

ICT enabled approach for humanitarian disaster management: A systems perspective

Abstract:

Purpose – Each stage in disaster management faces different challenges concerning information gathering, sharing, interpretation and dissemination. However, a comprehensive understanding of different Information and Communication Technology (ICT) systems utilised for humanitarian disaster management is limited. Therefore, the paper follows a systems thinking approach to examine ten major man-made and/or natural disasters to comprehend the influence of ICT systems on humanitarian relief operations.

Design/methodology/approach – A longitudinal, multi-case study captures the use of ICT tools, stakeholders involvement, disaster stages and zones of operations for relief operations over the past two decades. A systems thinking approach is utilised to draw several inferences and develop frameworks.

Findings – Multiple ICT tools such as geographic information systems, online webpages/search engines, social media, Unmanned Aerial Vehicles/robots, and artificial intelligence are used for rapid disaster response and mitigation. Speed and coordination of relief operations have significantly increased in recent years due to the increased use of ICT systems.

Research limitations – Secondary data on the past ten disasters is utilised to draw inferences. The developed ICT-driven model must be validated during upcoming humanitarian relief operations.

Practical implications – A holistic understanding of a complex inter-relationship between influential variables (stakeholders, disaster stages, zones of operation, ICT systems) is beneficial for effectively managing humanitarian disasters.

Originality/value – Broadly classifying the ICT systems into surveillance, decision support and broadcasting systems, a novel ICT-enabled model for humanitarian relief operations is developed.

Keywords:

Humanitarian Operations, Disaster Relief Operations; Information and Communication Technology; Disaster Management; Systems Thinking.

1. Introduction

The significance of humanitarian disaster management is rising due to the increased frequency of disasters since the 2000s. The increased mismatch between humanitarian needs and the availability of resources demands efficient disaster relief operations (Heaslip, 2018). Disaster management is about reducing the impact risk and coping with human lives and economic loss (Quarantelli, 1988). United nation's office for the coordination of humanitarian affairs (OCHA) has developed information systems (e.g. ReliefWeb) to tackle humanitarian disasters.

Robust information management systems are critical to the success of disaster management (Yates and Paquette, 2011). Information and Communication Technology (ICT) has the potential to deliver clear, accurate and instant information for relief operations (Gomez and Elliot, 2013). According to Li et al. (2012), the ICT is an emergency response mechanism filling the communication gap in a disruptive event situation. However, approaches to building an ICT network for early warning have lacked research on humanitarian disaster management (Sagun et al., 2009; Meier, 2011; Damoah et al., 2021). Real-time information could increase the accuracy of priority decision-making and inter-sectional communication. Once the disaster strikes, communication accessibility is always challenging for relief organisations. In such situations, ICT acts as an informational connection between disaster management actors and the affected population (Price and Richardson, 2011; Palen et al., 2007). Nonetheless, ICT suffers from information bottlenecks, lateness and inaccuracies, hindering the efficiency of relief operations and causing long delays in receiving humanitarian aid (Greenough et al., 2011).

Disaster management involves complex settings, which may be influenced by multiple factors (Coetzee and van Niekerk, 2012). Improving humanitarian disaster management is becoming critical due to an increasing number of disasters/events (Altay and Green, 2006; Dubey et al., 2019). Recent geopolitical events (e.g., Ukraine war, 2022) in different parts of the world have highlighted the need for efficient humanitarian disaster management. However, limited studies focus on developing models/systems for humanitarian disaster management (e.g. Maon et al., 2009; Charles et al., 2010; Goldschmidt and Kumar, 2016). In the past, individual disasters have been studied to understand the role of information sharing in humanitarian relief operations (e.g. Bharosa et al., 2010; Altay and Labonte, 2014; Ozili, 2022); but the holistic picture is still missing. Furthermore, most of these past studies focus on phases of disaster management and do not provide adequate consideration for the evaluation and analysis of the disaster (Asghar et al., 2006).

Evidently, there is a lack of studies within the humanitarian supply chain and disaster management literature capturing the ICT's role, considering the latest technological and societal advancements. Therefore, this study attempts to address this gap by developing a comprehensive ICT-enabled model for efficient humanitarian disaster management by understanding different ICT systems, and associated networks utilised in the past humanitarian disasters. To achieve this defined goal, the study aims first to capture the advancement of ICT in past humanitarian disasters and later develop a comprehensive model for humanitarian relief operations. This paper adopted systems thinking theory to understand better ICT tools, applications and practices from the secondary data collected on selected disaster cases. A multi-case study approach is followed to compare the insights drawn and develop an ICT-enabled model for humanitarian relief operations.

The paper is structured as follows. The literature review section illustrates the theoretical background of disaster management and ICT studies. Section 3 discusses a system thinking approach as part of the research methodology. Multi-case analysis section (4) presents a longitudinal study of the selected ten cases. Section 5 discusses the findings and develops a conceptual framework and model. Finally, section 6 concludes with a discussion on theoretical and practical contributions, limitations and future research directions.

2. Literature review

2.1. Disaster management

Academic literature on disaster management discussing definitions, processes and associated activities is evident (e.g. Nisha de Silva, 2001; Cottrill, 2002; Pettit and Beresford, 2005, 2009). According to Mohan and Mittal (2020), “*disaster Management refers to the protection of the lives and property in huge amounts, whenever some kind of disaster occurs whether man-made or through natural phenomenon*”. Disasters can originate from natural or man-made sources or a combination of both. Safran (2003) developed the ‘*disaster cycle*’ involving four phases - prevention, disaster/emergency, transition and recovery. Information sharing and collaboration are inevitable for efficient disaster management (Kovács and Spens, 2009). Earlier, Scott and Batchelor (2013) developed a disaster management cycle by linking processes with information. The disaster cycle consists of mitigation and preparedness as stages for pre-disaster management, and responsiveness and recovery stages for post-disaster management.

Most importantly, preparation and coordination are vital for operational excellence in disaster management (Botchie et al., 2019). Different activities involved in each stage/process may vary depending on the nature and complexity of the disaster. Accurately identifying risks and providing timely information is crucial for disaster management (Kovács and Spens, 2009). However, disaster management has inherent challenges, which may originate from the lack of knowledge about where and when a disaster will occur, its geographical extent and the event's impact (Van Wassenhove, 2006).

