2 Background

This chapter elaborates on the background of this thesis. First, it defines the body of terms when referring to disaster and the domain of emergency response. Subsequently, core information is summarized on all disasters, which are relevant for the presented work. Moreover, this chapter introduces the notion of infrastructure, which forms of infrastructure can emerge in the aftermath of disasters, and how people creatively engage in critical situations to form new infrastructures. Then, it presents crisis informatics as an emerging field of research, and highlights its importance by outlining disaster situations in which people have exploited different mediums of ICT. Finally, this chapter closes with a review of existing mobile emergency systems.

2.1 Terminology

This section introduces relevant terms with regard to the application domain of emergency response.

2.1.1 Emergency and Disaster

An **emergency** is an unexpected situation of danger. Examples of an emergency are a car accident, a coal fire, or a power outage. Most emergencies can be handled through routine procedures by one or more agencies. However, when emergency response fails, emergencies can turn into disasters.

A **disaster** is similar to an emergency, but on a much bigger scale. Compared to an emergency it usually involves several agencies of emergency response, which requires response organizations to carefully coordinate their efforts. Disaster situations can comprise either man-made or natural disasters. A natural disaster, for example, is an earthquake, a flooding, a hurricane, a wildfire, and further natural hazards. Examples of man-made disasters are terroristic attacks such as bombings, industrial accidents such as nuclear explosions, or transport accidents such as train crashes.

Several definitions have been developed for the term disaster (Kreps 1984; Gilbert 1998; Perry 1998). Lots of those studies, such as (Gilbert 1998), focus on the destructive nature of a disaster. For instance, how many people lost their lives or homes. Other disaster researchers have developed models to systematically frame the process of how society recovers from a disaster. Most models define time stages where key social processes emerge before, during, and after a disaster (Powell 1954; Dynes 1970; Mileti et al. 1975). The most widely known model is the one of Powell (1954). Powell's model proposes to divide a disaster into eight stages (depicted in Table 1). First, there is the stage of *pre-disaster* that denotes the period of time before the disaster emerges. Then, in the *warning* stage the potentially affected community is informed about the threat; though, in many cases there might be no warning. The third stage of *threat* is when people perceive changed conditions and take preventive actions, such as evacuating people at risk. The *impact* stage denotes

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the climax of a disaster. At this stage the whole community understands the adverse effects and begins to think about contingency plans. Afterwards, in the *inventory* stage individuals take stock of disruptions. People adapt to what happened and collectively agree on a course of action. For instance, people agree on the resources, which should be protected first of all or which places to go for shelter. In the *rescue* stage people help themselves and people who are nearby. Such help arises in a spontaneous and unofficial manner. Finally, in the stage of remedy professional first responders enter the disaster zone. In the final *recovery* stage the community restores its properties. Often, this stage is referred to as the post-disaster phase. Depending on the destructiveness of a disaster the recovery stage can be of different length.

Stage 0: PRE-DISASTER
State of social system preceding point of impact
Stage 1: WARNING
Precautionary activity includes consultation with members of own social network
Stage 2: THREAT
Perception of change of conditions that prompts survival action
Stage 3: IMPACT
Stage of “holding on” where recognition shifts from individual to community affect and involvement
Stage 4: INVENTORY
Individual takes stock, and begins to move into a collective inventory of what happened
Stage 5: RESCUE
Spontaneous, local, unorganized extrication and first aid; some preventive measures
Stage 6: REMEDY
Organized and professional relief arrive; medical care, preventive and security measures present
Stage 7: RECOVERY
Individual rehabilitation and readjustment; community restoration of property; organizational preventative measures against recurrence; community evaluation

Table 1 Eight socio-temporal stages of disaster

Source: (Powell 1954)

Some research points out that disasters do not take place across specific stages of time. For instance, Neal (1997) shows that the actions occurring in the stages described in Powell's model may overlap and that the recovery process might be long and complex. Further, Palen et al. (2009) argue that the boundaries between the stages are fuzzy and that different groups of people may experience different stages at different times.

2.1.2 Crisis, Crisis Management, and Emergency Response

A typical definition for the term *crisis* is that of a "larger" disaster, i.e. a situation in which societies suffer from damage or unavailability of routine infrastructure (Kreps 1984). Due to their similarity, both terms are often used synonymously. However, the latter term covers way more than the former one. Besides man-made or natural disasters, a crisis can refer to severe physical disease, economic decrease, starvation, inadequate housing and further. All these examples show that the term crisis can refer to situations that can last for a significantly longer time than the term disaster encompasses.

