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Managing Systemic Risk in Emergency Management, Organizational Resilience and Climate Change Adaptation

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Abstract

In urban systems, major risks need to be managed by bringing together emergency management, organisational resilience and climate change adaptation. In this endeavour, policy making must make use of disaster science. This chapter applies the theory of cascading, interconnected and compound risk to the practice of preparing for, managing and responding to threats and hazards. This methodology is illustrated with an example from the United Kingdom, namely the work of the Greater London Authority and its partner organisations. London has long been a champion of resilience strategies for dealing with systemic risk. The chapter investigates the potential and limitations of this approach. There remains a need to identify common points of failure, especially where they relate to interconnected domains and where they are driven by climate change. Radical new thinking is required in order to ensure operational continuity in the face of growing systemic risk.

Keywords: systemic risk; emergency management; organisational resilience; climate change adaptation; capacity to adapt; risk management priorities

Contents

Introduction

Systemic risk is a well-known challenge to policy makers, but it has often appeared in different guises. Over the years, it has been associated with the collapse of the financial system, climate change, terrorism and globalization (Centeno et al. 2015). Its relevance has been increased by the Covid-19 pandemic in which the fragility of interconnected networks has become clearer to the public and to decision makers. There are different elements that need to be considered in order to understand the root causes of this process (Pescaroli and Alexander 2018). In recent decades, risk has become more complex and harder to predict, requiring a shift in the paradigm of managing it (Helbing 2013, Linkov et al. 2014). According to the International Risk Governance Council:

> "traditional probabilistic risk-assessment methodologies, which are based on linear or well-established cause-and-effect-relationships, cannot be successfully applied to risks that arise in such systems and may even have counter-intuitive and unintended consequences" (IRGC 2018, p.9)

The societal use of technology continues to evolve strongly and orients the use of geographical space, the environment, and the synchronization of time. Powered by the increasing dynamism of the world, interconnectedness is a fundamental feature of these systems, but they may be exposed to disruptions which have highly varied causes (IRGC 2018). The increasing complexity of supply networks, outsourcing, and the evolution of just-in-time production systems have reduced the redundancy and tolerance of disruption of the supply chain (Burnard and Brahma 2019). Crisis management now needs to move beyond hazard-oriented scenarios and tackle multiple threats that develop simultaneously (Pescaroli and Alexander 2016). These include the concurrency of climate extremes, hybrid attacks that are conducted in the midst of ongoing emergencies, and the cascading effects of technological failure (Pescaroli and Alexander 2018). Unfortunately, the term 'systemic risk' has often lost its significance as it is bandied about between science, policy and practical application.

In the following sections, we explore the political and operational challenges of integrating systemic risk into the practice of emergency management, organizational resilience and climate change adaptation. This is accomplished by means of a theory-building process supported by the analysis of experience derived from the Greater London area of the United Kingdom. In particular, using a multi-disciplinary perspective on disaster studies, we explore the unifying role of critical infrastructure. Our goal is to move towards the creation of a roadmap that can be used by decision makers.

Systemic risk is the likelihood that particular failures in a subsystem or organisation will have repercussions throughout the system in which they occur. We regard it as a latent property with the potential to be cumulative. It can remain unnoticed in organizations, but when triggered it can compromise operational capacity. According to the IRGC (2018) systemic risk can be considered as:

> highly interconnected risks "with complex causal structures, non-linear cause-effect relationships", and there is "lack of knowledge about interconnections in an interdependent and complex environment, prevention" (IRGC 2018, p.12).

This is substantially different from so-called 'conventional risks' that are associated with “recognisable patterns and management regimes that are relatively stable”.

In the social, political, economic, and ecological domains, systemic risk can be associated with cascading, compound, interacting and interconnected crises and their interaction with the root causes of emergencies and disasters (Pescaroli and Alexander 2016, 2018). Organizational resilience is defined as “the ability of an organization to anticipate, prepare for, and respond and adapt to incremental change and sudden disruptions in order to survive and prosper” (BS 2014). Climate change adaptation is described as “the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities” (IPCC 2018). These three concepts can be viewed in the light of the need to create some form of “dynamic flexibility” in order to manage extreme situations (Alexander 2013).

In the following sections the paper approaches the challenges of managing systemic risk in emergency management, organizational resilience and climate change adaptation. It then develops a case study based on London’s experience of understanding and managing systemic risk, after which it offers some discussion and a conclusion. The case study is analysed in two complementary steps that have organisational resilience as a common element. First, the paper explores how emergency management approaches systemic risk, focusing on some initiatives developed by the London Resilience Partnership from 2002 onwards. This section includes examples of exercises, contingency plans and responses to complex incidents. Secondly, the paper analyses how systemic risk is integrated into strategies and practices of climate change adaptation, such as the use of scenario planning to identify common contexts. The review takes account of the work of the London Climate Change Partnership from 2001 onwards. It also considers decision-making pathways, and various means of understanding interdependencies between different operational domains.

