Words into Action Guidelines:
National Disaster Risk Assessment
Special Topics

C. Cross-Sectoral and Multi-Risk Approach to Cascading Disasters

Key words:
cascading risk, cascading disasters, cascading effect

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An introduction to cascading risk and cascading disasters

From utilities to the internet, over the last two decades technological networks have increased in interdependency and level of integration with society. They have also become more unstable and their behaviour has become harder to predict. Critical infrastructure (CI) is defined as those assets or systems that are vital to maintaining the socioeconomic functions of society. It is also an essential pillar that supports the provisions of the Sendai Framework for Disaster Risk Reduction.

CI can be conceptualized as nodes in the built environment that group together physical, functional and organizational attributes. With the increased complexity of the built environment, the definitions and sectors have evolved in concert with one another. They incorporate lifelines for the delivery of resources and services, essential sites for communities, and assets such as chemical plants, which are potentially vulnerable to hazards.

A causal chain generates secondary disasters from the interaction between anthropogenic and ecological systems. Despite major efforts by the international community, many challenges are still present in efforts to mitigate such phenomena. For example, current risk management strategies are insufficient for estimating the probability of rare events and coincidences, and for understanding cascades and event trees[1]. To improve the operational management of complexity, a system-wide approach to resilience is needed that embraces new forms of analysis, new methods and new tools[2]. Cascading disasters and risks present substantial challenges both to citizens and to the emergency management community.

The emerging nature of the field implies that for a long time it has remained ill-defined, and only recently has there been substantial investment by the European Commission, in the form of the Seventh Framework Programme and Horizon 2020 projects, which have enabled concept and practices to be defined better.

Starting from the idea that cascades could be modelled as a dendritic structure of evolving secondary events[3], it has been suggested that cascading disasters reveal complex risks, where the effects of primary triggers are

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1 Helbing, D. (2013). Globally networked risks and how to respond. *Nature* 497 (7447), pp. 51-59.

2 Linkov, I. and others (2014). Changing the resilience paradigm. *Nature Climate Change* 4, pp. 407-409.

3 May, F. (2007). Cascading disaster models in postburn flash flood in: Butler, B.W. and Cook W. The fire environment – innovations, management and policy. Conference Proceedings. Washington, D.C. Department of Agriculture Forest Service, pp. 446–463.

amplified by the non-linear progression of the crisis over time[4]. In other words, the consequences of the initial or trigger impact become the primary sources of further crises, which, instead of decreasing as time progresses, become larger and require more resources to bring them under control.

The primary effects of the physical trigger are amplified by the disruption of entire sectors of critical infrastructure, such as air transportation and energy supply, and often by the hazardous components of CI, such as nuclear plants. The path of cause and effect exploits vulnerabilities that accumulate on different scales. They are manifest in unexpected events that escalate into full-blown cross-sectoral disasters. The vulnerabilities can be accumulated in macroscopic dynamics, such as the technological drivers of globalization, or micro dynamics such as local CI management or decision-making for land-use control.

As cascades are different from other topics analysed in the literature, new instruments are needed to mitigate them. This is because sectors of CI influence each other. For example, losses in the energy sector can disrupt the water sector, which depends on electricity for pumping and other functions. The connections are complex and dynamic. Similarly, cascades differ from compound disasters, because the latter are more focused on the concurrent and combined nature of climate extremes, such as flooding that occurs during a cold wave or heat waves that contribute to wildfires[5].

What is particularly needed to address cascading risk is to create scenarios, tools and information that could join the triggers with their patterns of consequences and thus help visualize the potential structure of secondary emergencies. The following examples will clarify the most salient issues for national risk assessments

Examples of cascading risks and disasters

The literature on critical infrastructure has analysed many examples of cascades in areas defined by high concentrations of technology, such as the energy shortage that followed Hurricane Sandy in 2012 in the United States, and the distributed effects of the 2015 floods in York, in the United Kingdom. Much less evidence has been provided for developing countries.