The terms crisis management, disaster management or emergency management are used to express nearly the same thing, as the boundaries between all notions are not clear-cut. Similarly, the terms crisis response or emergency response are utilized to describe the same thing. Nevertheless, the author likes to use the terms crisis management and emergency response in the remainder of this work to express the following. *Crisis management* refers to the whole process of sub processes involving humans and systems to deal with an unexpected disaster situation. And, *emergency response* is rather used in the context when referring to the application domain and the organizations and agencies being involved in crisis management.

2.1.3 First Responders

A common misconception of the meaning of the term first responders is that this only encloses trained professionals that are commanded to enter a disaster zone, such as fire fighters or paramedics. However, in many situations victims either help themselves or are assisted by people who are nearby and have the courage to help spontaneously and in an unofficial manner, as it was already underlined in the rescue stage of Powell's (1954) model. This is why Palen and Liu (2010) point out that first responders are often not professionals, but people from the local communities or volunteers. In fact, in the light of disruptions those people emerge into groups of responders before professional response is ready to take action. Examples of such actions were observed during the recent 2011 Norway attacks (see section 2.2). It has been reported that people in the surrounding area of Utoya island noticed gunfire and observed people requesting to being picked up with nearby boats (Rosenberg 2011). Some people who made these observations used their private boats to rescue people from the island before the gunman would shoot them.

Further, volunteers' actions might be performed when the stage of 'remedy' has already taken place. At this stage, professional response necessitates the support of amateur first responders. Again, during the 2011 Norway attacks volunteers transported policemen with their private boats from the mainland to Utoya island, as previously the police boat had suffered from an engine failure due to being loaded too heavily. In retrospective on their investigations on the 2011 Norway attacks, Perng et al. (2013) framed such phenomenon as 'peripheral response'.

Summarizing, professional first responders are those people belonging to formal response units (fire brigade, ambulance, police, etc.), and amateur first responders are members of the public, that often are the first one to arrive at the incident site taking action to help people in need.

2.1.4 Resilience

Originally, the concept of resilience has been developed in the fields of ecology and psychology. In the field of ecology Holling (1973) points out that resilience defines the persistence of relationships within a system. It reflects to which degree a system is able to deal with *"changes of state variables, driving variables, and parameters"* and still survive. In Hollings' definition resilience is a property of a system and its persistence is the result. In the field of psychology mainly studies, such as (Benight et al. 2000; Galea et al. 2002), have looked into how people retain a positive stance despite experiencing a disaster or war. Manyena (2006) gives a detailed literature review on resilience while taking a stance of psychology. However, to sustain the scope of this thesis, the author prefers not to discuss ecological or psychological views on resilience. Rather, the goal is to view resilience from a disaster and system perspective.

Examining the effects of the World Trade Center attacks in 2001 Kendra and Wachtendorf (2003) define resilience as the ability of an individual or organization to adapt to or to 'bounce back' from unanticipated disruptions of technological systems. In general, resilience reflects how people deal with a situation in order to regain an acceptable state (Wildavsky 1989; Comfort 1999). Similarly, from a system perspective Hollnagel et al. (2011) indicate that the ability to respond to unforeseen events, such as disasters, is one of the four key abilities of resilient systems. Further, Urken et al. (2012) describe resilience as the ability of a system to mobilize still functioning elements of the system in order to restore the stability of a system. And if restoration might not be possible, the system shall try to degrade gracefully in order to minimize the adverse effects and "survive" in a temporally acceptable state. And, from a network perspective Sterbenz et al. (2010) define resilience as *"the ability of the network to provide and maintain an acceptable level of service in the face of various faults and challenges to normal operation"*.

This work defines resilience as the ability of humans and systems to regain a state that is temporarily acceptable.

2.2 Relevant Disasters

This section summarizes the basic information about man-made and natural disaster situations, which the presented work will refer to.

The 9/11 attacks were a series of four coordinated terroristic attacks that struck New York City and the Washington, D.C., metropolitan area, on 11 September 2001. It was reported that this man-made disaster was organized by the terror group al-Qaeda. The attacks killed 2996 people and caused at least $10 billion due to the destruction of property and infrastructure (IAGS 2004).

The **SARS epidemic** broke out on November 16th, 2002. The severe acute respiratory syndrome (SARS) probably took its course in the Guangdong providence of China (WHO 2003). The epidemic had a wide reach on China's population with low information from official sources on the epidemic per se and how to protect oneself from it (Palen & Liu 2007). Inconveniently, people were living and working in affected areas, helping the epidemic to rage across the region. In total, SARS caused the infection of 8.096 persons and 774 persons died (Smith 2006).