The common challenges of systemic risk

When dealing with systemic crises it is easy to lose one's grip on the complexity of the problem. In the light of the definitions given in the previous section, systemic risk is a cross-cutting issue that includes different operational and strategic domains. It points to the need to go beyond single-category thinking in order to develop broad, interdisciplinary forms of mitigation. The question of where to start has no easy and univocal answer. The first step is to understand what critical factors may be common to the fields of emergency management, organisational resilience and climate change adaptation. The concept of systemic risk, as used in the financial sector, is particularly useful for this purpose as it gives much weight to interdependency. Authors such as Smaga (2014) have identified the presence of mechanisms such as non-linearity, accumulation and contagion that occur after an initial shock is transmitted from one institution to another. The example of the 2008 financial crisis was also discussed by the IRGC (2018) and was used to illustrate the high risk of contagion among interconnected systems. Additional examples of systemic risk that can be used to highlight the existence of multiple causes, impacts and resistance to policy response are the ecological collapse of the Aral sea, the global depletion of fish stocks, the development of the personal transportation sector in terms of autonomous vehicles, and irreversible changes in the environment as an effect of global megatrends (IRGC 2018).

Complementary examples can be found in the field of disaster risk reduction. According to Pescaroli and Alexander (2016), the spread of cascading effects can be associated with the aggregation of vulnerabilities at points where societal functions interact with one another.

Disruptions spontaneously activate the vulnerabilities. The most visible element of this process is associated with critical infrastructure, defined here as “the physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society” (UNDRR 2017). High levels of complexity and independency mean that multiple failures are extremely likely. Because networks tend to be tightly coupled to each other, disturbances may spread quickly between them (Perrow 1999). The development of the field of business continuity management started from the assumption that interruptions are systemic and have both societal and technical aspects (Elliot et al. 2010). However, despite significant progress over the last decade, there are significant gaps in our knowledge of how interdependencies should be assessed and dealt with in practice (Pescaroli and Alexander 2018).

When the Covid-19 pandemic started, it was exacerbated by factors such as lack of preparedness, insufficiency of coordination, and failure to appreciate the vulnerability of network interconnections. For example, increased pressure on the healthcare sector reduces the opportunity to use regular services. Supply chain disruptions lead to empty supermarket shelves and logistical bottlenecks. Technological dependencies reveal the weakness of organisations that suffer cyber-attacks and on-line disruption because the fail to update their software. These manifestations of systemic risk can be seen as societal constructs that need to be understood holistically if they are successfully to be addressed (Hewitt 1995). In a seminal paper, Quarantelli (1997) observed that technology could have contradictory effects and could in its own right change patterns of vulnerability to hazards. As Wisner et al. (2004, p. 16) noted,

> “Even more generally, development planners often introduce technology at the so-called ‘leading edge’ of whatever version of rapid, systemic change they define as ‘development’. This may be irrigation technology in the form of a large dam that displaces thousands of families in what economists’ call ‘the short run’. It might take the form of low-income housing or the development of an industrial complex. Such development initiatives can have a series of unintended, unforeseen consequences".

Since the early 2000s, interdependent networks have been constantly pushed to the edge of their design capacity in order to maximize their performance (Schulman and Roe 2007). Emergency managers have frequently overestimated their own resilience, and have thus become the first victims of cross-sectoral failure (Luiijf and Klaver 2013). In the private sector, the increased complexity of the production and delivery of goods and services points to the existence of hidden interdependencies that could compromise the management of business continuity (Maclean-Bristol and Hiles 2011). Localized disruption of the supply chain is a critical challenge that organizations face. The answer is to introduce more flexibility into the system (Burnard and Bharma 2019).

A new role can be attributed to other emerging technology for monitoring and supporting risk management, including Earth observation, big data processing, and information-sharing platforms. Computational modelling and simulation have become increasingly valued for their ability to anticipate the dynamics of interaction among risk conditions. They have been used to frame alternative strategies and managing dynamic networks such as infrastructure interdependencies and supply chains. Appropriate tools have included assessment of reliability and dependability, optimisation and identification of propagation paths (Casajus Valles et al. 2020). Zio (2016) suggested that the complexity of systems often requires different models and approaches to be integrated into the means of supporting improved decision making. For example, to understand the Covid-19 pandemic “epidemiological analysis was coupled with an assessment of social and economic effect, which the scientific community carried out by activating its analytical and modelling capacities." (Casajus Valles et al. 2020, p. 480). Moreover, in primary infrastructure sectors network science has been applied as a means of enhancing resilience (Galbusera and Giannopolous 2019). Authors such Riddell et al. (2018) have pointed out that scenario modelling could be critical to the understanding and mitigation of decisional uncertainties. Based on their relative expected performance, alternative solutions can be applied experimentally to future hazardous events. However, more traditional approaches that are less resource-intensive need to be used by actors such as local authority decision makers, who lack the capacity to conduct highly sophisticated analyses.

Linkov et al. (2014) noted that the effect of the uncertainty associated with the vulnerability of interconnected networks has to be dealt with in the light of the future unpredictability of climate extremes. Risk analysis of foreseeable events should seek to build resilience into systems so that they can adapt to climate change and recover effectively from major impacts (Linkov et al. 2014). Traditional risk registers may be inadequate in this context. “Risk based approaches can be helpful to understand how specific threats an impact upon a system have, yet often lack the necessary characteristic of reviewing how linkages and nested relationships with other systems leave one vulnerable to cascading failure and systemic threat” (Linkov et al. 2019, p. 9). It may be appropriate to think in terms of 'threat-agnostic' or 'hazard-agnostic' approaches where resilience is defined regardless of a specific threat that hits the system and the rationale considers that “is often impossible to predict what hits the system, how much of a disruption will ensue, and what the likelihood of a threat scenario is” (Linkov et al. 2019, p. 27). A particularly relevant approach is the emerging use of stress tests intended as “a systematic method of crisis scenario analysis and of evaluating measures taken to reduce the societal risk exposure” (Galbusera and Giannopoulos, 2019). These can be regarded as critical tools to identify coordination or capacity gaps that could undermine resilience in critical infrastructure sectors such as banking or energy. Modelling tools could create synergy with more “traditional approaches” to scenario building (Pescaroli and Needham- Bennet 2021).

