

# Future Cities: Building infrastructure resilience



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With expertise earned over centuries, Lloyd's is the foundation of the insurance industry and the future of it. Led by expert underwriters and brokers who cover more than 200 territories, the Lloyd's market develops the essential, complex and critical insurance needed to underwrite human progress.

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# Executive summary

Global exposure to disasters has risen over recent decades (United Nations, 2015). This trend that is likely to continue because most global population increases will take place in Asian and sub-Saharan African cities, which are more at risk from natural hazards (United Nations, 2014b).

In addition, cities are also exposed to a greater diversity of risks than ever before, including rapidly emerging cyber threats and terrorism (Lloyd's, 2015b).

The rising costs of disasters is a growing concern for the public sector and the insurance industry alike; direct losses from disasters in the past decade are estimated at US \$1.4 trillion (United Nations Office for Disaster Risk Reduction, 2014).

The Lloyd's City Risk Index found that \$4.6 trillion of the projected GDP of 301 of the world's leading cities is at risk from 18 threats over the next decade.

Clearly, cities must mitigate these risks if they are to realise their growth aims but this is a complex task.

Cities are made up of a diverse and complex mix of institutions, ecosystems, assets and infrastructure that are connected and mutually interdependent. Disruption to one part of the system - utility and transport networks, communications systems and water supplies, for example – can cause failure in other parts, with far-reaching local and global implications.

This makes assessing city risk extremely challenging - secondary and cascading impacts cannot be predicted through traditional approaches such as spatial risk assessment. The task is made more difficult by the rapid growth and development of urban systems, particularly in emerging economies.

While risk management remains a priority for cities, it is not enough on its own. Increasingly, city officials, investors and insurers are looking to build resilience as a complementary approach to address urban risk and uncertainty (Cambridge Centre for Risk Studies, 2015).

In order to better manage risk and recover quickly from future disasters infrastructure owners and operators must move beyond asset-by-asset risk management to build resilience within, and between, infrastructure systems. This requires consideration of how infrastructure performance might change when shock or stress events occur.

## Report overview

Lloyd's worked with Arup to develop a new set of principles to guide the planning, design, construction and operation of some of the key components of city infrastructure to improve resilience.

The study analyses four different critical infrastructure systems - energy, water supply, Information Communications Technology (ICT) and transport - through three case studies. These demonstrate how infrastructure has been impacted by catastrophic events in the past, how stakeholders responded at the time, and indicates what actions they could take in the future to effectively address risk and enhance resilience.

The report presents:

- An introduction to infrastructure resilience and city resilience concepts.
- An overview and analysis of the key trends that affect city infrastructure risks and resilience.
- Discussion of the key city risk and resilience principles derived from analysis of real-world case studies and consultation with infrastructure sector specialists.
- Analysis of the potential implications and considerations for the insurance industry, including sector-specific insight.
- A series of recommendations and next steps that could help move action forwards within the insurance industry.

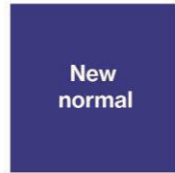
## Key findings

The report identifies three approaches or “pathways” that can improve infrastructure performance after a shock or stress event, as set out in Figure 1 (below):

Figure 1: Infrastructure resilience pathways

**Transforming performance**  
Working towards a new and improved state, rather than simply reverting to 'business as usual'. This requires reflection on successes and failures, learning, and growing. Recovery after infrastructure failure or collapse provides a crucial opportunity – although not the only avenue for such change.

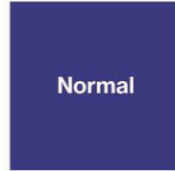
**Transforming performance**



↑ Enhanced interdependencies ↓



↑ Normal interdependencies ↓



**Preventing failure**

Ensuring infrastructure systems can withstand the direct and indirect impact of disasters. Though individual components might fail temporarily, the overall system continues to fulfil its normal functions, and also support any additional emergency demands that arise.

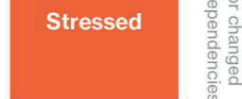


MANAGE RISK

**Preventing failure**

ADAPT AND RESUME

New or changed interdependencies



Interim interdependencies



**Expediting Recovery**



Failure of critical interdependencies



**Expediting recovery**  
Supporting infrastructure systems to become functional again as soon as possible after stress or collapse. This can save lives, prevent 'cascading failure' of other urban systems, and minimise potentially devastating social and economic outcomes.

EXPEDITE RECOVERY

EXPEDITE RECOVERY

EXPEDITE RECOVERY

EXPEDITE RECOVERY

REFLECT, LEARN, AND GROW

REFLECT, LEARN, AND GROW

- “Normal” state: business-as-usual operating conditions, where an infrastructure system is performing normally or as expected.
- “Stressed” state: changes in infrastructure system performance can occur due to pressure from a shock or stress.
- “Collapse” state: collapse occurs when an infrastructure system can no longer function to a level above minimum support.
- “Recovery” state: infrastructure systems require additional actions or support to restore their performance after a state of stress, or on a much larger scale after system collapse.
- “New normal” state: in the wake of a disaster or disruption it can be tempting to focus solely on efforts to restore a system to “business as usual”. As a result, opportunities to reflect on past mistakes and successes may be missed.