The **2005 London bombings** occurred on 7th July 2005. A series of attacks were undertaken to harm people using London's public transfer system during rush hour in the morning; these bombings are often referred to as 7/7. Four suicide attackers detonated four bombs—three bombs were placed in the London underground and the fourth bomb was placed on a double-decker bus. Besides the four bombers, 52 people were killed and over 700 persons were injured (Storey & Addley 2010).

Hurricane Katrina formed on 25 August 2005. It was the deadliest and most destructive tropical storm. In detail, this disaster killed at least 1883 people and resulted in an economical damage of $108 billion. Hurricane Katrina came with an advanced forewarning. Many people evacuated in preparation of a serious tropical storm. However, they could not return back as early as expected. The most damage emerged from the levee breaches of the lake Pontchartrain causing city-wide flooding (Knabb et al. 2005).

The **2007 Virginia Tech shooting** happened on 16th April 2007. A student of the Virginia Tech University ran amok and shot 32 persons and himself. Further, 17 others were wounded in two separate attacks (Kelman 2014).

The **2008 Hurricane Gustav** was the second most destructive tropical storm of the Hurricane season in the Atlantic in 2008. Several countries were affected, for example Cuba, Jamaica or US Southern States (Beven & Kimberlain 2009). Hurricane Gustav caused the death of 153 people and an economic damage of $6.5 billion (Rogers et al. 2013).

The **2009 L'Aquila earthquake** struck central Italy on 6 April 2009 with a magnitude of 6.3. It was reported that in L'Aquila, which is located in the Abruzzo region, 3.000 to 10.000 buildings have been damaged. The earthquake caused the death of 308

people and approximately 1500 people were injured. Several buildings collapsed and around 65.000 lost their home. The earthquake was felt throughout Abruzzo, as far away as Rome or Umbria (Kennedy 2009).

The **2010 Haiti earthquake** came about a 7.0-magnitude near its Port-au-Prince capitol on 12 January 2010. Due to the earthquake's intensity, as well as the vulnerable infrastructure of Haiti, the earthquake caused severe destructions over the island. By 24 January, at least 52 aftershocks were recorded. Nearly, three million people were affected by the quake (Millar 2010). Between 200.000 and 250.000 people died. In the aftermath of the earthquake, thousands were trapped beneath collapsed structures, which included hospitals and transport facilities.

The **2010 Chile earthquake** occurred off the coast of central Chile on Saturday, 27 February 2010. The earthquake had a magnitude of 8.8 on the moment magnitude scale, with intense shaking lasting for about three minutes (Saavedra 2010). It ranks as the sixth largest earthquake ever to be recorded by a seismograph. It was felt strongly in six Chilean regions, which together make up about 80 percent of the country's population. Tremors were felt in many Argentine cities (Pallardy 2014), and as well in the far north as the city of Ica in southern Peru (approximately 2.400 km). The earthquake's intensity was stronger than the 2010 Haiti earthquake that happened nearly one month before. But, as Chile's infrastructure was more resilient, the effects of the earthquake were relatively 'weak' compared to the 2010 Haiti earthquake.

On 24 July 2010, a stampede happened in the **2010 Love Parade** event in Duisburg, Germany. The Love Parade was an electronic dance music festival, which was carried out annually. The stampede caused the death of 21 people, and at least 500 persons were injured (Helbing & Mukerji 2012). As a consequence of this tragedy, the organizer of the festival announced the permanent end of this music festival.

The **2010/11 Tunisian Revolution** was an intensive campaign of civil resistance. This resistance included a series of demonstrations, which took place in several Tunisian cities, such as Tunis, the capital, but also other towns such as Sidi Bouzid. The resistance started on 18 December 2010 and achieved on 14 January 2011 the suppression of the longtime president Zine El Abidine Ben Ali. Ben Ali's attempt to suppress public protests resulted in over 300 dead and 2000 injured people (Lamont & Boujneh 2012).

In the course of the **2011 Egyptian Revolution**, i.e. in the late January 2011, many Egyptians protested against the current regime by occupying public places all over the country, such as the famous Tahir Square in Cairo. Eventually, the military took sides with the crowd, which resulted in the resignation of the former president Hosni Mubarak. Clashes between security forces of the Egyptian government and protesters resulted in at least 846 persons were killed and over 6.000 persons were injured (BBC News 2011).