New scenarios, tools and information should connect cause with effect and help one to visualize the probable structure of secondary emergencies (UNISDR 2017). Weather impacts can cause disruption that leads to cascading failure, and climate change can affect the sensitivity of systems. For example, climate change can limit the availability of water for cooling power stations. Adaptation measures can also have unintended knock-on effects across different sectors. Examples include the effect of flood defences on habitats and species, and the impact of air conditioning, which contributes to the urban heat island effect and causes poor air quality with particular impact upon disadvantaged people. In order to derive some lessons, the next section describes a case study based on London, a 'champion city' that is trying to promote a model approach to systemic risk.

The London case study

With nearly nine million inhabitants, 300 languages spoken in local schools, and 300 million journeys by public transport every month, London is one of Europe's largest and most complex urban areas (GLA 2020). It is ranked no. 2 in the Kearney 2020 Global City Index, prospering thanks to a mix of business activities, human and political capital, information exchange, and cultural experiences. Its role as an economic centre is supported by a complex network of interconnected infrastructure and services that foster timely exchange of information and goods. In more than 2000 years of history the city has shown its capacity to adapt to crises, including the Great Plague of 1349-54 and the Great Fire of 1666. London's Canonbury Tower, built in 1509, is where Sir Francis Bacon was first in the English language to use the term "resilience" in a scientific context, in his natural history of 1627, *Sylva Sylvarum* (Alexander 2013).

The focus on London's resilience planning was heightened when the city joined the Rockefeller Foundation's 100 Resilient Cities programme in 2018 (now known as the Global Resilient Cities Network). Designed to promote urban resilience around the world, the programme awarded grants to 100 cities that "have demonstrated a dedicated commitment to building their own capacities to prepare for, withstand, and bounce back rapidly from shocks and stresses" (Rockefeller Foundation, 2013). The process was developed in complementary steps. A preliminary resilience assessment was outlined in 2019 by the Mayor of London (2019). The two initial areas for actions were respectively "Understanding interdependencies to plan for resilient infrastructure…Ensuring that decision makers take critical interdependencies into account." and "resilient adaptation to climate change, including water systems…". These were followed by "safe and resilient buildings", "supporting business to enhance London resilience", and "adapting to a cashless society". Key themes for facing complex risk included resilience governance, embedding resilience thinking and developing adaptive solutions.

These elements were enacted in the publication in 2020 by the Greater London Authority of the *London City Resilience Strategy*, which was written in consultation with partner organisations (GLA 2020). The aim is to consider long-term shocks and stresses over the period ending in 2050, and to define actions and projects to fill the existing gaps in community resilience. The strategy distinguishes between 'shocks', sudden impact events that can immediately disrupt a city, and 'stresses', chronic issues that can lead to a major shock. The core concept is that emergency plans are essential, but they need to be developed in line with good governance. Indeed, "good governance requires a means of understanding the impact of policy and strategy, alongside the ability to innovate and adapt, to manage changing circumstances" (GLA 2020, p.64).

Using organisational resilience as a common, cross-cutting element, the following sections present some lessons on systemic risk in emergency management and climate change adaptation. The cases include:

- Exercise Unified Response (2016), which simulated the collapse of a building onto a transportation node, together with its knock-on effects.
- EARTH Ex (III/2019), a tabletop exercise that explored the cascading effects of 'black-sky hazards' and extended power failures.
- The UK's departure from the European Union in 2020 and the implications for planning and mitigating disruption, in particular with respect to dependency in supply chains.

- The Thames Estuary 2100 Plan (from 2011 onwards) and the use of 'adaptation pathways' to increase the flexibility responses to change and to create redundancy.
- The Covid-19 pandemic (from early 2020), which is of course a 'global system shock', and the challenge of managing it in concert with responses to of concurrent events and climate extremes.
- The 'Anytown' model of 2013, which was developed to facilitate information sharing among stakeholders who deal with infrastructure disruption.
- The GLA Infrastructure Mapping Application (IMA) and Infrastructure Coordination Hub (2020-2021), which represent practical approaches to the use of data in the management of systemic risk.

Interface between Emergency Management and Organisational Resilience

A notable milestone in multi-agency collaboration to prepare for and manage emergencies in London dates back to 1973 and the creation of the London Emergency Services Liaison Panel (LESLP). In 2002, the London Resilience Team was created, and in 2004, with the passing of the UK Civil Contingencies Act, this team was given increased responsibility for emergency planning and response. In 2010, the team was transferred to the Greater London Authority, and in 2016 it was combined with the London Fire Brigade Emergency Planning Team to form a collective unit known as the London Resilience Group. This exists to support the work of a partnership of more than 200 organisations which have responsibility for assessing risk, reducing possible impacts and ensuring the conduct of emergency planning, response and resilience. The core duties of the London Resilience Partnership include "continual development of capabilities, driven by the London risk assessments, planning assumptions and learning" (London Resilience Partnership 2020a). The process involves training personal, conducting exercises to assure that plans and arrangements are properly functional, and identifying lessons learned. Although some of those documents are not available to the wider public, there are two public scenarios in which the Partnership participated that can support the understanding of systemic risk.

