

# How Critical Infrastructure Orients International Relief in Cascading Disasters

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**Critical infrastructure and facilities are central assets in modern societies, but their impact on international disaster relief remains mostly associated with logistics challenges. The emerging literature on cascading disasters suggests the need to integrate the nonlinearity of events in the analyses. This article investigates three case studies: the 2002 floods in the Czech Republic, Hurricane Katrina in 2005 and the 2011 Tohoku earthquake, tsunami and Fukushima meltdown in Japan. We explore how the failure of critical infrastructure can orient international disaster relief by shifting its priorities during the response. We argue that critical infrastructure can influence aid request and delivery, changing needs to address the cascades, and contain cascading technology-based events. The conclusions propose remaining challenges with applying our findings.**

## 1. Introduction and background

In recent decades, technology and society have become more integrated than in any other period of history. Growing interdependencies of technological networks challenge the reliability of the systems and have increased their vulnerability to large-scale cascading disruptions (Amin, 2002; Little, 2002). A determining role is attributed to 'critical infrastructure', or 'CI', which concentrates the physical attributes, functions and organizational elements of society (Alexander, 2013). The European Commission (EC, 2006) encouraged all member states to include in their programmes the impact of CI disruptions in terms of scope, severity, population affected, economic losses, environmental effects, political effects, psychological effects and public health consequences (EC, 2006, p. 7). However, the definitions evolved over the years according to different national criteria and priorities, including not only buildings but also services and cyber assets (NATO, 2007). In comparing national legislation, the

word 'infrastructure' tends to include intangible assets such as supply chains and emergency services (OECD, 2008). Meanwhile, the attribute 'critical' is used to express the idea of being essential to economic and social well-being, as well as to public safety and governmental services. A similar meaning is taken by the concept of 'critical facilities' (United Nations International Strategy on Disaster Reduction, 2009), which has often been used synonymously in disaster literature.

Although the concept of CI is rooted in work from more than four decades ago, a rise of concern on the possible effect of disruptions is reported since the early 2000s. The need for strategies for CI protection was pointed out by events such as the 2001 terrorist attacks in the north-east USA; the 2004 tsunami in the Indian Ocean; the terrorist attacks against public transport in Madrid (2004), London (2005) and Mumbai (2006); and Hurricane Katrina in the United States in 2005 (EC, 2006, NATO, 2007). Two of those episodes had strong implications for international

disaster relief. The 2004 tsunami hit areas where critical infrastructure was under development, challenging the deployment of emergency relief with the inadequate capacity of local CI (Egan, 2007). Hurricane Katrina showed the potential consequences of full infrastructural breakdowns in Western societies, where relief resources were abundant but previous compound failures were relatively rare (Boin & McConnell, 2007). Since then, disaster management has improved. It is now clear that the effective delivery of emergency goods depends on both the restoration of damaged supply chains and the reactivation of social nodes (Boin, Kelle & Whybark, 2010). CI such as airports, schools, hospitals and telecommunications is vital for emergency response and good practices have been adopted to promote preparedness, minimize damage and limit disruptions (Lindell, Prater & Perry, 2007; Haddow, Bullock & Coppol, 2008, Tsunami Global Lessons Learned Project, 2015). However, some contextual differences still exist.

The studies on CI and international relief are mostly focused on humanitarian logistics in developing countries, while it seems they are assumed to be a problem of management in the other areas. On the one hand, the impact of disasters on developing regions is often magnified, for example, by poor construction that presents physical constraints to actions (Kovacs & Spens, 2007). On the other hand, it has often been assumed that richer societies have the capacity to deal with the material effects of disasters on their own, and their lessons learned could be mostly about managerial issues (McClintock, 2009). Those very same regions are more subject to studies that address CI interdependencies or possible cascading disruptions in vital services (Little, 2002; Luijff, Nieuwenhuijs, Van Klaver, Eeten & Cruz, 2009; Van Eeten, Nieuwenhuijs, Luijff, Klaver & Cruz, 2011). Even when their implications for disaster management are considered, the contributions tend to analyse the effects of networked failures more than their implications for international operations (Berariu, Fikar, Gronalt & Hirsch, 2015; Helbing, Ammoser & Kühnert, 2006). Assuming the capacity of CI to affect emergency management in terms of deployment and the coordination of humanitarian relief, there are no clear answers to how CI can orient the goods delivered by international relief to developed countries. Moreover, if they are seen as spaces that concentrate and generate vulnerabilities for all societies, then the traditional focus on triggering hazards is revealed to be inadequate (D'Ercole & Metzger, 2009).

The perspective highlighted by Pescaroli and Alexander (2015) suggests a relation between the disruption of critical infrastructure and the nonlinear escalation of emergencies that distinguishes cascading. This could be associated with the cross-scale

accumulation of vulnerabilities paths waiting to happen, more than with low probability, high-impact processes (Pescaroli & Alexander, 2016). CI may act as vectors of impact, interrupting the vital functions of society and spreading breakdowns from one sector to the other, but also concentrating in the roots of failures different levels of negative feedbacks, such as corruption or mismanagement. This approach suggests identifying the nodes that are more likely to generate secondary events, improving preparedness levels to contain escalation of events (Pescaroli et al., 2016). However, the relation between CI and cascading is far from being integrated in multilevel strategies that could modify the vulnerability paths, as in the case of the EU Floods Directive where the attention is focused on the trigger hazard, localized impacts and limited time scale (Nones & Pescaroli, 2016).