2.2. Information and communication technology

Information collection and sharing are vital for humanitarian relief organisations, as the circumstances of each disaster are different, and it is difficult to fulfil the objectives with limited resources and time (Tapia et al., 2012). The information flow could positively affect the intra or inter-organisational collaboration quality in relief operations (Li et al., 2013). The critical function of the ICT is timely information delivery to improve collaboration among organisations (Paton and Flin, 1999; Janssen et al., 2010). ICT is also essential for evaluation and damage assessment for making better decisions (Careem et al., 2006). Challenges in information exchange occur due to inter-organisation relationships between different stakeholders (Comfort et al., 2004) involved in the pre-event mitigation and planning, along with responding and rebuilding after a disaster. Various stakeholders such as policymakers, government-linked groups, military, commercial organisations, and non-government organisations interact during disaster management to provide relief support for health, food, water, clothing and infrastructure (Pettit and Beresford, 2009). Due to the lack of a single decision-maker in the context of disaster response, coordination between stakeholders is necessary. This complex interaction plays a significant role in the effectiveness of relief operations for humanitarian disasters. Often a centralised decision-maker is not efficient (Sahin and Robinson, 2002), as this type of communication is found to be time-consuming and complicated. Another important factor in disaster management is the ability to manage ICT sources. Challenges include accessing hardware, access to a reliable source(s) of power and adequate systems that will function in a disrupted environment. Due to an increase in mobile and telecommunication technology, there is an increase in the use of social media for disaster management (Gao et al., 2011; Özdamar et al., 2015). However, implications of such social networks and other technological advancements (e.g., Unmanned Aerial vehicles) remain unexplored in the extant literature.

3. Research methodology

This paper adopted systems thinking theory to extract ICT tools, applications and practices used in the selected disaster cases. Systems thinking is a methodological approach attempting to understand how multiple dimensions interact and how they can be brought into an appropriate relationship for improved results (Stermann, 2000). This approach is particularly suitable for investigating an unstructured situation (Checkland, 1981; Checkland and Scholes, 1990). Furthermore, it is a problem-solving approach for ‘*difficult to model*’ problems and helps build cause-and-effect relationships (Ghadge et al., 2020; Er-Kara et al., 2021). Soft-systems thinking approach is recommended in complex, dynamic and interlinked contexts (Sushil, 2000; Khyrina et al., 2012). On the other hand, hard-systems approaches based on simulation and modelling are apt for analysing quantitative data.

According to Cavallo and Ireland (2014), disaster relief operations are based on the hierarchy (top-down) model and cannot identify the nature of challenges. Complex phenomena such as disasters present many emergent and cascading effects (Helbing, 2013). The information available from these events is insufficient to perform statistical analysis (Ruggeri et al., 2005), as disasters are characterised by interdependent activities whose impacts are difficult to predict (Lorenz et al., 2009). Thus, soft-systems thinking is a suitable methodological approach for the given problem and therefore adopted in this study.

The soft-systems thinking approach is utilised in this study to measure how the primary cause (ICT) is associated with different subsystems. According to Forrester (1994), systems thinking integrates case studies in improving complex conceptual models, emerging from the basic description of the existing system. Past disaster cases are used in this research to study the link between ICT and disaster management and are assessed using the systems thinking approach.

In this study, natural and man-made disasters are methodically studied to understand the different activities involved during each stage of the disaster cycle. Secondary data on ten natural and man-made disasters occurring in the last twenty years (2000-2020) is utilised to support the study. The cases were chosen to comprehensively cover natural disasters such as flood, earthquake, cyclone, hurricane, tsunami, biological calamity, etc., as well as man-driven disasters such as the 9/11 attack, Ebola and pandemic. The selection of cases was primarily driven by the disaster’s broader impact (regional/global) and the intelligent use of ICT for relief operations. The secondary data consisted of cross-historical sources such as regional and international news, international/governmental relief reports, journal articles, documentary

films, internet sources and textbooks. In addition, secondary data provides transparency to the data collection process, as the data is publicly available (Papachroni and Lochrie, 2015). The multi-case study method is a combination of multi-sources, and it contains a large amount of data to interpret some in-depth phenomena and follows replication logic (Drake et al., 1998; Yin, 2009). The longitudinal, multiple-case study approach attempted in this study is expected to capture previous relief operations management to understand better the interaction between ICT tools and stakeholders in a typical disaster. The conducted cross-case analysis identified differences and similarities between cases in terms of the use of different ICT tools and their applications. It also helped to identify common themes/patterns such as the zone of operation, stage of disaster, type of ICT system, etc. A comprehensive understanding of the technological and societal advancement in using ICT for disaster management over the past two decades has been a primary motivation for choosing ten disaster cases.

4. Multi-case analysis

Disasters can originate from different sources, and the impact of such disasters depends on the extent of their geographical spread. The speed of onset is the quickness at which the disaster strikes a region. Some of natural disasters like earthquakes, hurricanes, tornados and tsunamis tend to occur suddenly, devastating the entire region. In contrast, some calamities like famine, pandemics, heat waves, etc., tend to cascade their impact gradually and may be localised or cover large regions. Disaster management requirements for each event are different; hence, it is essential to consider a holistic (also referred to as systems) perspective for identifying appropriate ICT-based approaches for disaster management. During the disaster recovery process, multiple important activities are determined by Médecins (1997). This covers some key activities such as initial assessment, provision of water, food, shelter, health care and the control of epidemics. These activities require information sharing tools to coordinate between disaster response teams and global volunteers. Before 1990's, humanitarian disaster operations were managed with the help of radios, paper forms and clipboards (Portsea, 2011). However, post-2000, the internet era and technological and societal advancements have brought new tools, techniques and mobile/digital networks to manage humanitarian disasters better. The following section discusses the author selected ten (comprising of natural, human-made and Hybrid events) cases to generate insights into ICT systems, applications, challenges and practices.

1. 9/11 Attack (2001)

The twin towers in New York City and the Pentagon in Virginia (USA) were targeted by the radical religious group in the 9/11 attack on September 11th, 2001. Terrorists hijacked four aircraft killing nearly 3,000 people and contributing to the several years of warfare in Afghanistan against attack conspirators (BBC, 2001).