The purpose of *"Exercise Unified Response"* was to test London's emergency services' ability to work effectively together and with other responder agencies from across the London Resilience Partnership (such as Local Authorities, transport and utilities sectors). The exercise was also designed to validate arrangements for integrating assistance of specialist teams (such as urban search and rescue, and disaster victim identification) from elsewhere in the UK and the European Union (EU).The exercise was held in London in February 2016. It was organised by London Fire Brigade on behalf of the London Resilience Partnership and was co-funded by the EU. At the time it was considered to be Europe's biggest exercise event to date. It lasted four days and had a budget of approximately €2mn.

The exercise successfully brought together personnel from over 100 organisations (and ten EU countries) to test activities and capabilities for dealing with a large-scale emergencies. It highlighted many areas in which it was necessary to improve future preparedness and response. The scenario was derived from the London Risk Register. It simulated the humanitarian, infrastructural and wider economic impacts of the collapse of a building onto an underground railway station. The simulated event generated more than 1,000 casualties. As one of the participants wrote on the second day,

> "We recognised the need to think wider than the direct implications of the building collapse and bridge the gap between the ongoing response effort and the implementation of recovery activities. In order to achieve this, local authorities were handed the chair role for the Strategic Coordination Group and identified strategic objectives (around health, transport, economy etc) against planning assumptions (i.e. how long will we be responding for and for how long impacts will be felt). Essentially this is our way of saying that whilst the response continues and saving life is our primary focus, we need to understand and mitigate the impacts on London and beyond" (London Resilience Group 2016).

Although the consequences of a loss of transportation for London were considered, promoting a wider focus on secondary emergencies and escalation points should help to improve the strategic framework for managing future events, whatever the nature of their primary triggers. In an increasingly interconnected world, emergency planners need to consider the existence of intersectoral factors and identify the connections that are less evident and could change the need for assistance and coordination (Pescaroli 2018).

The purpose of *Earth Ex* was to explore the national and international consequences, and the critical resilience planning opportunities, associated with an extreme 'black-sky' disaster (i.e., severe disruption of the normal functioning of critical infrastructure in multiple regions for long periods of time). The exercise was hosted by Resilience Shift in partnership with the Electric Infrastructure Security Council and was attended by leaders from a wide range of infrastructure, government and service sectors. It took place in London in February 2019 and Glasgow in March 2019 (Aldea-Borruel et al. 2019). The exercise identified serious planning gaps across sectors from food and medicine supply to transportation, security and finance, both in the UK and other nations. It concluded that where planning did partially exist it usually considered timescales that were far too short. Earth Ex involved tabletop exercises organised by the hosts. These explored the interdependencies and cascading effects that could affect emergency response and continuity management. It promoted common training and scenario building (Pescaroli et al. 2017). One of the most common elements noted by participants was that preparedness for short duration electricity outages improved if there were sufficient generators and enough bunkered fuel (Aldea-Borruel et al. 2019.) However, longer-term power outages would have seriously disruptive effects that would need to be contained and must be addressed in resilience planning. The cause of the long-term outage itself does not represent the core problem. There are some criticalities that need to be addressed such as the fragility of the supply chain, including food and water shortages, and finding the right means of communicating with the public. In other words, it is not the direct impact of the event but addressing the vulnerabilities that could exacerbate cascading effects (Pescaroli et al. 2017). In order to minimise disruptions independently of their primary trigger, it is essential to develop multisectoral planning. Emphasis should be given to all-sector resilient communication and thus to interoperability. Measures need to be developed to create redundancy in lifelines. When technological failures compromise operational capacity, this may require a shift to low-tech solutions (Letwin 2020).

Valuable lessons can be learned from some aspects of London's experiences of systemic risk at the interface between organisational resilience and emergency management. The 2020 Chair of the London Resilience Forum, Dr Fiona Twycross observed that: "The Grenfell Tower Fire was the largest fire London has seen in peacetime and the largest collective and sustained response to an emergency in the history of the Resilience Forum. Preparations for leaving the European Union have used extensive resources from the resilience community and required a level of planning across a breadth of issues not previously included in our preparations" (London Resilience Partnership 2020a). The Grenfell Tower Fire occurred in June 2017 in the 24-storey Grenfell Tower block of flats in North Kensington, West London, and caused the loss of 72 lives (MacLeod 2018). This approach implies a focus on cooperation in order to adapt to long-term stresses and prepare for short term emergencies. However, different barriers have to be understood.

As it overlaps with wider challenges of organisational resilience, the experience of Brexit contingency planning is particularly relevant here. First, systemic risk implies possible barriers in the domain of information sharing. London Resilience Partnership's work in this was centred on the implications of a 'no-deal Brexit', and it involved all key partners. The results of that work are outlined below. It can be noted indeed that "It was clear from informal discussions with some representatives of partner organisations and sectors, both in the run up to, and during the summit, that many felt unable to speak openly" (London Resilience Group 2018, p. 1). This included problems of commercial sensitivity, non-disclosure agreements, ill-defined remits, and the need to improve accessibility to information. Similarly, information itself may be in short supply due to hidden dependencies and a lack of wide-spectrum risk assessment in the supply chain. "For example, comprehensive assessments of the implications for critical supply chains and personnel need to be conducted by Partnership organisations where they have not yet been fully considered." (London Resilience Group 2018, p. 2) In particular, this includes mitigation of disruption to "food supplies, energy supplies, fuel supplies, and borders (people and goods)", and the many uncertainties that could hamper emergency planning. Following this process, the London Resilience Partnership developed a series of workshops on food supply chains and their interdependencies and vulnerabilities, including "an analysis of the impact and consequences of food disruption throughout the distribution system and the effects on retailers, markets and households" (GLA 2020). Further scenarios have been developed in cross-cutting collaboration with climate adaption planners. These are reported in the next section.