Is there just a gap in crisis management systems, or has the application of this concept the potential to affect the international delivery of aid? In this case, the lack of literature on how CI and cascading could influence international relief suggests a preliminary step. The focus of this article aimed to address two overlapping gaps in the current theory: 1) a low comprehension of how CI could orient international actions in developed countries in any aspect different from logistics and 2) the missing evidence about the relation of cascading disasters and CI with the international delivery of emergency goods and expertise.

Our hypothesis is that CI can become a main driver of needs as the event progresses and this can be seen in a shifting request for or offer of international aid. In other words, we hypothesize that the escalation is visible in the offer/request of specific goods or expertise that could be related to CI disruptions. For example, a widespread energy breakdown could require international relief to supply more generators, while compromised healthcare facilities could require the delivery of more field hospitals. After a short overview of the methodology adopted, our study will test this hypothesis with the analysis of three case studies. A separate section will draw a common picture of how critical infrastructure orients and directs international relief. Conclusions will indicate the implications of our research for practices and scholars as well as its limitations.

## 2. Selection of case studies

In the following pages, we describe the 2002 floods in the Czech Republic, Hurricane Katrina in 2005 and the 2011 disaster in Japan. The selection of cases was made according to the following criteria:

- (1) The events were in line with the definition of cascading disasters by Pescaroli et al. (2015). Namely,

we intended them as 'extreme events, in which cascading effects increase in progression over time and generate unexpected secondary events of strong impact. These tend to be at least as serious as the original event, and to contribute significantly to the overall duration of the disaster's effects. These subsequent and unanticipated crises can be exacerbated by the failure of physical structures, and the social functions that depend on them' (Pescaroli et al., 2015, p. 65).

- (2) Each event required a major commitment of international relief, but with different magnitudes.
- (3) The events involved developed countries and provided an overview of different geographical areas (North America, Central Europe and eastern Asia).
- (4) Primary data and secondary data had to be available to reflect the evolution of interstate relief during the emergency phase. The sources had to be reliable and allow a screening of the event in progress.

The approach adopted is a qualitative comparison of primary and secondary sources (King, Keohane & Verba, 1994). First, we briefly describe each case study. Second, we derive which CI was affected by the disaster and which cascades were generated. Lastly, we verify in the documentation which goods delivered by international relief could be correlated with CI. The main sources of data were the reports by the NATO Euro-Atlantic Disaster Response Coordination Centre (EADRCC) for both the 2002 floods and 2005 Hurricane Katrina, where the alliance was one of the coordinators of emergency response. The reports by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and the EC were the main sources for the 2011 event, which was not reported by the EADRCC. The online website 'Relief Web' (reliefweb.int) was used to cross-check information with other official sources. The documents provided a daily description of the disasters and of international relief, allowing the description of events in progress.

In the analysis, we intended CI as asset or system essential for the maintenance of vital societal functions and the well-being of citizens. We used the categories reported in the documentation by the UK Cabinet Office (2011) to avoid the problems in the classification (NATO, 2007, OECD, 2008). We referred to nine essential sectors and four other types of CI, such as food, energy, water, communications, transport, health, emergency services, government, finance, civil nuclear facilities, hazardous sites (e.g., chemicals); iconic sites and companies of strategic value (UK Cabinet Office, 2011). We associated 'icon sites' with 'national monuments' as suggested by OECD (2008),

approaching them in the larger meaning of cultural heritage to integrate community-based perspectives (Alexander, 1993).

This short paper cannot be exhaustive or fully precise regarding all the resources deployed for each disaster, but provides a first approach to an emerging topic. Similarly, it does not mention what would have happened if CI were not driving relief efforts and leaves this topic to future studies. Four assumptions are made based on the literature and experience with large-scale disasters in Western societies, so they are not subject to detailed analysis:

- (1) The logistical chain and the deployment of emergency response resources are affected by CI disruption. This assumes that international relief is likely to provide mechanisms such as trucks, planes and ships to deliver the aid.
- (2) The disasters considered imply a full mobilization of national resources which, for different reasons, may have been overwhelmed.
- (3) Goods such as medicine, blankets and medical supplies are provided in international relief, as well as expertise like healthcare professionals, and search-and-rescue teams. Similarly, this is true also for emergency grants.
- (4) The discussion of political/managerial root causes of CI disruption in each case study is reported in the *ad hoc* literature. Thus, these case studies do not analyse the impact of decision-making processes on the cascade.

The limitations of our study are reported in the conclusions where they are used to suggest new paths for future research.

### 3. 2002 Floods in the Czech Republic (Prague Metropolitan Area)

The August 2002 floods were a major cross-border event that hit Central Europe. Sequential waves of heavy rainfall occurred from 6 to 8 August 2002 and from 11 to 14 August 2002, affecting mainly the Czech Republic, Germany, Austria and Slovakia (Ulbrich, Brücher, Fink, Leckebusch, Krüger & Pinto, 2003). In the Czech Republic, the event was labelled as the largest recorded in history, causing 19 deaths and affecting three point two million citizens (Hladny, Kratka & Kasperek, 2004). Although the first sequence of rainfall was contained, the capacity of the reservoirs was saturated and the basins were unable to absorb the second period of rainfall. The River Vltava submerged parts of Prague, peaking on Wednesday 14 August. The same day, international assistance started at different levels including the International Community, the European Union and bilateral agreements (Ekengren, Matzen, Rhinard & Svantesson, 2006). The

event activated the implementation of European regulations, such as the European Union Solidarity Fund and the Flood Directive. The state of emergency ended on 31 August, but the status of alarm remained until 31 October for the precarious conditions produced by the flood.

