flight manuals digital and helping provide information to the field so that helicopters can determine the best landing sites. Previously, flight manuals were printed every 38 days at considerable cost. Going digital will save \$20 million in printing costs (Ball, 2011) per year, which can be better used for other operational assets and aid benefits.

b. Infrastructure Damage

The National Geospatial-Information Agency has developed an infrastructure-damage application that includes 451 layers of infrastructure for first responders to identify and understand what previously existed in damaged locations (Ball, 2011). This application is particularly useful for navigation in heavily damaged areas where there are no longer street signs. The application provides layers of data that can be queried and zoomed into, with an integrated compass to navigate to areas of interest. With applications providing self-service information, the agency can spend more time analyzing information to provide greater intelligence to the field. These handheld applications save the agency a great deal of time and resources and deliver information in the way the user requires.

c. Aid Tracking

In Haiti, an organization known as Agricultural Cooperative Development International and Volunteers in Overseas Cooperative Assistance (ACDI/VOCA) distributes aid rations and provides guidance on health, nutrition, hygiene, and sanitation to vulnerable people, particularly mothers and children. Previously, they monitored their activities by collecting paper forms and fingerprints of recipients to ensure that they pick up their rations, attend health trainings, and keep child-wellness appointments (Murphy, 2011). But this kind of monitoring takes time and leads to long lines at distribution sites, making it difficult to ensure that the right people get what they need.

In order to replace tracking by paper with more efficient technology that can work in places where electricity and Internet access are unreliable, ACDI/VOCA worked with the Humanitarian Free Open-Source Software (HFOSS) Project, a National Science Foundation-funded activity at Trinity College in Hartford, Connecticut, to develop a free, open-source software. HFOSS has since developed and tested a smartphone application that will allow the field teams to easily and quickly update records during distributions and register new beneficiaries in remote areas. If there is cell reception, field staff will be able to immediately send data, such as the name and health status of a child or mother, by SMS to a server maintained by ACDI/VOCA in Jacmel, Haiti. If there is no reception, they can store the data on the phones and send it later. Once these entries arrive in Jacmel, staff will update the database. This way, prior to each distribution, an updated beneficiary list will be e-mailed to field offices and uploaded to each smartphone.

During distributions, field staff will be able to search beneficiaries' records, mark their attendance, and make changes in their status. The smartphones will be charged and updated at ACDI/VOCA's field offices, which are solar powered and have regular Internet access.

d. Field Level Operations Watch (FLOW)

While there are many humanitarian projects, such as providing safe drinking water to developing countries, it is not enough simply to install a water point and celebrate the number of people with access to clean water on that particular day. Organizations need to be accountable for the projects put in place and ensure that they are operating effectively.

According to the International Water and Sanitation Centre in the Netherlands, of the 600,000 to 800,000 hand pumps installed in sub-Saharan Africa over the past 20 years, approximately one third failed prematurely, resulting in a wasted investment of more than \$1 billion (Pump Scout, 2010). FLOW provides the technology needed to transparently and accurately assess the status of programs to avoid future unsuccessful commitments.

Developed by the organization Water For People, FLOW is an on-the-ground, remote technology that broadcasts immediate, instant reports about whether their water and sanitation projects are working or failing. This injects a whole new level of transparency, efficiency, and accountability into their humanitarian work.

FLOW combines Android cellphone technology and Google Earth software to let field workers and volunteers record data from tens of thousands of water points around the world. That information is then displayed on an online global map to signal whether a project is up and running, broken, or on the verge of disrepair and needing immediate action.

e. REUNITE

After a disaster has occurred, aid workers and the media often interview people who have been separated from their families. These records are usually stored in tapes, paper form, or digital media. These media are easily neglected, lost, or damaged, and although there are systems to solve this problem, such as the public search facilities set up by charities such as the Red Cross, there is no universal system to provide this vital task.