In 2007, Cyclone Sidr struck the south-west coast of Bangladesh – with 240 km/hr winds and a six-metre storm surge. Water and sanitation infrastructure

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[4] Pescaroli, G. and D. Alexander (2015). A definition of cascading disasters and cascading effects: going beyond the"toppling dominos"metaphor. Planet@Risk, Global Forum Davos. 3(1), pp. 58-67.

[5] Intergovernmental Panel on Climate Change (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

was heavily damaged, including 11,612 tube wells, 7,155 ponds, and over 55,000 latrines. As human waste was generally not treated, waterborne diseases became a major public health concern. In many communities, drinking-water sources (tube wells and ponds) were contaminated with salt water and debris[6]. Further research is needed to understand how the specific needs and strategies at the local level can affect broader strategies for mitigating cascades.

Box 1
Eruption of Eyjafjallajökull volcano

The eruption of the Icelandic volcano Eyjafjallajökull in April 2010 is one of the events that have raised the tone of the debate about cascading risks. Although its direct physical damages were limited, it released an ash cloud that temporarily stranded 8.5 million airline passengers.

This disruption of the aviation sector became the main vector of the crisis. It highlighted the dependency of modern society upon functioning global networks. The temporary cessation of civil aviation increased the pressure on other forms of transportation, revealing its fundamental role in ordinary activities, from the delivery of perishable goods to air freight transportation of medical supplies, including organs for transplant.

Despite many precursors, volcanic ash clouds were not considered in the risk registers of countries that were involved in the 2010 crisis, such as the United Kingdom. One wonders what other, unconsidered triggers could cause high levels of disruption to critical infrastructure.

Box 2
Tōhoku earthquake

The triple disaster in Japan that started with the Tōhoku earthquake of 11 March 2011 had serious consequences in term of loss of life and long-term impacts on the environment. The consequences also included a boost to the worldwide debate on nuclear safety. Although only about 100 people died as a direct result of the primary trigger, the earthquake, about 18,000 were killed by the ensuing tsunami, and there was uncertainty about the consequences of the radioactive contamination resulting from the Fukushima Dai'ichi nuclear meltdowns.

The interaction between natural and technological hazards was amplified by local vulnerabilities, and the Fukushima nuclear accident was considered “a profoundly man-made disaster – that could and should have been foreseen and prevented” . Other critical infrastructure in the affected area was broadly compromised, which constrained efforts to contain the cascading effects of the primary disruption. This prompted the creation of new data sets to improve deployment in secondary disasters.

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[6] Jha, Abhas K., T.W Miner and Z. Stanton-Geddes, eds. (2013). *Building Urban Resilience: Principles, Tools, and Practice.* Washington: World Bank.

Implications of cascading risk and disasters for national risk assessments

Cascading risk and cascading disasters have serious implications for national risk assessment processes. It is vital not only to understand and assess cascades in critical infrastructure but also to know how to stop cascades from escalating. To address the possible impact of disruption, the United Kingdom and the United States ranked elements of CI according to their importance.[7][8] The Netherlands uses an area-based approach, which enables the interdependencies of critical infrastructure elements to be mapped and assessed[9]. International work has striven to address the relationship between CI and society. When Peru estimated the resources that are essential to emergency response and recovery if an earthquake or tsunami were to strike the metropolitan areas of Lima and Callao, a high likelihood of poor functioning or paralysis of vital services was identified. This required new maps to be produced and alternative supply routes to be planned[10].

However, there is still no coherent and fully coordinated approach that responds properly to the provisions of the Sendai Framework for DRR. Risk maps that include the loss of CI and the impact of this loss are generally unavailable or lack uniformity. In Europe, natural and technological hazards tend to be separated or overlain without an accompanying context[11]. Even when risk registers and national strategies are implemented, the tendency is to focus heavily on the impacts that are deemed most likely to happen, not on those with the most complex consequences.

New strategies have been employed to address cascading failures, increase resilience and share information on possible common paths for the disruption of infrastructure. First, in recent years constant technological and scientific progress has led to cross-domain modelling of interdependent systems and economic impact assessment of critical events[12].

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[7] White House (2013). Presidential Policy Directive – Critical Infrastructure Security and Resilience. Directive/PPD-21. Washington D.C.