### 3.1. Critical infrastructure and cascading effects

Critical infrastructure generated secondary emergencies that required complex efforts to be contained (Pescaroli et al., 2015). Some 124 wastewater treatment plants were damaged increasing the levels of organic pollution, while flooded industrial sites released contaminants into the water supply (Hladny et al., 2004). The risk of epidemics required massive programmes of disinfection and vaccination against hepatitis A, which were needed on 5 September, even after the end of emergency status. Flooding of petrol stations in Karlin contaminated drinking water (Risk Management Solutions, Inc, 2003). Chlorine leaked from the Spolana chemical plant in Neratovice, where local residents were evacuated and the situation had to be constantly monitored (NATO, 2002d).

Electricity, communication and transport infrastructure were heavily disrupted. This included electric and gas supplies, strategic thoroughfares such as the highway from Prague to the German border, river crossing points, rail transport and public transport such as underground and coach stations (NATO, 2002b, Chamra, 2006; United Nations Environment Programme/GRID, 2002). Vital supplies were heavily affected: electricity was fully restored in mid-September, gas in October and telephone services in November (Risk Management Solutions, Inc, 2003). However, the attributes of Prague as an administrative and governmental centre, and as a UNESCO World Heritage Site, complicated further emergency management. The involvement of public facilities included, for example, the evacuation of hospitals in the city centre, while four and a half kilometres of files was under water in the City Court of Prague (United Nations Environment Programme/GRID, 2002). The high concentration of historical and cultural sites in the city centre required that firefighters and volunteers were sent in to limit the damage and protect critical assets such as the Municipal Library of Prague, the Institute of Archaeology and the Charles Bridge (Crosby, 2004).

### 3.2 How CI oriented international relief

The documentation shows an unequivocal relationship among the subsidiary events related to CI disruptions and the delivery of emergency goods (NATO, 2002a–h). The early request of assistance was mainly associated with portable dryers, floating pumps and

submersible electric pumps, that is, dealing with the physical impact of water (NATO, 2002a,b). From 18 August onwards, the Czech local emergency authority added the request of vaccines against hepatitis A, chlorine-based disinfectants, insect repellents and/or cleaning products (NATO, 2002c). International relief was used to address health effects and contamination due to the disruption of wastewater facilities and treatment plants. After 19 August, the Spolana chemical spills required a constant monitoring and the preparation of specialized units to deal with chemicals (NATO, 2002b). The same day, NATO reported the chlorine leakage and the Russian Federation offered some generic technical assistance. International crisis specialists from Canada examined the situation in the Spolana chemical plant after chlorine contamination (Agence France-Presse, 2002a,b).

The consequences of joint prolonged failures of CI on drinking water caused further escalation of health concerns on 22 August when the Czech Republic added the urgent request for vaccines (NATO, 2002f). In the same document, Sweden offered protective clothing, cleaning and disinfectants. The next day, 23 August, the contamination of rivers and wastewaters became a high-priority task and the Slovak Republic added a mobile chemical laboratory (NATO, 2002g). Five experts of land rehabilitation were also offered by the United States, but it is uncertain if they may be linked to Spolana and the overall water contamination (NATO, 2002h).

Together with the cascading impacts on health caused by water contamination, the Prague case study is significant for the involvement of cultural and historical sites. Technical assistance for the restoration of cultural heritage was offered by Italy and Spain as a consequence of the damage to historical and cultural heritage sites such as in the Prague city centre, the Veltrusy Castle and the Terezin catacombs (NATO, 2002e–h). Although hospitals were flooded, the documentation does not reflect any consistent influence on international aid. Similarly, the energy disruption was not reflected in the documents: just a very modest number of generators was provided (NATO, 2002b).

## 4. 2005 Hurricane Katrina in the United States

Hurricane Katrina made landfall in Louisiana the morning of 29 August 2005 and generated a storm surge that propagated up the Mississippi River (United States Senate, 2006). The hurricane continued north, decreased into a tropical depression on 30 August and dispersed on 31 August over the Eastern Great Lakes. The damages extended over 144,840 square kilometres with around 300,000 homes destroyed or made uninhabitable (United States Senate, 2006). The impact

of the hurricane and the surge together caused 1,833 estimated fatalities (Knabb, Rhome & Brown, 2011). The emergency was distinguished by the need for a fast scaling up of the response capacity, which was not always possible and was revealed to be inadequate given the magnitude of the crisis (Ansell, Boin & Keller, 2010). On 2 September, US President Bush acknowledged as 'not acceptable' the management of the emergency by the Federal Emergency Management Agency (FEMA), mobilizing nearly 70,000 National Guard members in two days and 7,200 active duty forces on 3 September (Haddow et al. 2008). On 4 September 2005, the United States made an urgent request for assistance to NATO allies through the Euro-Atlantic Disaster Response Coordination Centre. Operations lasted until 2 October (NATO, 2005a–h). Together with the NATO channel, emergency goods and services were offered also from countries with diplomatic difficulties with the United States, but their reception was distinguished by inconsistency from the US government (Kelman, 2007).