At the University of Manchester, Gavin Brown, Peter Sutton, and Lloyd Henning developed the mobile and web platform REUNITE to provide a solution to this problem (Homeland Security Wire News, 2012). REUNITE records initial interviews using smartphones, and uploads them onto a central server. This information can then be accessed via computers by trusted aid workers away from the scene, who gather as much information as they can by coordinating with other users in a manner similar to a social network before passing details to aid workers on the ground. The interviews are quickly transcribed into a Web-searchable format. Relief workers on the ground can then download vital information and relay relevant messages to survivors. The information can only be accessed via an encrypted uplink, which helps address confidentiality issues.

f. Where's Safe

Where's Safe is a simple application that quickly identifies safe areas for people to go to in the event of a natural disaster or terrorist attack (Sutton, 2010). It is designed to replace the emergency radio-broadcast system, which does not reach a large number of people, by allowing people to find the nearest safe point simply by sending an SMS message.

When an emergency is declared, the emergency services activate a series of safe havens where people can seek shelter and protection. These are usually predefined locations such as polling stations, leisure centers, and other suitable public buildings. The application allows anyone to send a text message containing his location and receive information back telling him where the emergency is and where the nearest safe location is. Meanwhile, the server updates the count of people heading to that particular safe haven and is able to determine if it is full occupied. The remarkable feature of this application is that it runs entirely on SMS (Bradshaw, 2010).

g. Height Catcher

Malnutrition and lack of supplies are common in natural disasters, especially in prolonged emergencies such as floods. Currently, measuring the height of children is a cumbersome process that requires aid workers to carry and use a heavy wooden board to assess children less than two years old (Henning, 2010).

Using an open-source application with a camera-enabled mobile device, the Height Catcher application allows rapid and accurate assessment of height or length. Using the body-mass index, it quickly measures the level of malnutrition. The information is then entered on a smartphone, which instantly calculates what food or fluids the child needs. Aid workers can immediately calculate the individual and camp burden of malnutrition and text the results to a local office. This information is used to direct relief efforts and share with partner agencies for aid distribution and prioritization.

h. The Army App Store

Like the commercial Apple Apps Store and Android Marketplace, the United States Army has recently launched a smartphone application store (Sage, 2012). Named the Army Software Marketplace, it offers training applications for use on commercial smartphones and tablets. It radically reduces the time required to deliver applications to the force and allows Army members, organizations, and third-party developers to release applications for Army-wide distribution. Among the whole selection of military-related applications, some key applications include water-well locations, training guides, and Soldier View, an application that offers situational awareness through a topographical map and recent reports in the area, which soldiers can interact with and submit fresh reports from.

4. Conclusion for Solution Space

It is evident that the networking solutions, COTS devices, and wide variety of apps available today bring many possibilities for use in HADR operations. However, most of these technologies are still in the early stages of being widely implemented for operations. This is due to security reasons, mindsets, or the lack of a concerted effort to ensure interoperability among organizations. Organizations are often observed to be using these solutions within their communities in small doses. Nonetheless, the abundance of technological options available should provide greater opportunities for wider application in the future.

D. FEASIBILITY ANALYSIS

1. Solutions to Needs and Functional Mapping

The problem space has provided the operational requirements of HADR missions and the solution space has provided the network and smartphone apps technology available. Assuming that network and connectivity problems have been solved using some of the network solutions discussed above, smartphones apps can now be effectively used to fulfill the needs and functions of HADR operations, in terms of improving communications and situational awareness. While a few examples of suitable apps are

discussed in the previous chapter, the list is not exhaustive, and we can draw inspiration and derive more smartphone apps to fulfill operational requirements.

a. *Provide Supplies and Logistics*

Suitable smartphone apps would be those that can provide information on basic essential supplies and safe locations. Information can include where to find these supplies, the available quantity, and the fastest and safest way to get to these locations. Using their mobile devices, victims, supply providers, and aid agencies can now monitor the latest information on essential supplies, increase survival chances, and reduce chaos in distribution situations. Tracking of supplies can now be done using smartphone apps instead of paper, improving efficiency (Murphy, 2010).

b. *Provide Security*

Suitable smartphone apps for security would be those that can provide blue-force tracking and crime-monitoring updates. Security and military forces can use this system to improve response time and get real-time information from operations on the ground. The general population can also use their mobile devices to send distress signals and provide crime information to security forces. This would improve the security situation in the disaster area.