[8] United Kingdom, Cabinet Office. Keeping the Country Running: Natural Hazards and Infrastructure. London, 2011.

[9] Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (MBZK). Bescherming vitale infrastructuur (Protection of Vital Infrastructure). The Hague, 2005.

[10] National Institute of Civil Defence, Peru, and United Nations Development Programme (2011). Cooperazione Internazionale. Sistema de información geográfico y análisis de recursos esenciales para la respuesta y recuperación temprana ante la ocurrencia de un sismo y/o tsunami en el área metropolitana de Lima y Callao.

[11] De Groeve, T. ed. (2013). *Overview of Disaster Risks that the EU faces*. European Commission Joint Research Centre.

[12] Galbusera, L. and others (2016). *Inoperability Input-Output Modeling: Inventory Optimization and Resilience Estimation during Critical Events. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems Part A. Civil Engineering 2 (3)*.

Together with research on empirical approaches, agent-based models and interoperability input-output models, there has been an evolution in network-based approaches that aim to describe the connections and interlinkages between nodes of critical infrastructure (Ouyang 2014). The new resources available from geospatial technologies and computational tools have been integrated into digital support tools that consider local, regional, national and international interdependencies – for example, the Geospatial Risk and Resilience Assessment Platform, which is referred to in the resource section below. It is also possible to find new methods for improving training for disaster management in complex environments, such as fault trees, root causes and wider impact-tree analysis[13].

To improve the anticipation of crises, the PANDORA project, initiated by the Government of Denmark, has developed its "forward-looking cells strategy"[14]. A key driver is to approach complexity before possible events occur, involving different stakeholders in promoting awareness, in sharing information and in planning. For example, in the United Kingdom, London Resilience has produced a general model called Anytown, which could easily be replicated in other urban environments. In the United States, the National Institute of Standards and Technology has defined a step-by-step process to integrate buildings and infrastructure systems into community resilience (see resources section below).

A complementary approach suggests that the paths of cascades can be understood in advance of the triggering events by identifying sensitive nodes that generate secondary events and rapidly scale up a crisis. Risk scenarios based on hazard can be integrated with corresponding vulnerability scenarios based on escalation points that could be used to represent unknown triggers[15].

This approach was tested with two different studies. First, empirical comparisons showed that the disruption of critical infrastructure can orient international relief in terms of the goods and expertise needed in the emergency phase. Priorities can change as the cascade evolves, secondary emergencies escalate and new data sets are required for the optimization of deployment[16]. Secondly, the technological motivations of CI disruption can raise the emergency to larger geographical and temporal scales, which have

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[13] MacFarlane, R. (2015). Decision support tools for risk, emergency, and crisis management: an overview and aide Memoire. Emergency Planning College Position Paper 1.

[14] Danish Emergency Management Agency (DEMA) (2016). PANDORA Forward Looking Cell. Birkerød: DEMA.

[15] Pescaroli G. and D. Alexander (2016). Critical infrastructure, panarchies and the vulnerability paths of cascading disasters. *Natural Hazards 82(1).* pp.175-192.

[16] Pescaroli, G. and I. Kelman (2016). How critical infrastructure orients international relief in cascading disasters. Journal of Contingencies and Crisis Management, vol. 25, issue 2, pp. 56-67.

not yet been included in legislation on cross-border and cross-sectoral crises[17]. Knowledge of such cases could be improved with multi-level scenarios based upon vulnerability frameworks that are already available[18]. Distributed systems characterized by modular design and digital technologies could be used to increase the resilience of communities and emergency services.

The involvement of emergency managers, associations and representatives of the business community could help determine which consequences of a disaster could become the principal drivers of cascades. A practical example illustrates this point. Europe's biggest training event to date ("Exercise Unified Response", www.london-fire.gov.uk) took place in London in February 2016. The exercise lasted four days and simulated a building that collapsed onto an underground railway station, with over 1,000 casualties. It involved all the major authorities in London and special rescue teams from Hungary, Italy and Cyprus.