#### 4.1 Critical infrastructure and cascading effects

Katrina wiped out some CI in New Orleans, Louisiana, Mississippi and Alabama, raising cross-sector emergencies and affecting recovery over both the short and long term (Boin et al., 2007; Egan, 2007). It was distinguished by a wide cascade of secondary events that increased the pressure on national and international relief, such as the destruction of vital utility networks, diffused pollution and the loss of other strategic assets in the area (Moynihan, 2009). Problems were associated with the complexity of assessing damage and coordinating the restoration of CI (United States Senate, 2006). Energy facilities were devastated, leaving some three million citizens without electricity for up to several weeks (Knabb et al., 2011).

Offshore infrastructure was damaged; oil and gas production/refining in the Gulf of Mexico fell. The hurricane caused at least 142 oil spills which piled into the waterways (Haddow et al. 2008). Fuel shortages were the joint effect of the fall in refining capacity and the lack of electricity needed to pump fuel (United States Senate, 2006). Environmental and health hazards were associated with the impact on 466 chemical facilities, 31 hazardous waste sites, 16 toxic waste sites, 170 drinking water facilities and dozens of wastewater facilities (The White House, 2006).

Transport arteries such as highways and bridges were compromised, reducing the capacity of responders to deliver food, water and medical supplies (Moynihan, 2009). Communication was heavily affected. Three million customers were without phone

lines and 1,477 cell towers and 38 emergency call centres were out of order (The White House, 2006). Many Emergency Operation Centres were flooded or damaged, limiting relief operations and the operational capacity of the police in the New Orleans area (Moynihan, 2009). Healthcare facilities were heavily damaged or destroyed, leaving hundreds of patients without basic supplies (The White House, 2006).

#### 4.2 How CI oriented international relief

A substantial part of goods delivered by international aid compensated for FEMA's logistics failure, while coordination problems could be attributed to an absence of a preconceived scenario where the United States could need foreign assistance in their territory (Kelman, 2007, United States Senate, 2006, The White House, 2006). Different countries such as Canada and the Netherlands offered the support of naval vessels and helicopters, but in this case it is not known whether they could be associated with the logistic delivery of goods, with the support of search-and-rescue activity or with the escalation of events (NATO, 2005a–h). However, a consistent part of international relief in the aftermath of Hurricane Katrina can be seen without any doubt as the effect of cascades generated by CI disruption. On 4 September 2005, the first international disaster assistance request of the United States stated an urgent need for meals ready to eat (MREs) to satisfy a critical shortfall; 70,000 MREs were provided by Germany alone on the first day (NATO, 2005a). Less than twelve hours later, an updated request included bottled water, water trucks, energy generators, medical supplies, veterinary supplies, shelters, plastic sheeting and logistics crews (NATO, 2005b). Together with organizational failures of FEMA, the fall of vital services affected homes and shelters which were subject to extended power outages, producing shortages of drinking water, running water and rations (United States Senate, 2006, Haddow et al. 2008).

On 6 September, the offers made to the EADRCC included chemical analysis teams, water treatment and purification units, water clearing, disinfectants and naval vessels (NATO, 2005c). Despite the massive disruption of healthcare facilities and the presence of foreign medical teams and supplies, the number of field hospitals remained marginal. From 7 and 8 September, the international offers started to focus on technological support, power reestablishment teams, chemical analysis/detection teams, hazardous waste handling teams, counterpollution teams, decontamination teams, water purification units and chlorine tablets (NATO, 2005d,e).

On 14 September, the US authorities confirmed that MREs and external logistics personnel support

were not needed anymore. Instead, they accepted the delivery of three GSM (Global System for Mobile Communications) network stations from Sweden and 11,200 chlorine tablets from Italy (NATO, 2005f), which were needed due to the prolonged disruption of communication and water infrastructure. The role of telecommunication support organizations could have been even broader in terms of NGOs or the private sector as suggested by Kelman (2007). Moreover, later offers from international allies included elements such as high-power pontoons and lights (NATO, 2005g). It must be noted that the documentation showed a significant divergence between the goods offered by international relief and the goods accepted by the US government (NATO, 2005a–h, EC, 2005).

## 5. 2011 Tohoku earthquake, tsunami and Fukushima meltdown in Japan

At 05:46 (UTC) on 11 March 2011, an undersea earthquake occurred 130 kilometres east–south-east off the Oshika Peninsula along the coast of Tohoku, Japan, with a registered nine (Mw) magnitude (National Oceanic and Atmospheric Administration, 2011). It triggered a devastating tsunami that hit the Pacific side of the Tohoku Region and the northern part of the Kanto Region, overtopping or destroying the existing seawalls. Large areas were submerged and entire villages washed away, while the water travelled up to ten kilometres inland in Sendai (National Oceanic and Atmospheric Administration, 2011). According to the National Police Agency of Japan (2015), the two episodes together caused 15,893 fatalities, 6,152 injuries and 2,572 people missing. 399,767 properties were subject to total or partial collapse, and 747,055 buildings were partially damaged (National Police Agency of Japan, 2015).