The 9/11 disaster rescue response highlighted that the government disaster operational communication and planning lacked experience and collaboration (CNN, 2016a). The disaster's velocity and size overwhelmed the civil services' capacity in New York City. It could be assumed that the information flow on ground zero for those first responders was insufficient. People trapped tried to connect with their families by making mobile phone calls, which overloaded the telecommunication service networks (Comfort and Kapucu, 2006). Likely, the communication jam occurred not only among civilians but also among firefighters. They could not be warned to leave the buildings when they were falling. This chaos led to the death of more than 400 personnel, such as firefighters, police officers and EMTs, in the first hour of the 9/11 attack (Taylor, 2011). According to the 9/11 commission report (2012), the Fire Department of New York (FDNY) was facing the problem of the highly occupied radio channel, which is blamed for the bad disaster management.

Even the governmental operation encountered some challenges. For example, the office of Emergency Management (OEM) implemented the Geographic Information System (GIS) for pre-hurricane preparation, which oversaw the response to storm and weather issues (Kapucu, 2006). Furthermore, Bevc et al. (2009) pointed out that the role of the GIS application on 9/11 was to smooth the supply and demand pressure from ground zero and enhance communication and coordination efficiency among agencies.

2. Indian Ocean Tsunami (2004)

Indian Ocean Tsunami hit South Asia on 24th December 2004 with 9.1 magnitudes of earthquake. This shock ranks as one of the top 3 earthquakes in history, with 227,989 deaths and 1.7 million people affected across southern Asia countries (BBC, 2014; CNN, 2015a). Over 160 relief organisations and UN agencies went to Indonesia for the emergency response, and the recovery was estimated to have taken more than two years (BBC, 2005).

Before this disaster, there was no prevention of the tsunami hazard as it occurred infrequently. Nevertheless, some countries (such as Maldives, Bangladesh, and Sri Lanka) could not afford and maintain expensive monitoring equipment before the disaster strike (Coca, 2015). Although the communication was made from The Pacific Tsunami Warning Center (PTWC) in Hawaii, their reaction to warning the public was too slow. The disaster could have been avoided, but the authorities were unaware of the disaster preparation, with bureaucracy and inadequate infrastructure creating further chaos (Symonds, 2005). Athukorala and Resosudarmo (2005) criticise that these countries could not cope with the disaster due to poor preparation, even if they had an early warning.

Regarding the aftermath response, the ICT contribution was notable after the tsunami. For example, the implementation of *Sahana* software helped survivors find their relatives through the online bulletin. This software also could track and manage the response services and resources in different regions (Wattegama, 2007). Similarly, The United Nations Coordination of Humanitarian Affairs (UNOCHA) conducted the GIS approach for making humanitarian maps of information sharing in Sri Lanka and Sumatra to improve rescue efforts, and the satellite imagery cooperated with the GIS mapping technique for monitoring the tidal activities to prevent the second tsunami hit (Ramakrishnan et al., 2005). More recently, the United States National Oceanic and Atmospheric Administration (NOAA) has established the Deep-Ocean Assessment and Reporting of Tsunami system (DART II), using a deep-ocean sensor to identify tsunamis and communicate with the satellite (UNISDR, 2013).

3. Hurricane Katrina (2005)

Hurricane Katrina superstorm struck on August 29, 2005, damaging thousands of homes and commercial buildings. An estimated 1,800 people died, and 78,000 were housed in emergency shelters (CNN, 2005; BBC, 2005). The situation was dire because the flood damaged the city's infrastructure, including its power supply and communication system. The hurricane's magnitude and duration brought down the civil service and infrastructure (The New York Times, 2005). For example, Louisiana, Mississippi and Alabama areas had no customer telephone lines, and up to 2,000 cellular sites were damaged. Also, the strong winds destroyed 37 of 41 radio stations (US House of Representative, 2006). Moynihan (2009) argued that the search and rescue operations planned the relief activity immediately. However, the shortage of network meant a quick response to the hurricane was impossible. Different relief organisations (e.g. NGOs, NPOs, military units, etc.) could not collaborate in such a chaotic situation. The

interruption of mass communication jeopardised New Orleans city's capability and resilience during this time (Chewning et al., 2013). Similarly, the American Red Cross (2006) pointed out that their logistics and supply plan could not access the affected zones because the disruption of physical networks and communication channels made collaboration with government bodies nearly impossible.

In the early stage of the strike, mobile phones were commonly used for searching and rescuing people. For instance, city volunteers used messaging/texting as an approach to send and receive information among different buildings when power lines, phone cables and cell towers had malfunctioned; however, this method was vulnerable to battery depletion and fuel shortage (Krishnamurthy and Kwasinski, 2014; Davis and Robbin, 2015). Owing to such a vulnerable information network, few telecommunication companies had activated plans to restore the information and communication in the disaster area. For example- *Freedom4Wireless* had provided solar and battery-powered voice-over-Internet protocol (VoIP) equipments; Motorola had offered 2,500 communication devices such as radios, chargers, and consoles to restore and resolve the problem.

4. Cyclone Nargis (2008)

Cyclone Nargis hit the western part of Burma with 5-6 meters high storm waves on 2, May 2008. The cyclone took 22,464 lives, and 41,054 were still found to be missing a week after the disaster. The cyclone also demolished 95% of the houses in the Delta (The Telegraph, 2008; NASA Earth Observatory, 2008). According to Steele (2013), the relief action was not rapid because the military authorities did not allow foreign humanitarian personnel to enter Myanmar, although the local agencies lacked large-scale relief experiences. The government was reluctant to permit international aid to enter the country. Hence, there was no access to activate the relief plan almost a week after the disaster (Hurricanes: Science and Society, 2008). Subsequently, there was no usual international procurement, and everything had to be sourced locally. This resulted in the inflated price of the commodities, making goods unaffordable to the locals, which worsened the disaster's effect.