Finally in this section, the London Risk Register is designed to help communities and businesses create their own emergency and business continuity arrangements (London Resilience Partnership 2020b). It is developed every two-years in order to identify risks that could affect the city and is based on 'reasonable worst-case scenarios', informed by historical and scientific data. It is closely aligned to the UK National Risk Register.

Interface between Climate Change Adaption and Organisational Resilience

Systemic risk is often associated with changing patterns of climate. Over the years, London has been the subject of various experiments at multiple levels. For example, the Thames Estuary 2100 strategy for managing London's tidal flood risk offers a new route-map which aims to ensure that adaptation decisions are resilient to climate change (Reeder and Ranger 2011)**.** The project centres around 'adaptation pathways', which allow decision makers to time decisions and switch between different pathways in response to changes in evidence and understanding about sea-level rise and its impacts from the 2020s to the end of the century. Some critical challenges in the assessment process include large-scale investment, the lead-time required to improve infrastructure, the growth of climate hazards, and the increasing economic value of development on the floodplain. In particular, the residual uncertainties associated with probabilistic projections need to be mitigated. As Reeder and Ranger (2011, p. 3) put it:

> **"**incorporating flexibility [means] to build it into the adaptation strategy (rather than the individual measures) by sequencing the implementation of different measures over time, such that the system adapts to climate over time, but options are left open to deal with a range of possible different future climate scenarios,"

In other words, the methodology encourages the development of "what-if" outcomes, in which decisions are constantly adapted to differences in contextual patterns and redundancies are created. This is a classic form of adaptive management, as used for many years in ecological practice (Allen et al. 2011). The question is then how and why can scenario planning be used in a way that is complementary to emergency planning and resilience?

Since the 2000s, climate change adaptation and resilience have been practised together in London in order to mitigate vulnerabilities and interdependencies. The London Resilience Forum (the top level forum of the London Resilience Partnership) is a member of the London Climate Change Partnership (LCCP), which aims "to bring together and coordinate public, private and community sector organisations to prepare London for extreme weather today and climate change in the future" (London Climate Change Partnership 2020/a). Some recent areas of collaboration include the work of the LCCP with Public Health England in order to test new advice and messaging for managing heatwaves and protecting vulnerable communities against Covid-19. The work includes a case study about the application of heatwave guidance in learning-disabled communities (London Climate Change Partnership 2020). The long-lasting dialogue between proponents of resilience and climate change adaptation has allowed planners to recognize that some of the risks they confront will alter with changing climate. Similarly, climate change adaptation officers recognize that they can learn from resilience approaches when they must deal with interacting risks. One example of this collaboration is London's work on understanding interacting risks. This makes use of the 'Anytown' project that London Resilience Group developed in December 2012 with funding from the UK Government's Department of Environment, Food and Rural Affairs, UK Power Networks, Thames Water, and the London Climate Change Partnership. The project aimed to create a generic and replicable conceptual model to "raise awareness of the consequences of infrastructure disruption with all emergency response organizations in London" (Hogan, 2013). In other words, it seeks to provide a generic approach that could be easily applied in different urban areas without pretending to be fully comprehensive and facilitating communication among stakeholders (Hogan, 2013).

Anytown aims to ensure that each organization knows its own mode of interaction with the rest of the system. However, little evidence has been collected regarding connections across multiple sectors. In particular, the majority of the documentation available in the literature has been produced by academics in conjunction with infrastructure sector managers, which limits the ability of non-technical people, including end-users such as emergency managers, to understand the results. Moreover, there are difficulties in sharing data, including aspects such as limited capacity, differing mandates and lack of know-how for bridging the boundaries between sectors, which is precisely where coordination is needed. Part of this is due to the commercial sensitivity of information on this topic. The project developed a series of workshops designed to raise awareness and share information among members of the London Resilience Partnership. These produced evidence of the typical impacts of disruptions, particularly in cases where the impacts are largely independent of the initial trigger (Hogan 2013). Sectors covered during the workshops included electricity, communications, water distribution, transportation and food supply. In cases of particular need, the workshops were held to increase the understanding of complex crises, with particular emphasis on the local level. For example, the London Food, Adaptation, and Resilience teams worked together on building a better understanding of London's food resilience and how vulnerable populations could be protected from food shortages. Anytown was used as one of the tools to facilitate the assessment of the potential consequences of disruption to the UK's fresh food supply from Europe caused by a no-deal Brexit (London Resilience Group 2018, London Resilience Partnership 2020).

Following the prescriptions of the Sendai Framework for Disaster Risk Reduction (UNISDR 2015), in 2017-2018 the Anytown project benefited from integrative research carried out at University College London. During an Anytown workshop on transport failures, a study was developed of perceptions of cascading risk and interdependencies among the partners (Pescaroli 2018). The results showed that stakeholders were deeply concerned about cascading events and interdependencies, which are perceived as threats to health, assets and activities. However, in current policies, practices, and emergency management procedures, responses to these threats are not sufficiently developed. There was a strong belief that cascading events could become more common as a result of climate change and the accompanying pressure on society, its leaders and the built environment. Operational thresholds and uncertainties were identified as aspects that urgently required better definition and understanding. Dialogue and the availability of information needed to be increased in order to improve inter-agency coordination. The survey identified very low participation in training initiatives but a strong desire to improve the tools used to create resilience and ensure cooperation (Pescaroli 2018). In conclusion, it can be argued that despite the contribution of initiatives such as Anytown and the development of the London Resilience strategy, the reality on the ground is far from perfect.