c. *Exchange Information*

There are many apps that can be used to exchange information, depending on the kind of information transmitted. The external media agencies such as newspapers and broadcasters would be interested in apps that can provide photos, interviews, and videos about the disaster, and a centralized social-media app where everyone can upload their media would be appropriate. Relatives and victims who are concerned about their families' wellbeing can use apps that provide updates on lost and found people or provide a central database of survivors. With the huge amount of information present in a chaotic environment, apps that search databases and prioritize results could help to streamline the information-extraction process.

d. Setup Communication Links

The network solutions discussed above provide basic network connectivity for a disaster location. However, in order to fully restore communication links to normal, suitable apps could provide information on network strength within certain areas and provide updates on repair efforts. Also, these apps can provide information for the repair of equipment and for temporary networking devices for use. These would help alleviate network issues before communication links are restored.

e. Provide Emergency Response

Similar to apps for security, emergency response can be improved by the use of apps that provide emergency agencies with critical information on victims. Victims can use these apps to update their medical conditions and locations, and this information would allow aid agencies to prioritize their responses, take appropriate action, and prepare the equipment needed for the task.

f. Provide Infrastructure

To repair and rebuild damaged infrastructures, information is needed regarding the extent and location of damage. It would take time to access every building, and sometimes access to these areas can be difficult. Victims or aid agencies on the ground can use apps to provide pictures and information about damaged infrastructure to repair authorities, so they can distribute the data and manage their resources.

g. Provide Governance

For authorities to make better decisions, ground workers can use apps to share their information, allowing them to work within a common operating picture. Apps can also help authorities track their assets and resources and allocate them suitably to needed areas.

2. Benefits and Tradeoffs Analysis

This chapter examines the benefits of using smartphone applications and some associated tradeoffs.

a. Cost

Smartphone technology could not only help save lives in a disaster, it can also potentially ease the financial burden on aid organizations (Homeland Security News Wire, 2012). This could be in the form of savings from paper consumption, transportation costs, and delivery services, which are associated with manual forms of information dissemination and recording. Smartphone apps can effectively replace these physical modes and reduce operating costs. For example, it is estimated that it is ten times cheaper to use an open-source SMS tool to gather information in Nigeria about malaria than to send aid workers around with surveys (Hall, 2012).

One of the cost tradeoffs would be the expense involved in developing smartphone apps. However, these costs are often negligible, because these apps were often developed originally as commercial apps for market sale, and only slight modifications are needed to reapply these apps in a military or HADR context. Also, cheap or free open-source apps are easily available for download and use. Little training is required to use these devices and apps as they are becoming increasingly common.

Another tradeoff in using smartphones would be the startup cost of purchasing these devices. In order to keep up with the latest technology and prevent the devices' going obsolete, organizations might avoid mass fielding but make smaller buys in increments instead (Gould, 2011).

b. Security

The use of smartphones and shared networks runs the risk of security breaches. Organizations and authorities would be concerned about protecting the data on their devices and central databases. Appropriate security measures would have to be put in place, such as user authentication and data encryption. Also, unwanted disclosure of intelligence might also happen when there is wide information access and distribution. The general public might reveal important operational details through social media and other media-sharing apps, and jeopardize the operation. However, in a HADR operational environment, most of the data are usually unclassified, and the massive amount of information and media circulated is user generated. Aid agencies seldom

bring sensitive materials or classified equipment into HADR missions, thus reducing the complexity of security issues. Nonetheless, all these security tradeoffs need to be considered when using smartphone technology.

c. Information

During a disaster, it is often the people in the middle of it who have the best information, video, and photos of what is happening, and that information can be a huge benefit to those just entering the scene to help with relief efforts. Beyond using smartphone technologies to deliver aid, smartphones could also be used to store intelligence data for future missions (Sanborn, 2012). Traditional pen and paper methods result in rich, but highly variant and unstructured information, which is difficult to use in future planning (Heimbuch, 2010). Instead of using traditional methods such as writing in a notebook to record intelligence during civil reconnaissance, aid agencies and military forces can use smartphones to record detailed information about local social, religious, and ethnic composition, sources of instability, infrastructure, and more. Soldiers on the future battlefield could land in a country they visited five years earlier to deliver humanitarian aid and would already have important intelligence collected from the ground, including photos and coordinates of critical hospitals, roads, landing strips, bridges, and government buildings. That information would be readily available to commanders, on a moment's notice, for decades to come (Sanborn, 2012). However, this information is often kept within individual organizations and unwillingness to share them can prove challenging, even though it might greatly enhance the overall effectiveness of HADR operations if different organizations share and use the same pool of resources.