The emergency was amplified by a third event in the Fukushima Daiichi Nuclear Power Plant, located 262 kilometres from Tokyo. Here, the cascade impacted on a precarious situation in the site and blocked the cooling of reactors, leading to a full nuclear meltdown of the highest severity: while the earthquake damaged the electric substations and caused a loss of offsite electricity, the tsunami destroyed emergency generators, seawater cooling pumps and electric wiring systems. Despite the environmental triggers, the Japanese authorities defined what happened in Fukushima as ‘a profoundly manmade disaster’ that could have been prevented (National Diet of Japan, 2012). As its direct consequence, approximately 150,000 people were evacuated and an estimated 1,800 square kilometres of land in Fukushima Prefecture was contaminated by radiation (National Diet of Japan, 2012). Together with complex clean-up operations and major environmental concerns, the disaster reinforced worldwide public

sentiment against nuclear power, for example, influencing heavily the policies in Germany and Italy (Acton & Hibbs, 2012). The real consequences of the event in the long term are still unclear.

### 5.1. Critical infrastructure and cascading effects

Japan experienced a full disruption of the CI in the area. Government facilities, disaster management centres, fire stations and ports were destroyed by tsunami waves. In the aftermath, hospitals were reported to be without water, gas and electricity, leading to major concerns about patients. Around 4.4 million households were left without electricity and one and a half million were without water (Tsunami Global Lessons Learned Project, 2015). At least 25 power stations were shut down, while 195 drainage systems and 72 sewage treatment works were damaged (Kazamaa & Nodab, 2012). CI disruption hampered operations, with problems including debris on roads, fuel shortages and the lack of communication lines (OCHA, 2011a–i).

Japan’s disaster damaged 4,198 roads, 116 bridges and 29 railway lines, causing also 207 landslides and 45 dike breaks (National Police Agency of Japan, 2015). The strategic north–south route on the Pacific coast (National Route 45) was damaged by the tsunami, getting more difficult to ensure transport in the area (Kazamaa et al., 2012). Japanese refinery capacity fell 30 per cent and the general loss of power generated cascading disruptions in rail transport, manufacturing, potable water supplies and gasoline supplies (McGee, Frittmann, Ahn & Murray, 2014). Communications were disrupted by the joint effect of lack of power supply, communication buildings damaged or flooded by the tsunami, as well as relay networks and undersea cables severed. In the early aftermath, around one and a half million lines were interrupted and the Nippon Telegraph and Telephone Corporation restricted 90 per cent of mobile phone service to allow emergency communications among responders (McGee et al., 2014).

Together with the joint effect of the earthquake and tsunami, the Fukushima disaster can be seen as a driver of the cascading path driven by CI (Pescaroli et al., 2015). The government declared a state of ‘Atomic Power Emergency’ (OCHA, 2011a,b), which had effects both in terms of damage (contamination) and in terms of emergency challenges (displacement and security of citizens). It has been argued that the complete remediation of the site will take decades, with challenges associated with removing melted fuel and the recovery process (Acton et al., 2012).

### 5.2 How CI oriented international relief

Japan’s disaster of March 2011 hit one of the most prepared and organized countries in the world, whose

culture was not oriented towards receiving international aid (ICF Consulting Service, 2014). At the end of the month, Japan had received 134 offers from countries and 39 from international organizations, accepting relief items just from 29 of them (OCHA, 2011g). In the early aftermath search-and-rescue teams, medical supplies, common emergency goods (e.g., blankets), and special units such as for WASH were accepted (OCHA, 2011a–i). The US military based in Japan heavily supported the delivery of aid and the restoration of CI in ports and airports, deploying around 18,000 personnel together with ships, aircrafts and helicopters in ‘Operation Tomodachi’ (OCHA, 2011a–i, United States Government, 2011b). Much of the international relief received for the 11 March disaster can be linked to CI disruptions, including delivery of food supplies, bottles of water, water tanks, emergency lights and lanterns, generators and body warmers, fuel, liquid natural gas, gasoline and rubber gloves (OCHA, 2011a–i, Government of Japan, 2011b).

OCHA reported that fuel shortage was ‘still the biggest obstacle to delivering relief supplies and keeping people warm’ on 25 March (OCHA, 2011h). As a consequence, in early April, the People’s Republic of China delivered 10,000 metric tons of gasoline and 10,000 metric tons of diesel (Government of the People’s Republic of China, 2011). OCHA reports also list communications support, with the deployment of more than 37 broadband global area network terminals by the International Telecommunication Union (OCHA, 2011d) and Télécoms Sans Frontières (OCHA, 2011a,b).

The Fukushima meltdown was another key driver of the action, and the uncertainties about contamination oriented international relief at different levels. The situation influenced the procedures of the EC from the beginning, when ‘additional personal protective equipment and medical checks’ were required for the teams in charge of needs assessments (ICF Consulting Service, 2014). The meltdown also required the mobilization of particular skills, expertise and supply. Two reactor experts from the US Nuclear Regulatory Commission (NRC) were deployed on 12 March (OCHA, 2011b), but their number was soon raised to nine additional units with different expertise (United States Government, 2011a). In a later phase, the International Atomic Energy Agency was involved in assessing the power plant and food safety (OCHA, 2011i).