The logistics cluster had rapidly taken GIS to map the relief routes, which focused on restoring the transportation of the emergency supply chain and improving the information flow among relief organisations, reaching out to different cities/towns in the Delta (Logistics Cluster, 2008). Due to political difficulty, the International Federation of the Red Cross (IFRC) implemented a regionalisation strategy to support the operation. The preparation and

communication were completed out of Myanmar, and the IFRC used their Regional Logistics Unit in Kuala Lumpur to provide reliable (comparing other routes, the journey is shorter), costless (the procurement was 28% less than in Myanmar) and rapid response (supply would be ready in 3-5 days) to the disaster (IFRC, 2008). The Myanmar government lacked awareness of disaster management, such as proactive medical care and disaster warning program (Lateef, 2009). The IFRC and UNICEF launched a few programs to enforce disaster management in at-risk villages. Local schools were made emergency hubs for training local children, and medical kits were kept at such strategic locations (IFRC, 2011).

5. *Haiti Earthquake (2010)*

Haiti suffered a 7.0 magnitude earthquake in 2010 that caused the death of over 220,000 people and injured more than 300,000 (CNN, 2015b). Because of the poor economy and overpopulated city, the government could not respond in the aftermath of the earthquake (Rencoret et al., 2010). As a result, more than 1.5 million homeless Haitians were waiting for international relief and emergency aid (ABC, 2016). Margesson and Taft-Morales (2010) recognised that the challenges such as weak transportation, limited communication system and dysfunctional infrastructure were commonly seen in the first two weeks. Also, the coordination actions were hindered because some relief officers and ground personnel were killed or missing during the disaster (BBC, 2010c). The major problem with the operation was an inadequate communication system to link with the object/person. For instance, the information on the relief goods should be shared through some media like radio, TV or newspaper (Moloney, 2011).

Although the relief operation faced several obstacles, the effort of ICT implementation was still noteworthy, especially in the early hours after the earthquake. One of the successful cases of ICT application was utilising the web and social networks to disseminate and exchange information while the mobile phone lines were down – *Ushahidi* was used for collecting the information via SMS or webpage from people in the affected zones to understand better the kind of response required (BBC, 2010b). Likewise, *GoogleGroups*, a platform that allows individuals or volunteers to share information, was also used in earthquake relief, sharing instant information and supporting the missing people search (King, 2010).

6. *Pakistan Floods (2010)*

The floods were caused by the unusual monsoon in July 2010, which brought the worst floods since 1929, causing environmental and humanitarian crises in Pakistan. Overall, 23% of the

crops were flooded (estimated 1.9 billion USD loss), with more than 1 million people displaced (Emily, 2011). It is assumed that about 2.3 million people were without food or emergency shelter. The overwhelmed government had no option but to wait for international aid (BBC, 2010a). The catastrophe revealed that the Pakistan government was lacking in disaster management. Implementing Remote Sensing, GIS, Space Technology, Wireless Sensors Networks, Satellite Technology, Mobile Technology, and Social media are essential in disaster relief (Shafiq and Ahsan, 2014). Pakistan's government did not adopt any disaster management system because the political convention relied mainly on their military forces to take responsibility of any relief action. But the military lacked relief distribution expertise, and the situation worsened (Madiwal and Virk, 2010). In contrast, during the relief operation, the UN and its related clusters harnessed mobile phones as emergency telecommunication enhancement, which assisted the World Food Programme by using GPS and SMS as the main tools in evacuation and rescue actions (United Nations, 2010). As to information sharing and collaboration, many clusters had set up document-sharing websites to receive and share information among intra-organizational sectors (NetHope, 2011).

7. Japan Earthquake (2011)

The Japan Earthquake struck the eastern coastal regions of Japan with a magnitude of 9.0. This triggered several tsunami waves of nearly forty meters, causing widespread devastation (WHO, 2012). Japan considered itself well-prepared for earthquakes, having planned an early warning system following previous earthquakes. The death and causality numbers were caused mainly by the tsunami (Sorkhabi, 2012), as they also damaged two nuclear plants, which were forced to shut down, and a state of emergency was announced due to the threat of the nuclear crisis (BBC, 2011; Ghadge et al., 2011). The effect of the disaster was not only humanitarian but also economic and environmental (National Post, 2011).

Although this humanitarian disaster was the deadliest in Japan's history, implementing an early warning system played a critical role. The Japan Metrological Agency (JMA) installed an Earthquake Early Warning system in 2007, and this project reduced the damage from earthquakes before this disaster (Lin, 2011). Based on previous earthquake experiences, JMA had strengthened disaster preparation. The Earthquake Disaster Information System (DIS) used satellite images to evaluate the damage and plan the relief map with GIS for early damage access. On March 11th, this mechanism warned the inhabitants 3 minutes before the first

tsunami wave arrived, and this information was also delivered via different communication channels.

After the tsunami, the infrastructure in the coastal areas was mainly ravaged, including roads, railways, phone services, power lines, and radio towers – relief actions were barely keeping up and sending supplies to the emergency areas owing to debris, limited fuel and access were difficult (OCHA, 2011). Although the government rescue teams equipped 1,500 radio and satellite phones to restore communication and seeking for the survivors, the disrupted logistics could not play a part in relief. As a result, people were inclined to use other ICT applications (e.g. Twitter, email, Facebook and other social networks) to build a connection with the government and relief agencies for adequate support (Aizu, 2011). This was the first major natural disaster where social network communication was widely used for relief operations. Regarding the nuclear crisis, it was revealed that the information disclosure between the Japanese government and the public was lacking (Suzuki and Kaneko, 2012). The nuclear crisis was due to ineffective communication and insufficient information between government bodies (Guntzburger and Pauchant, 2014).

8. Typhoon Haiyan (2014)

The typhoon Haiyan struck the Philippines on 7th November 2014, with heavy rain and strong winds triggering landslides and destruction. The trail of the typhoon damaged 80% of the houses and buildings (CBC, 2013). Although, after the strike, the UN, US, and Japan launched emergency relief programs to support the affected regions; lacking fuel and trucks slowed down the pace of the action (BBC, 2013). After the typhoon, some international humanitarian agencies such as the World Health Organization, World Food Program (WFP), and UN Development Program (UNDP) arrived in Tacloban city for the early emergency response, and their priority was restoring the communication system to avoid duplication (Guardian, 2014). In the first month of response, the Emergency Telecommunications Cluster (ETC) rebuilt the first response radio to provide vital information for the locals because most of the infrastructure was severely damaged, and therefore general communication services were down (Hall and Ashcroft, 2013).