3. Lifecycle Management

Despite all the available networking and smartphone solutions that are seemingly ready for use, there is still a need to address lifecycle-management issues in order to effectively incorporate smartphone technologies into HADR missions.

a. *Hardware*

The unpredictable nature of HADR missions makes it difficult and expensive for organizations to stockpile hardware such as smartphone devices and networking solutions. Also, the rapid evolution of technology makes it unwise to procure large quantities of hardware at a time. Hence, organizations must find ways to either use the hardware they purchased during peacetime or be able to quickly acquire sufficient quantity when the need arises. Aid agencies and military forces must work together with technology companies to ensure that sufficient quantities are available for operations, but yet maintain cost prudence in their purchase.

Another approach would be to use the common devices that most aid workers already have in possession, such as their daily iPhones and Blackberry phones, and develop apps that can work across these different platforms, just as games are developed for multiple platforms. This way, organizations can save on hardware costs and maintain their operational edge.

b. *Software*

While most people are familiar with using smartphones and apps these days, certain job-specific applications still require some form of formal training for users to effectively maximize application potential. Organizations must therefore constantly train aid workers to familiarize them with these smartphone solutions so that they can use them appropriately when a crisis occurs. This, in turn, takes time and effort for the organizations, who must put a due amount of focus into smartphone solutions for their operations.

Another lifecycle management aspect of smartphone software would be the research and development of suitable apps for HADR missions. There must be sufficient impetus and profits for software companies to want to develop these apps. Organizations must provide these incentives in various forms, such as advertisements, publicity, and profit.

Similarly, although there is a huge resource of open-source software in the public, organizations must work closely with developers to ensure the quality and suitability of their software for mass usage in their operations.

c. During Operations

Because aid agencies and military forces come from different places and arrive at different times, effort must be made to synchronize these various organizations and let them operate within the common virtual space. Some simple methods would be using Internet-based platforms for easy access for everyone. However, robust security measures would have to be put in place to reduce vulnerabilities and mitigate the threats of working with the Internet.

While it is ideal that information should be shared and central databases streamline information overloads, political and social constraints can sometimes prevent this happening. Authorities or organizations might want to impose information blockage on sensitive figures and personal information such as victim particulars. Organizations and authorities must therefore have a common understanding of the information boundaries they are working in.

d. Post-Operations

After HADR operations, organizations need to find ways to upkeep or dispose of hardware that was procured specifically for the mission. They can work with technology companies to dispose of or update their hardware, or find ways to store them or use them for other purposes during peacetime. Also, software needs to be continually updated, even after operations, to ensure compatibility and optimal performance. For this reason, budgeting must include post-operations maintenance and disposal to ensure that it is cost-efficient to field this smartphone and networking equipment in the first place.

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IV. CONCLUSIONS AND RECOMMENDATIONS

HADR operations present challenges on many fronts. The large number of stakeholders and time-criticality hinders interoperability and operations efficiency. Information exchange is often stifled due to lack of communication links, and this leads to further operational obstacles.

The advance of smartphone technologies has reached a mature stage and is becoming an essential daily communication tool for many. Smartphones and applications now provide a way to bridge the communication barriers between various stakeholder groups and provide a common operating platform and environment for better organization of HADR operations. Innovative applications can fulfill operational requirements and meet the needs of stakeholders in different ways.

While there are millions of smartphone applications on the market today, there are only a handful designed specifically for HADR operations. Despite this, it is important to understand that smartphone applications are extremely flexible in terms of how they are being used. Entertainment and daily utility applications can be easily modified and applied to all kinds of operations.

In an age where smartphones are slowly replacing traditional computers and ways of communication, organizations need to examine their modes of operation and find ways to incorporate smartphone technologies. More importantly, there must be a centralized effort in using these smartphone technologies to bring together the various stakeholders in a HADR situation and realize a greater effect.

An area that could benefit from future research is a more detailed quantitative analysis of the potential contributions of these smartphones through computer simulation or wargaming. This would give a further insight into how much actual benefits these smartphone solutions could provide in terms of aid effectiveness, and could help better understand how these devices could be used in an operational environment.

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