Under the headings of these pathways, the report sets out a number of principles that city officials, asset owners, operators and other stakeholders can apply to planning, design and operations to improve city infrastructure resilience.

These include:

### Preventing failure

- **Planning and design principles:** promoting integrated planning, valuing ecosystem services, prioritising emergency preparedness, designing for robustness, incorporating redundancy and increasing diversity of systems.
- **Operations principles:** investing in information management, maintaining assets, and expanding disaster risk management.

### Expediting recovery

- **Planning and design principles:** planning the emergency response, designing with recovery in mind, and allowing “fail soft” options.
- **Operations principles:** promoting inter-agency coordination, mapping critical resources, and creating independent recovery systems.

### Transforming performance

- **Overarching (planning, design and operation) principles:** building in flexibility, reflecting on the past, planning for the future, consulting widely, driving a culture of safety, developing incentives, and managing demand.

## Conclusions

While the benefits of reducing asset-scale risk are often clear, managing compounding risk and building system-level resilience can be more difficult to achieve, particularly in cases where there are multiple owners, where the benefits of greater resilience are indirect, and where benefits are distributed unevenly across, or outside, the system.

The public’s and policymakers’ understanding of risk is critical. Insurers must work with city officials, businesses and communities to help them better understand the economic and social consequences of poor risk management, and to encourage the development of appropriate solutions.

Implementing risk assessment and resilience can also be particularly challenging in developing countries where interventions may be less financially viable, or in places with moderate or low-frequency hazard profiles, where there can be greater complacency. Improving resilience at a city and international scale requires action at many

levels. The role of education and shared understanding is fundamental to facilitating action and incentivising change.

The provision of risk transfer through insurance and reinsurance gives insureds the confidence to undertake activities that carry risk, and allows them to recover when things go wrong. To achieve this, high quality data is important, especially as risks are constantly changing.

Brokers have an important role to play in this process. They can help insureds to better understand the risks they are facing, and ensure good quality information is passed on to the underwriters so they can write better insurance policies.

Building resilience for all stakeholders means finding new ways to break down silos within and between government, the private sector and communities. This would help promote the benefits of resilience and incentivise resilience-building activities.

With a common knowledge base as a foundation, it would be possible, collectively, to build a better understanding of tomorrow’s risks. This could facilitate better pricing for investors, more informed decisions by policymakers and ensure a smoother journey to a more resilient future.

Lloyd’s hopes this study stimulates this discussion and, where appropriate, prompts innovation among insurers, governments and city stakeholders to help improve resilience, mitigate risk and protect infrastructure.

## Principles for enhancing city infrastructure resilience: Implications for the insurance industry

The insurance industry can play a key role in supporting this report’s approach by working in partnership with other stakeholders to improve city infrastructure resilience. These partnership areas are:

### Data use and collection

The use of improved data collection, hazard mapping and other tools to manage and quantify increasing catastrophe risks in underwriting processes will allow more accurate risk based pricing. Additional data collection, tools and research are important to identify future trends and anticipate future risks, as well as to understand current risks better. The insurance sector is not alone in this.

By using new/better sources of data, insurers may be able to alert clients to potential losses before they occur,

assess damage in close to real-time, speed up claims processes and prevent false claims, reduce administration through automation, and create more personalised products and services (Gasc, 2016).

### The use of metrics

In many cases, the report suggests that indices be created to track the current level of resilience. If such indices were created then they could, in principle, be used in models and underwriting processes as well as by city planners and other stakeholders. Ensuring that any metrics, such as those involved in the Sendai Framework for Disaster Risk Reduction, are useful and useable by stakeholders will be the key to their uptake.

Ensuring that more detailed data is available at city-wide level is important considering there can be high levels of spatial variation of risk – even at asset level. If each building had standardised data files containing agreed exposure information, this could be used directly by insurers, banks, asset managers and facilities managers.

Insurers should work with governments to help them understand their risks, and develop policies aimed at improving construction standards or building in inappropriate areas (such as flood plains). Better risk management could lead to lower risk premium pricing, reducing the overall cost to economic growth.

### Models and tools development

Risk models are often created on a case-by-case basis in response to specific requests. The greatest need for this work is in developing countries and areas with low insurance penetration. Finding a way to take a strategic view to allow proactive development for countries – such as the Vulnerable Twenty Group (V20<sup>a</sup>) – so they can be taken off the shelf, ready to use, is an area currently being explored by the Insurance Development Forum.

Insurers need to work collaboratively with other stakeholders to provide tools that could offer a more transparent and comprehensive approach for analysing and pricing risk from extreme events. Ensuring these tools and their outputs are in an agreed format that can be used by other stakeholders will facilitate the flow of engineering and scientific knowledge throughout society.

### Using models to quantify risk quantification

As the number of models and the amount of data available increases, so does the potential for stakeholders other than insurers to use that information to make risk assessments and to anticipate the potential impacts of hazards. This would help governments,

communities and individuals to make informed decisions about resilience, insurance, investment, wider policies and interventions. Risk quantification is the key to this.