The interruption of information and communication access lasted for weeks; meanwhile, Google set up several relief services such as "*Google person finder*" and relief maps. The first was for searching for missing people, and the latter was for tracking the latest shelter status, command centres and communication posts. These services can be easily

accessed remotely through devices such as PCs and mobile phones (Schroeder, 2013), facilitating a quick recovery during Typhoon Haiyan.

9. Ebola (2014 - 2015)

Ebola is a hemorrhagic fever prevalent in West Africa from 2014 to 2015, causing lethal contagious illness (CNN, 2016b). This disease infected over 10,000 people, mostly in West African countries, Liberia, Sierra Leone and Guinea. Ebola is highly contagious, with a high mortality rate and can be spread through infected blood or body fluids (CDC, 2015). ICT tools played an important role in education and information sharing during the disease outbreak, helping the public to neglect the rumours and panic about the Ebola virus (Niederberger et al., 2016; CRS, 2015). Also, the Information Management Unit (IMU) was helping the ground teams to collect epidemic data and map out possible health risky areas (IOM, 2016).

ICT tools were used to react to such highly contagious diseases with a rapid and safer response. Some of the mapping services like “*Humanitarian OpenStreetMap*”, which has a sharable and collectable data geolocation feature (very similar to the GIS approach), were used to quickly review the data of the infected region (TechChange, 2014). Likewise, other potential ICT tools, such as SMS/Social Media warning messages, provided a safer and more helpful channel for communication and dissemination during the prevalent period. Furthermore, ‘*healthmap.org*’, an online epidemic disease database, helped to provide a free tracking service for visitors, providing relevant information such as the prevalence of disease and epidemic general knowledge (Maxwell, 2014). The Ebola Response Connectivity Initiative (ERCI) project had partnered with some NGOs, social media, and IT companies to incorporate information sharing on Ebola, improving the information transmission and delivery through satellite and Wi-Fi-based applications (Invenco, 2015).

10. Covid-19 Pandemic (2020)

Covid-19, an infectious disease, was first found in Wuhan city of China around November 2019. The epidemic quickly spread worldwide as a pandemic (WHO, 2020). Over 500 million people were infected globally, with more than 6.5 million deaths to date (May 2022). Digital health technology is believed to facilitate a quick response to the pandemic through containment and mitigation processes, including surveillance, testing, contact tracing, and strict quarantine (Whitelaw et al., 2020). Mobile phones and social media were the first sources

Table 1. Overall impact of selected disasters (multiple sources)

Disaster	Type	Death and causality	Relief span	Impact of disaster	Learning from relief operations		
					Information	Communication	Technology
9/11 attack (2001)	Man-made (quick onset)	2996 deaths and more than 6000 injuries; 1064 first responders died from respiratory cancer.	Estimated 9 months ((The debris and wastes were removed till May 2002)	The threat of war after the attack.	The poor capacity of critical infrastructural support, such as elevators	Poorly designed communication channels in public service departments	Sudden congestion in the bandwidth of telecommunication channels Use of GIS in matching demand with supply
Indian Ocean Tsunami (2004)	Natural disaster	Total death 226564 (Indonesia 165708; Sri Lanka 35399; India 16839; Thailand 8345; Maldives 102; Malaysia 80; Myanmar 71); 1.3 million people affected.	It took at least 5 years for some level of normality	\$ 8.71 billion 5-6 million people needed food and water \$ 105 billion	Inadequate infrastructure to support various emergency operations	Use of software-enabled bulletin board to search for missing people	Use of GIS in conjunction with a humanitarian map

Hurricane Katrina (2005)	Natural disaster	1833 (mostly in Louisiana, and 50% of victims were above the age of 74) and 273,000 displaced	At least 5 years	800,000 housing units destroyed or damaged	– Dependence of commutation channel on-ground situation such as water, wind etc.	– Dependence of coordination and collaboration on the communication channel	Use of SMS and VoIP to communicate Solar/battery power equipment
Cyclone Nargis (2008)	Natural disaster	138,366 dead, 2.4 million affected	Over 4 years	\$10 billion Lacking food and water Many children became orphaned Diseases were prevalent after the cyclone.	Inadequate capacity of government and exclusion of foreign help	Lack of ICT tools	Lack of ICT tools
Haiti earthquake (2010)	Natural disaster	220000 dead, 300000 injured and 3500000 affected	More than 5 years	\$7.8 billion (Haiti's GDP in 2008 was \$11.6 billion) The capital city was severely damaged as well	Poor infrastructure	A limited communication system Ambiguous roles and responsibilities in public agencies	Use of web, SMS and social networks for communication

				as the civil service.			
Pakistan Floods (2010)	Natural disaster/ Man-made	1985 deaths and more than 1 million displaced	At least a year	\$ 43 billion	Inadequate integration in GIS and various communication networks	Inadequate integration in GIS and various communication networks	Use of SMS and GPS for locating and evacuation
				2.5 million people suffered a high risk of starvation			
Japan Earthquake (2011)	Natural disaster/Man-made	15894 deaths, 6152 injured, and 2562 missing; estimated over 300,000 displaced	Still ongoing (because of the nuclear plant explosion)	Slow and ambiguous reaction caused Fukushima nuclear crisis \$ 14.5 to 34.6 billion	Use of social media networks and emails for communication	Successful use of an early warning system	Use of satellite images for evaluation and planning
Typhoon Haiyan (2014)	Natural disaster	6201 deaths, 4,095,280 displaced, and 1061 missing	Over 4 years	\$ 2.86 billion	Development of emergency telecommunication cluster to support destroyed communication services	Development of emergency telecommunication cluster to support destroyed communication services	Development of emergency telecommunication cluster to support destroyed communication services
				41000 housing destroyed			

Ebola virus disease (2014-15)	Man-made	11,310 deaths and 28616 cases	5 Years	Prevalence of diseases GDP in Guinea dropped 1%; Sierra Leone's economy deflated by 30% 16000 children lost parents or caregivers	ICT-based education and information sharing	Use of ICT for mapping of health-risky areas	Use of ICT for mapping of health-risky areas
COVID-19 pandemic (2020)	Man-made	Over 500 million were affected globally and led to 6.5 million deaths	Ongoing	Global shutdown of borders 5.2 % contraction in global GDP Expected Global recession	ICT-based education and information sharing	ICT-based contact tracing applications	Use of drones and robots to monitor lockdowns and mitigate the spread

Source: Multiple online sources cited in the reference list.

of information used by the Chinese government to trace the origin and spread of the virus by collecting Real-time locations of people. The pandemic quickly spread to Italy, Iran and later across the world.