Although the consequences of a loss of transportation for London were considered, promoting a wider focus on secondary emergencies and escalation points could help to improve the strategic framework for the future, whatever the nature of the primary trigger. In an increasingly interconnected world, emergency planning needs to consider the existence of intersectoral factors and identify the less evident connections that could modify the need for assistance and coordination[19].

In this sense, the International Risk Governance Council developed an approach to risk governance that could be a step forward because it integrates cascading risk into resilience-driven strategies. Of particular relevance is the application of a tiered approach that supports the assessment of resilience and its translation into applied management actions[20]. This kind of information may be critical to the work of emergency managers and the development of situational awareness tools at the operational, strategic and policy levels.

This is particularly relevant for developing countries, where increasing the awareness of new strategies and support for the training of local people could make a significant difference by increasing the flexibility of response and matching it more closely to local needs.

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[17] Nones, M. and G. Pescaroli (2016). Implications of cascading effects for the EU Floods Directive. *International Journal of River Basin Management* 14(2), pp. 195-204.

[18] Birkmann, J., S. Kienberger and D. Alexander (2014). *Assessment of Vulnerability to Natural Hazards: a European Perspective.* Amsterdam: Elsevier.

[19] Alexander, D. (2016). *How to Write an Emergency Plan*. Edinburgh: Dunedin Academic Press.

[20] Linkov, I. and C. Fox-Lent (2016). A tired approach to resilience assessment. IRGC Resource Guide on Resilience. Available from www.irgc.org/risk-governance/resilience/

Resources for further information

Various resources are available online:

The Research Group on Cascading Disasters at University College London is developing a series of guidelines written for non-academic users to improve the understanding of cascading risk. The documents and other papers are available at: www.ucl.ac.uk/rdr/cascading.

Similarly, the International Centre for Infrastructure Futures is releasing policy briefs and presentations on critical infrastructure interdependencies and societal resilience. The documents are available at: www.icif.ac.uk .

Other international sources provide information and guidance outside academia. The International Risk Governance Council produced policy recommendations on Managing and Reducing Social Vulnerabilities from Coupled Critical Infrastructures, while their Resource Guide to Resilience focuses on the governance of risks distinguished by high uncertainties. These and other reports can be downloaded free of charge at: .

Other resources and compilations of lessons learned have been produced by initiatives such as the Rockefeller Foundation's One Hundred Resilient Cities: www.100resilientcities.org.

A wide range of methods and digital tools could be used to address cascading failures. The Joint Research Centre of the European Commission created the GRRASP platform, based on open source technologies, to support the analysis of cross-sectoral interdependencies and critical infrastructure disruptions: www.ec.europa.eu/jrc/en/grrasp.

The European Commission has also funded projects on cascading effects that produced methodologies and software for modelling cascading effects, such as FORTRESS (www.fortress-project.eu), CIPRnet (www.ciprnet.eu), CascEFF (www.casceff.eu), PREDICT (www.predict-project.eu) and SnowBALL (www.snowball-project.eu). The websites of these projects have made different resources available for download, including decision-support systems and deliverables.

The interaction between cascading risk and compounding drivers can be widely explored by accessing the resources provided by the United States Climate Resilience Toolkit, which includes a catalogue of more than 200 digital tools for building resilience: www.toolkit.climate.gov.

Different resources are available in open access for supporting the training and preparedness of stakeholders. London Resilience, which acts on behalf of the Mayor of London, London's local authorities and London Fire Brigade, has developed Anytown, a conceptual model designed “to improve the understanding of infrastructure interdependencies by non-experts”. The model is generic and has been developed to be used easily in different urban contexts. This and other information can be found at www.londonprepared.gov.uk.

In the United States, the National Institute of Standards and Technology developed the Community Resilience Planning Guide for Buildings and Infrastructure Systems. The guide aims to support the prioritization and management of resources to improve preparedness and recovery by using a practical six-step process to identify the linkages and dependencies between the social dimensions and the vital services provided by infrastructure (www.nist.gov). Also on its website, the Institute provides standards and guidelines on cyber security for critical infrastructure.

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