When relief goods are considered, Fukushima drove the international relief in particular between the end of March and early April. Canada provided 150 portable radiation survey meters, readers for dosimeters and 5,000 personal dosimeters (Government of Canada, 2011, Government of Japan, 2011b). Another 400 dosimeters and 5,000 masks were provided by

Russia, and some other smaller contribution was given by the Republic of Korea (Government of Japan, 2011b). The EU member states provided through the civil protection machinery around 100,000 paper masks, dosimeters, radiological detectors, protective suits and gloves and a radiation measurement vehicle (European Commission, 2011; Government of Japan, 2011b). Two barges from the US military carried fresh water to assist in the cooling down operations at the nuclear power plant (OCHA, 2011g). Moreover, the United States contributed three semiconductor detectors, 33,000 dosimeters, 99 protective body armours against nuclear, biological and chemical weapons and 9 metric tons of boric acid (Government of Japan, 2011b). A C17 aircraft carried a special pump from Australia to cool the nuclear power plant (Government of Japan, 2011a). The long-lasting pattern of this crisis can be associated with the 1,000 radiation survey meters, 1,000 personal radiation dosimeters, 1,000 protective masks and filters received from Ukraine on 4 August (Government of Japan, 2011b). The US Marines Chemical and Biological Incident Response Force (C-BIRF) was deployed to provide emergency training to the Japanese Self Defense Forces (SDF) operating in the Fukushima area (Feickert & Chanlett-Avery, 2011).

## 6. How CI orients international disaster relief in cascading disasters

Our case studies demonstrated that, in cascading disasters, CI can orient the actions of international disaster relief in many ways different from the process of logistics delivery alone. Even if every disaster has unique aspects, our data suggest the existence of some recurrent and overlapping paths that associated the escalation of events with CI disruption and the progressive changes in relief. This evidence is discussed in the following paragraphs, and Table I presents an overview and synthesis of the case studies.

### 6.1. Direct effect: CI as functional nodes

The first point to consider is that CI can influence international relief in being functional nodes, meaning the physical places where the services and assets that are vital for society are concentrated (Alexander, 2013; Ansell et al., 2010; Boin et al., 2007; D’Ercole et al., 2009). This element is well known in the literature, but our cases provide more evidence. We verified that the disruption of energy and communication can be the main drivers of cascading failures, as effectively demonstrated by some authors (Luijff et al., 2009; Van Eeten et al., 2011). CI interdependencies heavily affect emergency response (Berariu et al.,

**Table 1.** Overview of How CI Oriented International Disaster Relief in Our Case Studies

Case	CI involved	Cascading effects	International relief
2002 floods	Spolana chemical plant	Contamination of environment and the potential effect on health	Specialized personnel, experts on land rehabilitation
	Water sector	Contamination of environment and the effects on health	Vaccines, chlorine-based disinfectants, cleaning products, protective clothing, mobile chemical laboratory, experts on land rehabilitation
	Icons and monuments	Intangible effects on the community	Specialized personnel on the restoration of cultural heritage
2005 Katrina	Energy sector	Social disruption and cascading effects on others sectors (e.g., water)	Energy generators, power restoration teams, high-power pontoons, lights, meals ready to eat (MREs)
	Water sector Water sector and hazardous sites	Social disruption Contamination of environment and the potential effects on health	Bottled water, water trucks Chemical analysis teams, water treatment and purification units, water clearing, disinfectants, chemical analysis/detection teams, hazardous waste handling teams, counterpollution and decontamination teams, water purification units, chlorine tablets
	ICT sector	Social disruption	GSM network stations, technological support
2011 Japan	Fukushima nuclear plant	Heavy contamination of environment, the effects on health and on global politics	Radiation survey meters, readers for dosimeters, personal dosimeters, masks, radiological detectors, protective suits and gloves, a radiation measurement vehicle, water barges, semiconductor detectors, body armour, pumps, filters, CNBR training, nuclear experts
	Energy sector	Social disruption and cascading effects on others sectors such as water CI.	Food supplies, emergency lights and lanterns, generators and body warmers, fuel, liquid natural gas, gasoline, diesel
	Water sector Transport sector	Social disruption Social disruption, emergency services	Bottles of water, water tanks Full mobilization of US army, with tools and expertise
	ICT sector	Social disruption	Broadband global area network terminals

2015; Tsunami Global Lessons Learned Project, 2015); however, despite the loss of services and assets that is commonly described as direct effects of extreme events on CI (Alexander, 2013), their consequences for international relief must be seen as effects of cross-sector disruption that struck primarily food and water supplies. Excluding Prague, a massive mobilization of MREs, water bottles and water tanks was observed. Although it could be expected that extended energy shortages could be associated with the delivery of substantial amounts of generators, this seems less relevant than expected. Generators are present in all the documentation, but their amount is not proportionate to the magnitude of the disruption, while it is possible to observe items such as individual

heating supply or torches. Similarly, the deployment of teams for the restoration of communication networks has been reported, but in moderate amounts compared to the loss of services. The presence of gasoline and diesel is reported in Japan, while in Katrina, oil offers were linked to bilateral agreements and diplomatic discussions (Kelman, 2007).