In Sweden, authorities developed a platform for healthcare workers to report real-time data on volumes of patients with Covid-19 and resource availability (Becker's Health Information Technology, 2020). Multiple countries developed similar online platforms to keep citizens updated with the latest information about pandemic and prevention plans. The covid-19 dashboard and web-based platforms such as *Worldometer and Healthmap* provide live information on the number of infections and deaths worldwide (Johns Hopkins University, 2020). Social media platforms were constantly used for health alerts (e.g. Facebook, Twitter, WhatsApp, Weibo). Large quantities of data on several parameters collected through multiple ICT tools/devices were used for predictive analysis using AI techniques to identify peaks of spread in regions/countries. Robots and drones were used to provide additional support for medical staff and to disinfect affected areas. 3D-printed face shields and ventilators were used to reduce the shortage of medical equipment in most affected regions. Thermal imaging and other temperature-detecting applications provided proactive measures to stop the virus from spreading. Table 1 collates the information on the overall impact of (man-made and natural) disasters and learning drawn from relief operations discussed in this section.

5. Findings and framework development

5.1. Analysis

Following the soft-systems thinking approach, multi-cases were analysed holistically using template analysis. Unique and common variables were identified from the cases to develop a holistic understanding. Standard ICT tools originating from the multi-case study coding are presented as learning. ICT learning from the case study (Table 1) also helped to identify and plot the progression of ICT systems over the past two decades for humanitarian relief operations. Evidently, since 2010, the ICT application has increased the use of internet/social media-related tools for information gathering (Rauniar et al., 2014; Ngai et al., 2015), which increases the accessibility of information diffusion and exchange during operations. Increased social connectivity through Twitter, Messenger, Facebook, etc., has raised further awareness regarding relief operations. With the advent of modern search technology, online search systems and warning systems are also found to be primarily/key sources of data collection and sharing. Despite all these developments, the GIS is found to be the most common and reliable

ICT tool used for disaster relief operations. Table 2 presents the development of ICT tools used for humanitarian disaster management over the past two decades.

Table 2. Longitudinal development of ICT tools for disaster management

Year and ICT use for disaster management
2001 • Radio • Mobile phone/cellular network • Phone lines • GIS mapping
2004 • Online relief website (<i>Shahana</i>) • GIS • Satellite imagery • DART II
2005 • Mobile phones and SMS • Online webpage (<i>BoingBoing</i>) • Radio and some other communication devices
2008 • Myanmar information management (MIMU) • GIS
2010 • Mobile phones and SMS • Phone line • Online Database webpage (<i>Ushahidi</i>) • Social networks (<i>google groups</i>) • GIS • Basic telecommunication infrastructure
2011 • Satellite imagery • GIS • Some social media networks • Tsunami early warning system
2014 • Radio station • Online community webpage (<i>Google person finder</i>) • Social media (Twitter)
2015 • GIS with online webpage service (<i>Humanitarian OpenStreetMap</i>) • Mobile phones and SMS • Social media • Online Database webpage (<i>healthmap.org</i>)

- ERCI project – Wi-Fi with satellite service

2020

- Mobile phones and SMS (e.g. *NHS app for pandemic*)
- Digital interactive maps (*Worldometer*)
- Social media for health alerts (Facebook, Twitter, WhatsApp, Weibo).
- Online Dashboards/ webpages (*healthmap.org*)
- Robotics and Unmanned Aerial Vehicles (UAV)/drone technologies