The **February 2011 Christchurch earthquake** came about 22 February 2011. It was a powerful natural disaster that severely damaged Christchurch—the second-largest city of New Zealand located in the Canterbury region. The earthquake's intensity was measured to have a magnitude of 6.3. This killed about 185 people and between 1.500-2.000 persons got injured (McSaveney 2014). Further, the earthquake caused widespread damage, in particular to the central part of the city and eastern suburbs. In fact, this earthquake was part of the aftershock sequence of the previous 2010 Canterbury earthquake, which occurred on 4 September 2010. Moreover, this earthquake caused as an aftershock the June 2011 Christchurch earthquake.

The **2011 Norway attacks** occurred on 22nd July 2011. Two sequential lone wolf terrorist attacks caused in total 77 casualties in the Oslo region (CNN Wire Staff 2011). The first attack was a car bomb explosion in the government quarter of the city of Oslo. The second attack occurred nearly two hours later on Utoya—an island located 38km northwest of Oslo city—where the same perpetrator, dressed as a policeman, shot members of the youth division of the Norwegian Labor Party.

Hurricane Sandy was a tropical storm that came about 22 October 2012. It killed several people (148 direct, 138 indirect) and caused a huge economic damage. Estimates assess a damage of $68 billion, at total surpassed only by Hurricane Katrina. Sandy killed at least 286 people in seven countries; for instance, the Bahamas, Cuba, Jamaica, most of the eastern United States, and eastern Canada (Blake et al. 2013).

The **2013 Boston bombings** happened on 15 April 2013. Two pressure cook bombs, i.e. improvised explosive devices, exploded during the Boston Marathon. The explosions killed 3 people and injured circa 264 persons (Kotz 2013). The blasts occurred near the finish line of the marathon and blew out windows on adjacent buildings, though did not cause any structural damage.

The **Syrian civil war** (also known as the Syrian uprising) is an ongoing, armed conflict that started in the early spring of 2011. Inspired by the Arab spring dream a peaceful uprising took place in March 2011. Nationwide demonstrations against President Bashar al-Assad's government spread out spontaneously. However, the governmental forces responded with violent crackdowns. The conflict gradually morphed from peaceful protests to an armed rebellion after months of military conflicts. So far, this war has caused the death of about 200.000 people (Smith-Spark 2014) and about 5 million people have been displaced (Charron & Arnaud 2012).

2.3 Infrastructure

This section summarizes the meaning of the term infrastructure, what forms of infrastructure can emerge in disaster situations, and how people creatively use infrastructural elements in the light of disruptions

2.3.1 Disambiguation of 'Infrastructure'

This thesis draws on Susan Leigh Star's (1999) ethnographical fieldwork to examine the notion of 'infrastructure'. The essential point that resulted from Star's longitudinal fieldwork is that infrastructure is never a thing, but a relation between humans and systems. This means how people interpret and take action towards the availability of infrastructural elements creates infrastructure.

Star (1999, p.380) underlines that infrastructure is commonly understood as a "system of substrates", such as railroads, wires, pipes or plumbing. These are elements that usually become only visible in the presence of failure or disruption. For example, when people look at the signal strength icon of their mobile phone as a result of entering spaces with low or no network coverage. Or when people cannot access remotely persisted data, as cloud services temporarily become unavailable.

According to Star (1999), infrastructure is a fundamental "relational concept", and not solely a system. She points out that certain groups (e.g. residents) can take a technology for granted, such as the functioning of the plumbing system, while another group (e.g. a plumber) can regard such technology as an object of common analysis or challenge. Elements like streets are not per se "infrastructure", but can be regarded as infrastructure based on the relation people establish to the streets. Streets become an element of infrastructure for people who drive cars on them. Infrastructure denotes rather an ongoing process of interpretation of the relations humans have with things they engage with, than referring to an enclosed element being a part of these relations (Star & Ruhleder 1996).

Dourish and Bell (2011) stress, that it is important not to consider "infrastructure" as being quiescent and stable. Infrastructures must rather be actively maintained, and relationships to them must be continually negotiated. Following the above example, due to the wear of streets, streets need to be restored from potholes. Furthermore, the way people use streets requires continuous regulations depending on how and to what extend they can be used. Similarly, in terms of ICT people consider elements like telecommunication networks or email servers not as their immediate infrastructure. Rather, they experience it as an integral part to perform common tasks (Pipek & Wulf 2009), such as composing emails or replying to emails.

With regard to the technical context of this thesis services and network require continuous re-interpretation in order to find new opportunities. The following section details what this notion of infrastructure can imply for the relationship people lose, build and appropriate with technology in the light of disasters.

Immediately, one critical question arises: If infrastructure is a "relation", but not a thing or system, then how can humans appropriate infrastructure? In the scope of emergency response, this thesis proposes that it is the effects of a disaster that are appropriated. This means, in response to disaster situations, people with different

contexts come together to form new relationships, which can be appropriated to exploit new opportunities.