In response to the need to understand and manage systemic risk, in 2020 the Greater London Authority launched a project entitled "Improved Decision-Making for Infrastructure Resilience". This was further supported by the newly inaugurated London City Resilience Strategy (GLA 2020). The project aims to exploit London's vast stores of data in order to help improve resilience. The Greater London Authority has already set up an infrastructure coordination hub that facilitates cooperation between infrastructure providers. It has also developed an infrastructure mapping application (IMA). The prototype was released in 2015 and the model has since been further developed (GLA 2017). The scope of the IMA focuses on London's need for improved coordination of infrastructure delivery in order to minimise disruption. It relies on the sharing of highly sensitive information at unprecedented levels, which has become possible thanks to the work of the GLA Infrastructure team in building trust among partners, backed by agreements that permit information sharing while continuing to assure confidentiality. Complementary to this, an there is an infrastructure coordination service to support better coordination of infrastructure planning and delivery. One benefit of this approach is improved ability of infrastructure operators to collaborate on roadworks to reduce disruption and costs (GLA 2021). A report by Arup and University College London released in October 2020 pointed out some of the existing gaps and recommended action in six domains, as follows (ARUP and UCL 2020):

- convene interdependency workshops to define data requirements for interdependency management, identify open security and confidentiality issues for data sharing, and promote practical lessons learned of success and failures;
- implement new functions into the Infrastructure Mapping Application used by the Greater London Authority;
- raise stakeholder awareness of the Infrastructure Mapping Application;
- seek to influence regulation;
- promote consideration of cross-sector benefits;
- widen the scope of stakeholder engagement.

To sum up, the study revealed that, although London has a significant level of resilience and maturity, there is still fragmentation across infrastructure sectors, between tactical and strategic decisions, and regarding information sharing (Arup and UCL 2020). Furthermore, the default assumption by infrastructure providers that "we plan to make things work, you plan for failure" suggests that organisations working on resilience internally may not communicate well with each other. They may have a false sense of security about their preparedness. However, rapid evolution of policies and practices gives opportunities for other applications to be tried out and synergies to occur through other technological developments. In 2021, the GLA used the infrastructure mapping application in conjunction with London's Sustainable Drainage (SuDS) mapping to identify locations where roadworks and priority SuDS locations overlap. A pilot project, that still ongoing at the time of writing, has identified an opportunity for a gas works project in the London Borough of Enfield that can be reinstated with SuDS through a collaborative effort between Cadent and Enfield. Such opportunities can deliver improved flood resilience as well as other benefits including better water quality and biodiversity, with reduced disruption and costs of excavation and traffic management (GLA 2021).

In the next section we develop a broader perspective on the lessons learned in London and in the conclusions, we offer a roadmap for managing systemic risk.

Discussion

In recent years significant progress has been made in understanding the systemic components of cascading, compound and interacting risk (Pescaroli and Alexander 2018). Our case study has demonstrated that practices can be improved by gradual steps, in which research and practice are integrated, resilience is promoted, and a wide range of strategies is offered (Pescaroli 2018, GLA 2020). Clearly, London represents a well-established reality more than a low-maturity case study, and as such it presents an excellent opportunity to visualise the way forward. The development of effective governance processes remains a critical point of connection across fields and is needed in order to contain failures that affect simultaneously the market, networks and institutions (Ahrens and Rudolph 2006). Systemic risk itself requires the development of an inclusive and integrative framework for capacity building and best practice on knowledge management. It should define both procedures and social values (Klinke and Renn 2010). Measured against a holistic approach, a purely top-down sectoral approach will not build a truly vigilant and resilient workforce or create appropriate organisations (Drachal 2017). Even in London, there are still policy gaps that act as barriers to political and operational challenges to the integration of systemic risk into practices of emergency management, organizational resilience and climate change adaptation. In other words, the lessons learned from the exercises and the practices adopted in our case study suggest that there is not just a technological problem of assessing and understanding interdependencies. Instead, the critical challenges may lie in how the existing resources are used and how capabilities are mobilised in order to build resilience. Despite the many improvements that we have noted in describing London's progress on mapping with tools such as the IMA, the challenge of sharing data is combined with the need to promote a culture of understanding about why this is needed and why resources should be invested across operational domains. This remains a critical factor and is often inhibited by silo thinking.

Systemic risk should go beyond how we are conceiving disaster risk reduction towards a new concept of operational continuity. To construct a baseline rationale, systemic risk must be considered in terms of its temporal characteristics. By definition, dynamics such as cascading effects are developed across different time scales and are non-linear (Perrow 1999, Helbing 2013, Pescaroli and Alexander 2016). Our case study shows that there are still unresolved issues about bridging short-term decision making (in emergency management, emergency planning and continuity management) and medium- to long-term climate change adaptation. For example, in terms of information sharing and synergies, the scenario exercises on cascading effects and interdependencies described in our case study reveal a divergence of approach between asset management, infrastructure planning and incident management.