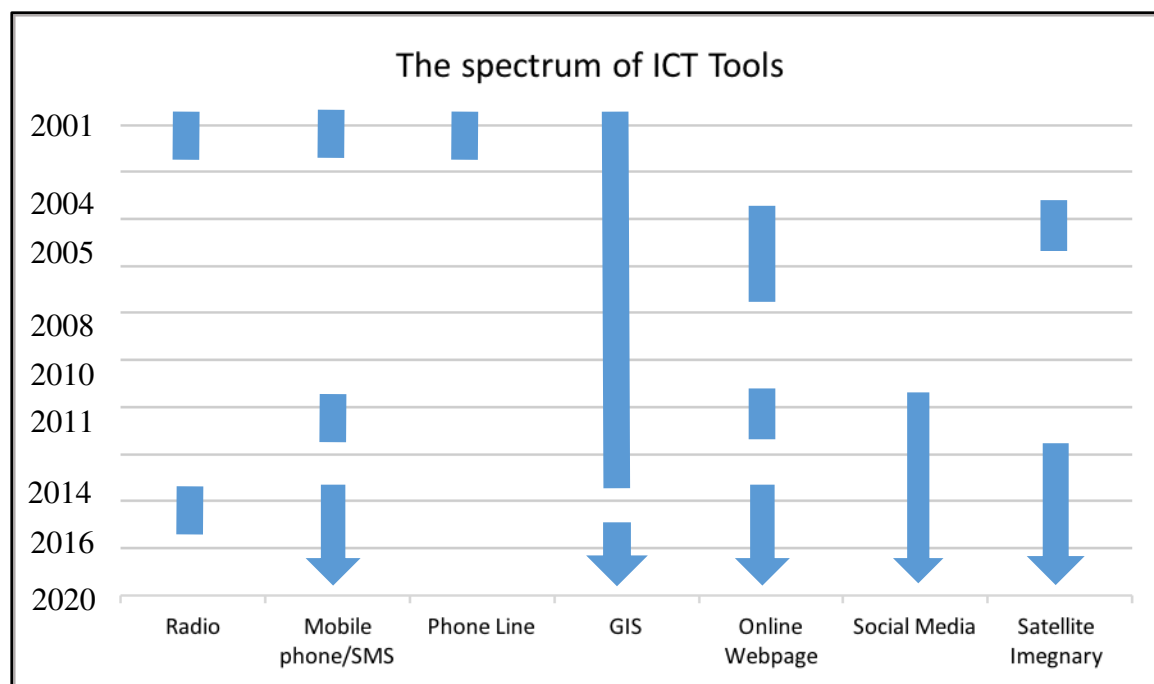


Figure 1. The application spectrum of ICT tools

Figure 1 shows the application spectrum of ICT tools, and the bars show the exploitation of such utilities over the past two decades. A cross-case analysis of ICT tools and applications used in selected disasters helped develop these insights. It can be deduced from the figure that GIS and online webpages/search engines are the most popular tools applied for assessing disasters. Mobile phone/SMS and satellite imagery are also commonly used in disaster response. Social network platforms have increased exponentially over the past 5 years for information gathering and dissemination. More recently, Artificial Intelligence (AI) has been used for data analysis to make critical decisions. For example, AI-driven systems are used to proactively predict natural events and make decisions regarding warning and rescue decisions. Digital technologies such as robots, UAVs/drones, and 3D printing/Additive Manufacturing were also distinctly used for quick disaster response. Some region-specific

technologies (e.g. Myanmar information management) were uniquely used, but they can be broadly termed as 'Information Systems'.

The phone line service and radio were not commonly used since 2000, although they played a vital role in pre-2000 disaster management. Such conventional communication and information exchanging devices are replaced mainly by online or wireless devices like online services, mobile networks and satellite services. Although SMS/mobile service is still a common and preferred means for information sharing, it could be inferred that today's information and communication systems mainly emphasise wireless technology, as it can instantly communicate and transmit information without physical infrastructure.

5.2. Framework development

A cross-case analysis of the above ten case studies captured the need for coordination between stakeholders, technology use, stage of disaster and zone of operation. A centralised system able to coordinate and share information between different elements involved in disaster management is lacking was established following a holistic assessment. With several people affected due to disaster, it is difficult for a single system to manage the recovery process. The lack of integrated systems for disaster management demands a common platform for seamless information flow (Dorasamy et al., 2013). It is evident through this multi-case study that the involvement of stakeholders and the ICT system varies during pre- and post-disaster stages.

The zone of operations is also believed to be an essential consideration (evidenced through the discussed cases), as the size of the affected region, the terrain and the nature of calamity critically drive the effectiveness of disaster management. A coordinated approach between these identified entities can provide an efficient ICT-based disaster management process.

Utilising some of the insights generated by cross-case analysis on the use of ICT systems/tools, stakeholders involved, disaster stages and zones of operations, a conceptual framework for ICT-based disaster management was attempted. Following the systems thinking approach, the author established the key elements involved in each identified entity and their association/interaction with each other. The building block of the ICT disaster management framework (shown in Figure 2) is based on the processes involved in a disaster management cycle: mitigation, preparedness, responsiveness and recovery. They are common for different levels as indicated in the figure. From a supply chain perspective, each relief operation is geared towards matching the demand of displaced/affected people with a supply of relief resources.

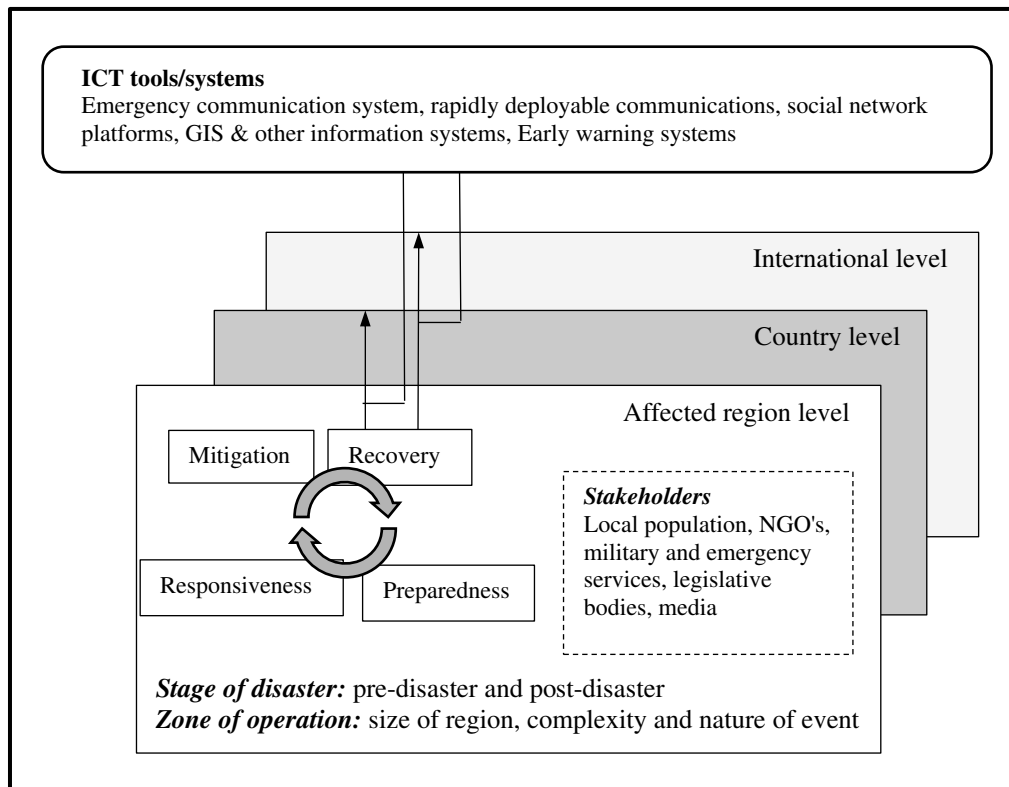


Figure 2: Conceptual framework for ICT-based disaster management

Following the observations made on different ICT systems used during past disasters such as identification of ICT for relief operations (Table 1) and their longitudinal development over the years, in this study, they are broadly classified as - surveillance, decision support and broadcasting systems. ICT-based technologies such as GIS, satellite imagery form part of a surveillance system proactively providing preliminary information about the onset of a disaster. Tsunami early warning systems, AI tools and similar online search/match systems form a part of a decision support system. Deployable communication systems such as radio, television, social media and other wireless/digital technology form a part of the broadcast system. Each system has unique responsibilities; however, they must be seamlessly integrated for efficient relief operations. Each ICT-enabled system links value-adding activities across a network of disaster management system through real-time information flow, thereby enabling system-wide coordination and collaboration.