Palen and Liu (2007) exemplify this by how people appropriated in the aftermath of the terroristic 9/11 attacks sidewalks as a notice board for missing persons. People placed photographs of missing persons on sidewalks, so that other people can look at them. The whole of all elements, i.e. *"the gaze of concerned others, with eyes, ears and social connections"* creates a potential to trace missing persons (Al-Akkad et al. 2013). All these elements brought together create an infrastructure. In that particular case a notice board where family members or friends could look for help in finding missing persons. Coming back to Star's (1999) definition of infrastructure, parts of a pavement are temporarily borrowed from its normal purpose of being a pedestrian thoroughfare in order to be used as a fundament to place photographs displaying missing persons.

It is important to note here that the pavement per se does not define the infrastructure. The heterogeneous relations that people establish to the photographs placed on parts of the pavement, making it work as a notice board, form the infrastructure. In fact, when relations with elements break down, which is often the case in disaster situations, infrastructural elements become disrupted and remain in this state until they are re-appropriated or incorporated into new arrangements. What this thesis pursues, is to examine how surviving technological elements of infrastructure, shortly *remnants of technology*, can be brought together in order to create new relations forming new infrastructure(s).

Such 'opportunistic' infrastructures might be formed by elements, which are not explicitly meant to support the work of emergency response. Though people affected by a disaster may appropriate elements in unforeseen ways to support their immediate needs, as section 2.4 will explain by some real-world examples.

The author uses the term infrastructure to describe the whole of the relations humans form with technological structures lying beneath applications and the interactions they enable. Throughout this work the author sets the focus on network infrastructures, mostly with smartphones as the central technological infrastructural element.

2.3.2 Forms of Network Structures during Emergency Response

During an emergency response operation, available forms of network structures can be classified through three possible forms of deployment depicted in Figure 2.

Existing structures refers to network structures already present in the impact zone of a disaster. Portions of preexisting infrastructure, which survived the adverse effects of a (large-scale) disaster, may to some extent be operable. For instance, cell towers providing GSM/UMTS, or access points offering WiFi networks might still constitute a resource for communication, which is available inside the disaster impact zone.

These everyday communication elements are, for example similar to fire hoses being a central element for fire fighters to extinguish a fire.

Additionally, fire fighters or other professional first responders may carry with them elements that are *deployable*, i.e. elements that can be used for in-situ deployment of networks. For instance, Ramirez et al. (2012) describe the Landmarke platform that enables the deployment of a mesh network. Fire fighters usually carry door jams with them. These door jams are enhanced with networking technology and used to establish the mesh network. Real-world evaluations of the Landmarke platform have proven a potential to support indoor navigation inside smoke-filled buildings. Although, such a form of network structures might connect to existing network structures, its deployment is carried out in an ad-hoc manner.

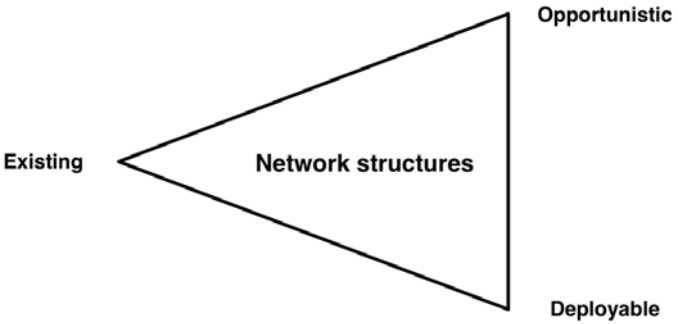


Figure 2 Forms of network structures in disaster situations

The third and last form of network structures is *opportunistic*. Opportunistic refers to the co-incidental use of resources being at hand. For instance, cell phones or tablet computers, which people usually carry with them, can be exploited opportunistically as a resource to communicate in disaster situations. People might use these elements to form new network structures in an improvised manner. Analogue, in the aftermath of a disaster that caused a power outage, a reconstruction engineer may reappropriate obsolete power generators, as described above in section 2.1.

The last two forms of network structures, i.e. deployable and opportunistic, can be classified into ad-hoc constructed networks. In this regard, Manoj and Baker (2007) point out that it is more challenging to deploy elements in an ad-hoc manner in situations where portions of preexisting infrastructure have survived the effects of a disaster, which is the usual case. A common challenging factor is the interference between surviving elements of existing network structures and elements of ad-hoc constructed network structures.

This thesis focuses on the design and evaluation of systems leveraging opportunistically network structures in an ad-hoc manner. In particular, this thesis

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