Although the accessibility of airports and roads oriented the deployment of international relief as assumed, the role of transport infrastructure is less defined. In Japan, the ordinary logistical efforts happened together with the 'restoration of critical infrastructure, such as damaged airfields, in order to sustain operations' (Feickert et al., 2011, p. 4). This was made by the US army, which contributed to the restoration



of strategic transport lanes to allow the transit of supply and to limit secondary emergencies. However, it cannot be expected that those circumstances would be common. According to Feickert et al. (2011, p. 1), 'the situation was unique in that U.S. forces and associated resources were located in close proximity to deal with the crisis', while the US army was training regularly with the SDF on disaster relief exercises. The armed forces were able to mobilize trained corps that could act on transport infrastructure, such as or heavy vehicles, but those were already in the field and were deployed according to pre-existing bilateral agreements.

### 6.2. Indirect effect: CI as self-standing hazards

Despite CI disruptions commonly being associated with the loss of services, our data show the existence of further patterns. It is evident that some sites, such as nuclear power plants, wastewater facilities and industrial facilities, if damaged or disrupted during extreme events can generate indirect effects like environmental pollution or contamination (Alexander, 2013). After a triggering event, their attribute of self-standing hazards is often revealed: while the functional capacity of the CI in terms of providing materials and services falls, the very same hazardous components or materials that are used in the production process may be released, originating cascades.

In our cases, the international assistance consistently provided expertise or goods to contain the escalation due to the malicious effects of the CI itself. This idea does not contradict the possibility that some escalation is generated by cross-sectorial interdependencies (e.g., electricity failing that stops water pumps). Instead, it integrates the evidence that vulnerable equipment and materials like storage tanks, pipelines and paperwork can generate secondary disasters after some environmental triggers (Helbing et al., 2006; Krausmann, Renni, Campedel & Cozzani, 2011). This is observed in the offer of or request for emergency supplies such as purification units, chlorine tablets, vaccines and dosimeters but also in expertise or specialized training to deal with what are generally known as chemical, biological, radiological and nuclear (CBRN) hazards.

Some particular considerations emerge from the analysis of Katrina. In the EADRCC official documentation (NATO, 2005a–h), a significant divergence can be seen between the goods offered and the goods accepted, which is a common procedure in major emergencies (e.g., OCHA, 2011a–i). However, the international offers in Katrina are much more oriented to tackle the secondary disasters in term of pollution or contamination, than the official request made by the US government. This pattern was not

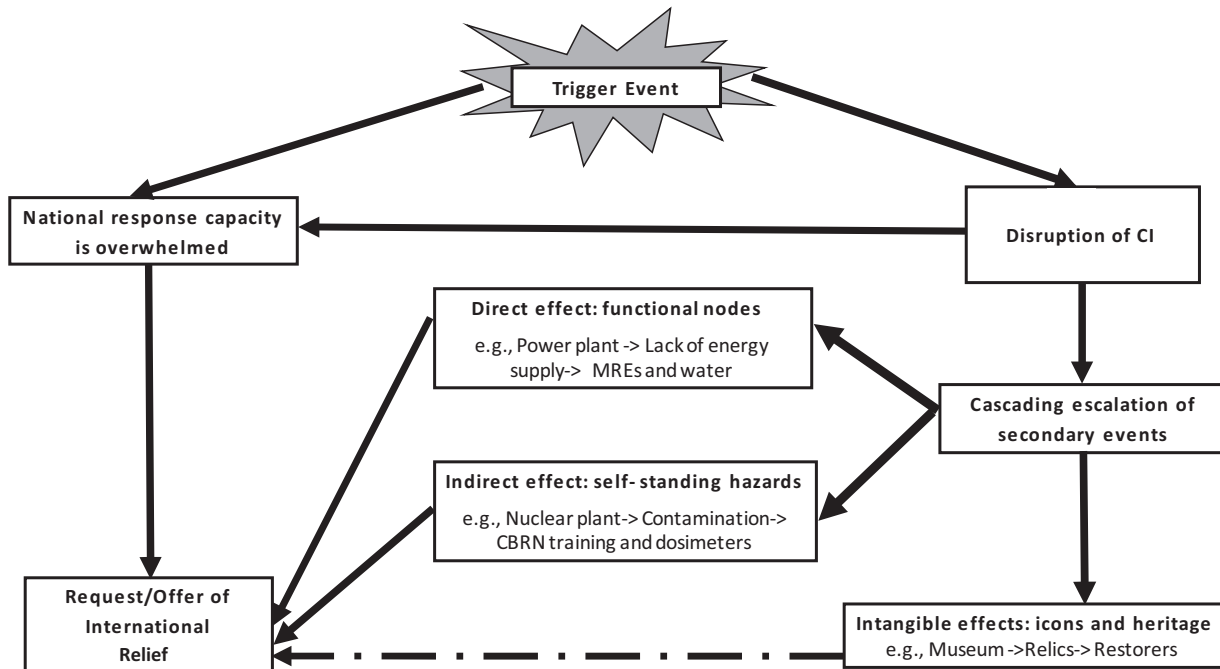
verified in the other documentation and suggests the need of further research to understand any recurrence.

### 6.3. Intangible effects: CI as historical and cultural heritage

Finally, our discussion must consider the existence of intangible effects on society, intended as those that are not strictly measurable in monetary terms but may influence choices and behaviour. They include possible impacts on cultural heritage, associated with national monuments and iconic archaeological sites (Global Platform for Disaster Risk Reduction, 2013, Lazari, 2014). In our cases, the impact on heritage can be seen in the Prague floods when Italy and Spain offered specific expertise for the restoration of relics. This followed a mobilization to protect sites such as the Charles Bridge and the Institute of Archaeology. However, no other evidence was found and the consistency of this relation suggests the need for future research.