Flexibility is underpinned by clarity of purpose, which requires clear goals, well-set priorities and a strategy to achieve them. Authors such as Booth et al. (2020) have identified policy implementation gaps in climate change adaptation and disaster risk reduction, including institutional barriers, diverging political priorities, miscommunication and incompatible timescales of operation. Despite efforts to create innovative methodologies such as adaptation pathways, London also suffers from these practical problems (Reader and Ranger 2011) and the Anytown model (Hogan 2013).

One of the core issues may be how risk itself is conceived and translated into development practice. The London Risk Register includes only risks that are likely to manifest themselves during a two-year timespan (GLA 2020). It uses a single-threat approach which may be not suited to preparedness against the cross-sectoral effects of cascading failure (UNISDR 2017). On the positive side, it is is based on ‘reasonable worst-case scenarios’ informed by historical and scientific data, modelling and professional expert judgement of both the likelihood and impact of a risk (London Resilience Partnership 2020b). In terms of resilience against systemic risk, there are many critical issues. This is evident in our examples in the previous section concerning the planning for a no-deal Brexit, the challenges in interoperability to power failures, and the recognised lack of broad-spectrum risk assessment in the supply chain.

The tendency to focus on threat-oriented scenarios tends to dominate policies. Instead, there should be a concentration on the need to understand cross-cutting cascading effects produced by multiple threats and hazards. In other words, the risk register tends to be viewed as a hazard-and-threat register. 'Worst cases’, likelihoods, and frequencies are based on historic or perceived data but are not treated holistically. Neither is the recurrence of extremes fully understood (Sornette 2009). Secondly, this approach limits the ability to understand, address and flexibly respond to disruptions and their underlying vulnerabilities, including the identification of points at which they could escalate into cascading dynamics (Pescaroli and Alexander 2016). In London this has been visible in the challenges for preparing for a no-deal Brexit (London Resilience Partnership 2020) or for wide-area power failures (Pescaroli et al. 2017; Aldea-Borruel et al 2019). Linkov et. al. (2014) argued that a static approach to risk tends to reduce the ability to adapt the system.

In the wake of Covid-19, some of the research on interdependencies confirms the lessons learned in London that were described in the previous sections. For example, Galbusera et al. (2021) surveyed critical infrastructure during the Covid-19 pandemic. Their study revealed shifting patterns of supply and demand. Despite widespread awareness of external critical dependencies, for example in electricity supply, information technology and the maintenance of public safety, the study identified a lack of understanding of 'hidden' dependencies such as the that related to satellite infrastructure, on which much else depends. Other strategic challenges emerged with respect to the concurrency of the pandemic and other natural hazards such as earthquakes, wildfires and hurricanes. Clark-Ginsberg et al. (2020) noted that any activities for promoting resilience among infrastructure stakeholders need to include both organisational and technological perspectives. As suggested by Linkov et al. (2019), in order to support adaptation, a process should be adopted that is hazard- or threat-agnostic. In our opinion, resilience to systemic risk needs to move in this direction. What is needed is an approach that focuses on understanding common vulnerabilities to multiple threats, or in other words the common points of failure that could endure different timescales (Pescaroli et al. 2018). For example, supply chain management of essential goods or assets could be an essential means of dealing with the risks associated with interdependencies (Burnard and Bhamra 2019). Based on London’s experience, this could help mitigate at least some of the problems that emerged in the exercises on cascading effects, in the management of Covid-19, in responding to contingencies such as a no-deal Brexit, and in linking climate change with organisational resilience.

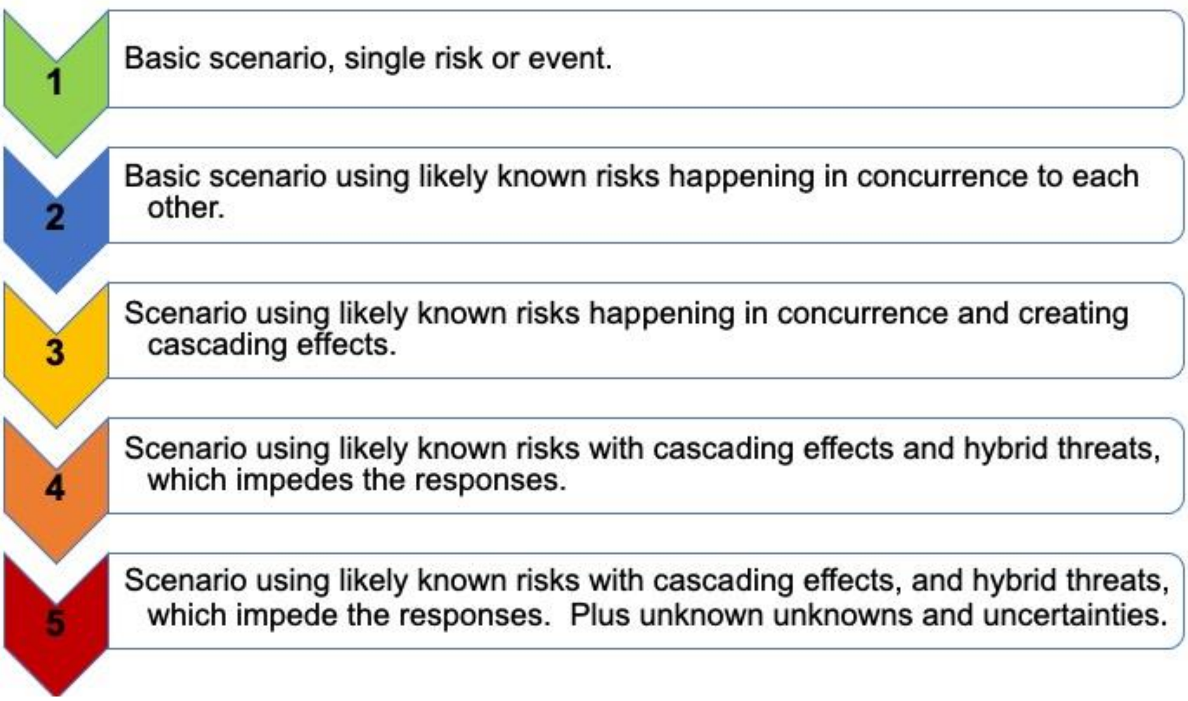
Scenario and stress testing should consider what sorts of impacts will occur and when facing the worst possible timing of an impact. An interesting and complementary approach is that used to increase the resiliency of the financial sector to systemic crises (Bank of England 2018). Despite many limitations, such as an excessive focus on cyber security, it looks at systems and processes on the basis of the essential services they support. Indeed, the document specifies that:-