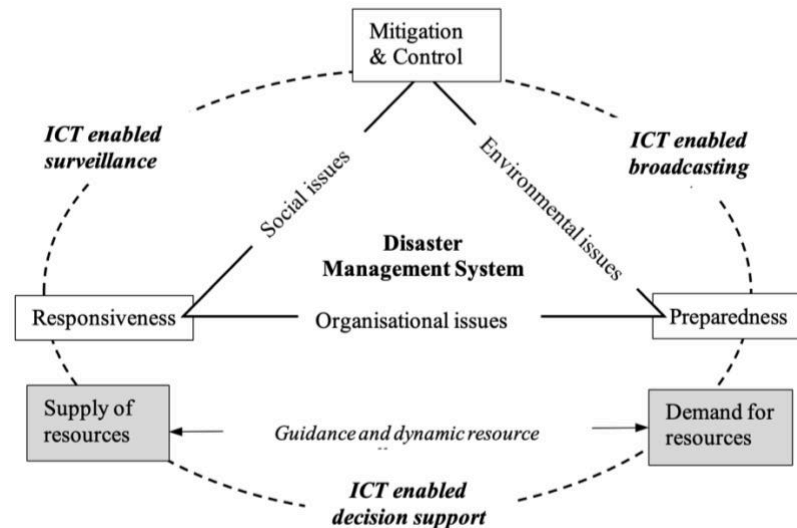


Figure 3: ICT-enabled model for humanitarian relief operations

An ICT-enabled integrated model in Figure 3 presents ICT systems (surveillance, decision support and broadcasting) for quick relief operations. The model captures a dynamic concept for recovery at every possible disaster management stage. It is found from the multi-case study that relief efforts are hindered due to external challenges such as political, diplomatic, and bureaucratic issues. A cyclic process comprising mitigation, preparedness and responsiveness is central to disaster management. The social structure of the society, its vibrancy (e.g., level of education), inclusiveness, and embedded social capital affect cyclic processes of disaster management.

Similarly, the nature and organisational structure of government departments, its agencies and NGOs determine the flow of resources in the relief operations and associated compliance reports. An integrated system adopting appropriate ICT systems during the cyclic process (mitigation, preparedness and responsiveness) of managing disasters and rapidly overcoming social, organisational and environmental issues will lead to an enhanced level of recovery.

By combining insights from cross-case analysis and holistic thinking for developing an integrated model, the research provides a unique platform for an ICT-enabled model for humanitarian relief operations. The challenge for humanitarian logisticians is determining bottlenecks and communication infrastructure's usability (Baldini et al., 2011). The developed model addresses these issues and is expected to help researchers and practitioners close the gap

of understanding the complex interactions of ICT systems with multiple processes and external challenges.

6. Conclusion

6.1. Discussion

The study aimed to capture the advancement of ICT in past humanitarian disasters and develop a comprehensive model for humanitarian relief operations. Following a multi-case, longitudinal study, ten major natural and man-made disasters spread across two decades were selected for the study. In addition, collated secondary data on selected cases were examined following a soft-systems thinking approach. Taking an ICT application and cyclic approach, this study proposed a conceptual framework for ICT-based disaster management and further developed a unique integrated model for humanitarian relief operations.

The application spectrum of ICT tools captured over the past two decades shows that GIS and online webpages/search engines are the most popular tools for assessing disasters. Mobile phone/SMS, social media, and satellite imagery are also commonly used in disaster response. More recently, Digital technologies such as 3D printing, robots and UAV/drones are evidently used for disaster response management. Following the longitudinal study, it is evident that GIS, mobile networks and other digital technologies (such as AI, robotics, etc.) will outperform compared to some of the traditional technologies (such as radio and landlines) used in the past for humanitarian relief operations. It is also observed that the speed and coordination of relief operations have significantly increased in recent years due to the increased use of ICT tools.

6.2 Contribution to theory and practice

The study contributes to the theory by extending the literature on humanitarian supply chains and disaster management. The ICT-driven framework and model proposed in this study are derived from adopted systems thinking and multi-case analysis, bringing a unique contribution to the theory. The proposed framework and model are highly relevant for all stakeholders involved in any disaster relief operations. Thus, this study contributes by capturing a holistic picture of the ICT spectrum interfacing with humanitarian disaster management. The study also makes a practical contribution by providing vital insights regarding the broader use of multiple ICT tools for natural and man-made disasters. Appropriate use of such tools, depending on the stage of disaster and zone of operation, is expected to be valuable for stakeholders of relief

operations. Uniquely identified and classified ICT-based systems for surveillance, broadcasting and decision support will be helpful in the future for quick relief operations. It is clear from the study that the ICT-based tools used for humanitarian disaster management have undergone rapid development over the past two decades, as ICT has constantly been evolving. The need for an integrated approach to collaborative mapping and increased use of disruptive technologies is evident from the ICT-enabled model. Latest digital technologies, such as 3D printing can be used to build shelters or produce equipment in a short span to recover from the pandemic or similar events. Robots and UAV/drones can be effectively used in hazardous and remote regions for rescue and recovery. The Internet of Things (IoT) has recently been used as proactive ICT tools to assess impending disasters. Due to the explosion of information broadcast through social media, data analytics and AI techniques are increasingly used to filter relevant information and make decisions. It is expected that the key findings and frameworks developed in this study will benefit relief organisations in understanding the challenges and appropriateness of ICT systems at different stages of disaster management.

6.3 Limitations and future avenues

The study had limitations in collecting primary data; hence, widely available secondary data was utilised to draw inferences. Furthermore, generated inferences can be biased based on the researcher's perception and interpretation of the event, stakeholder's response and application of ICT tools. Also, the ICT-enabled model for humanitarian relief operations is theoretical and has not been tested in a real-world setting. Future research can test the framework and the model developed in this study. Since the inferences are drawn from a good mix of man-made and environmental/natural events, future studies could advance the use of ICT applications in Unmanned Aerial vehicles (UAV), robots, online/digital donation systems and AI for rapid, transparent humanitarian relief operations. It is evident from this study that ICT plays a vital role in any disaster management, and thus advanced research on ICT-based approaches for managing humanitarian disasters is commanded.

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