Literature suggests that, in the past, only very rarely has disaster assistance included assets to preserve and restore historic and cultural heritage, even if it was recognized as an important issue (Jones, 1986). For Katrina, contextual differences are too strong to support a true comparison. Prague's historic centre is a UNESCO World Heritage Site and the flood involved unique treasures for humanity dated back to the medieval period, while in the most affected area of the United States there was nothing similar, despite New Orleans' internationally renowned culture seen particularly through cuisine, language and music (Gotham, 2007; McKinney, 2006).

The Japan case is more complex. Although no UNESCO World Heritage Site was heavily affected, 744 national landmarks were damaged in 19 prefectures, including 6 special historic sites, 90 historic sites and 16 natural monuments (Agency for Cultural Affairs, 2012). Among the documents considered, no international relief efforts referred to them. First, perhaps the magnitudes of the disasters were different, and in Japan, the cultural heritage might have come after the need to contain loss of life and support survivors. Second, some cultural differences in the communities could influence the relation with buildings, landmarks and the environment (Alexander, 1993). Last, it is possible that the type of heritage involved was different in quality and quantity, requiring a higher level of expertise in Prague. For example, the flood in Prague's National Library involved rare books dating back to the fifteenth century and was compared with the 1966 flood in Florence, when world-renowned museums, including the Uffizi Gallery, were devastated (Ray, 2006).



**Figure 1.** Schematic overview of how CI orients international disaster relief in cascading disasters. The dashed arrow suggests the need of further testing for icons and heritage.

## 7. Conclusions

Our analysis verified that critical infrastructure can orient the request for and offers of international disaster relief in developed countries, shifting priorities as the events progress. In our cases, some major efforts in terms of goods and expertise are provided not only for the response to the primary triggers (flood, hurricane, earthquake, tsunami) but also to contain the escalation of secondary events and CI disruptions. Three overlapping paths have been pointed out (Figure 1):

- Direct effects due to the disruption of CI as functional nodes, associated with recurrent consequences on food, water and energy supplies;
- Indirect effects due to the potential of CI as self-standing hazards, associated with the needed goods and expertise used to tackle technological events;
- Intangible effects related to historical and cultural heritage.

Those findings seem to support and extend the existing theories on cascading dynamics and networked events with evidence for international relief (Helbing et al., 2006; Pescaroli et al., 2015, 2016). The key recommendation is that international disaster response should not focus just on primary triggers. Instead, the structure of international disaster relief should acknowledge that a consistent part of its

provision of goods and services is used to limit, address and prevent the escalation due to the role of CI in cascading disasters. The development of some systematic databases could be of use to understand better the recurrent gaps in national capacities and to support faster deployment.

The evidence we presented has many limitations. We recognize that some integration with quantitative analysis methods such as data mining techniques could be desirable in future. The availability of primary and secondary online sources could be used to create new data sets, for example, correlating the effects of CI disruption, the countries involved, the types of triggers and the secondary events. The first point for further testing is where and when the role of international relief becomes a *condition sine qua non* to limit the cascade associated with CI. Is there any threshold that could be common between the delivery of emergency goods, such as MREs, and expertise, such as CNBR teams? What about historical and cultural heritage as CI? Are they effectively part of an escalation process? Is there any consistency in the offer of or request for aid? Which actors provide which resources?

Similarly, further studies should address the contributions of nongovernmental organizations (NGOs) and the private sector in defining how and where they are more likely to exceed state-driven support. For example, the NGO Télécoms Sans Frontières sent teams to provide emergency communication

assistance both in Katrina and in Japan (Kelman, 2007; OCHA, 2011a). Bilateral offers could relate CI disruption to 'disaster diplomacy' issues (Kelman, 2007), in particular related to supplies like oil or to military resources such as engineers and amphibious vehicles. Many questions remain on how transport infrastructure could orient international relief in cascading. Despite the common logistic challenges, there could be other drivers such as expertise or tools that need to be addressed with problem trees and considerations about diplomatic affairs.

A final but critical point that should be addressed in future is the differentiation between accepted and offered relief. Priority should be given to understanding the differences in national and international response related to cascading events, and the drivers of decision-making process. We recognize the need for testing and improving our evidence with in-depth incident evolution analysis and problem trees that could explain the relationships between roots of cascades and reflections on the delivery of goods and services. What if CI disruptions in cascading events could orient international relief more as a perceived escalation threat than as a real field need? Which could be the principal drivers in the decision-making processes? These questions remain open, but their relevance is unequivocal. The CI systems that are the backbone of our society are also potentially its Achilles' heel.

## Acknowledgements

This work has been carried out under the aegis of the EC FP7 FORTRESS project. FORTRESS is funded by the European Commission within FP7-Area 10.4.1 Preparedness, prevention, mitigation and planning, TOPIC SEC-2013.4.1-2 SEC-2013.2.1-2, Grant 607579. A special acknowledgement is made by Gianluca Pescaroli to Morena Zucchelli (Coopi), Robert D'Ercole (IRD) and Tiziana Vicario (Coopi) for their trust, their commitment and their unforgettable lessons on field. Their work should be taken as a model by many more.

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