> "It is particularly important to plan on the basis that operational disruptions will occur. This is because it is not possible to prevent every risk materialising, and dependencies are often only identified once something has gone wrong. The assumption that operational disruptions will arise could be used to inform strategy, planning and resourcing" (Bank of England 2018, p. 11).

This approach is then benchmarked against "impact tolerances" of the disruptions and calibrated by means of stress tests. To some extent, the documentation of the Bank of England develops what is known in continuity management as "business impact analysis" (BIA). The "technique represents the fundamental analysis of an organisation's resources and its vulnerability to loss or damage" (Elliot et al. 2010). BIA is the baseline process for understanding organisations in depth, and also embodies the operational implications of disruption. Clearly, one needs to ensure that the pace, direction and implications of threats to digital operations involve continuous, rather than punctuated, cycles of planning and testing.

A relatively direct way to implement stress testing and impact tolerances is by developing the five-step scenario process suggested by Pescaroli and Needham Bennett (2021, Figure 1). This could be used in synergy with the existing approaches of computational modelling and network analysis (Galbusera and Giannopolous 2019). First, scenarios are formulated using a more "traditional approach" in which a single threat or hazard is considered in isolation or with limited relationship to its context. In the following steps, there is a gradual but constant increase in complexity. A second step introduces concurrent events, such as flooding or heatwaves that happen during a pandemic. A third step includes cascading effects that reduce the capacity to maintain the continuity of services. Successively, communications increase in uncertainty. In the last stage, the priorities shift to invisible utilities and dependencies, such as those associated with third-party providers. This process should allow one to define the common points of failure and potential weaknesses that could be common to both known and unknown threats and hazards. The stress testing could then be used for cross-departmental training which brings together asset managers, adaptation specialists, continuity managers and emergency officers to consider bow to ally short term incident management with medium term infrastructure planning.

Figure 1. Steps for the development of complexity in stress testing (Adapted from Pescaroli and Needham-Bennett 2021)



In practical terms, it is necessary to move away from a static view of risk. A more flexible approach to scenario building and risk assessment plans assumes that some impacts or disruptions will happen independently of what caused them, and that they will occur in combinations. Planners should be 'hazard- or threat-agnostic'. In other words, they should approach resilience independently of the kind of primary event that disrupts the system (Clark-Ginsberg et al. 2020). As argued by Linkov et al. (2019) "the goal therefore is to be ready for whatever happens, even if it cannot be anticipated and has never happened before" (p. 3). This could be more suitable to situations of increased uncertainty because the identification of points of failure which are common to known threats could trigger vulnerability to unknown threats (Pescaroli and Alexander 2018). Considering the example of London reported in the previous section, there is a need for a significantly different way of approaching problems such as Covid-19, no-deal Brexit, or planning for cascading effects of weather extremes.

A new way to create a "societal impact analysis" could be to use methodologies such as adaptation pathways (Reader and Ranger 2011), and seek to integrate emergency response capacity and asset management into planning for societal resilience. The baseline could be a new approach to training, which focusses on benchmarking novel solutions and employs creative, lateral thinking. However, the way to develop this could be very complicated and could require some carefully targeted efforts. First, bridging short-term decision making and consideration of medium- or long-term risks are often functions of the kind of policy or regulation that discourages or prevents longer-term thinking. Secondly, resources for cross-sectoral working tend to be limited because their value is not recognized by funders, who would rather pay for highly visible new projects rather than the strengthening of core functions. It is always challenging to rebuild basic features. In conclusion, the whole process requires a combination of information sharing and reduction of political barriers.

Conclusion

It is time to develop new approaches to systemic risk in emergency management, organisational resilience and climate change adaptation. Disaster risk reduction needs to be able to tackle uncertainties and interdependencies. First of all, the roadmap of systemic risk management should become less conservative and more innovative. The possible disruptions that could arise in future years have multiple triggers and varied paths of development. In dealing with this, tools such as risk registers are not necessarily effective. The increased uncertainties associated with networked infrastructure and climate change suggest that it is necessary to create resilience by identifying and prioritising common points of failure in society. One could make creative use of scenarios for prioritising essential functions that assure the continuity and recovery of society, together with other tools such as adaptation pathways that merge short- and long-term approaches. At the end of the day, one might invoke a motto of Pythagoras: “Know thyself, and thou shalt know the Universe and God.”

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