Without quantification it is difficult to assess resilience and how effective action might be taken to enhance it. Models can be used to help make transparent statements, such as:

*“This asset is currently resilient to 1 in 10 risk of flooding. To be resilient to a 1 in 200 risk the following is recommended...”*

This kind of explicit disclosure of risk could act as a way to encourage stakeholders to understand and maintain their own detailed risk registers, and to hold open dialogue on the risks under consideration.

### Designing resilient assets

Infrastructure lasts a long time and risk levels are changing all the time due to ongoing global megatrends, therefore it is important to create building codes that are robust in the light of both current and future risks. Engineering studies will be necessary to achieve this since past data will not always be a good guide to the future. If such studies could be encapsulated in an index, then insurers could more easily factor this information into underwriting decision

Common building codes that include resilience provide a level playing field for insurers and other stakeholders, and make homes and buildings less vulnerable to the effects of hazards with less need for public or private disaster relief.

### Incentivising investment

Resilience ratings could help investors integrate resilience considerations into all aspects of their portfolio-management activities. For example, if credit-rating agencies start to look at resilience as a measure of performance and factor this in to their assessments, this could provide an incentive to take action. Ensuring this information is in a useful and usable format will be the key to its use in city infrastructure risk assessment.

There is also a need to improve the risk/return profile of investment in green growth in this space, which can include adaptation (Climate Business Group, 2012). By focusing on reducing and managing the risk side of investment, this could facilitate the deployment of other forms of capital at the scale needed for growth.

<sup>a</sup> The Vulnerable Twenty (V20) Group of Ministers of Finance of the Climate Vulnerable Forum is a dedicated cooperation initiative of economies systemically vulnerable to climate change.



## Incentivising resilience

It is in the interest of policyholders and governments to implement risk-mitigation measures, thereby potentially reducing both the cost of insurance and the damage from natural catastrophes. One way for the insurance industry to incentivise policyholders to introduce risk-mitigation measures is through risk-based premiums.

Another method is for insurers to give policyholders the option to share a greater proportion of the risk through offering policies with higher deductibles. All things being equal, this reduces the costs of insurance but leaves the policyholder exposed to more risk. They may, therefore, be incentivised to take action to reduce their residual risks.

Consistent with the ClimateWise “Investing for Resilience” report, insurers could also offer “resilience services”, which could include aspects of facilities management, disaster recovery, “build and operate” contracts, and insurance. This could include upgrading the property covered by the service to improve its resilience, carrying out regular maintenance, recovery and repairs, and providing financial compensation in the event of a disaster.

## Next steps for stakeholders

Many of the resilience principles identified in this research are already actively promoted and implemented as best practice by planners, designers, and asset owners and operators across the world. Lloyd’s and Arup hope this study adds to knowledge of resilience issues, stimulates new ideas and raises new research questions.

There are numerous next steps that stakeholders could take to improve city and infrastructure resilience – the challenge remains in making change happen at scale. One starting point is the establishment of a demonstrator city to act as a testbed.

Emergency response and disaster relief agencies often hold live exercises to test their plans, which could provide a common starting point among stakeholders. Adopting a shared scenario process and risk models for a given city could help develop a broader systems model for all parties to coordinate and plan their responses. The results could be used to create a template that could be applied to all cities.

Continued innovation, reflection and collaboration across sectors and industries are critical to address any constraints on creating resilient, inclusive, prosperous cities. The framework in this report can guide all those stakeholders that are interested in ensuring tomorrow’s cities are built on resilient foundations.

## Methodology

This report was developed collaboratively by Lloyd’s and Arup.

Arup undertook a structured research process across four key stages: a comprehensive desktop review of existing literature; development of a new research model; case study research; and consultation with key infrastructure sector specialists to develop principles for enhancing infrastructure resilience through planning, design and operation.

Lloyd’s delivered a collaborative workshop involving city-sector experts and insurance practitioners to discuss the key findings in Arup’s research, and identify potential implications and considerations for the insurance industry. This resulted in a series of recommendations and next steps that could help the insurance industry contribute to making cities and infrastructure more resilient.

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# 1. Introduction

Over the past 50 years cities have witnessed dramatic and successful changes in the way infrastructure is delivered, with significant improvement to quality reliability, safety and continuity through technological advance, effective planning and learning.

Today's cities are growing at an unprecedented rate and will be the engines of growth in the 21<sup>st</sup> century; they are now home to the majority of the world's population, jobs, and GDP (United Nations, 2014b; UN-Habitat, 2012). By 2050, 66% of the world's population will live in urban areas, up from 54% today (United Nations, 2014b). Cities will attract talent and investment that will drive the next wave of economic and social development around the world.

Alongside this rapid change, cities also face an uncertain and increasingly complex array of risks. The 2015 Lloyd's City Risk Index presented an analysis of the potential economic impact of a range of threats to the world's major cities over a 10-year timeframe, revealing that US \$4.6trn of economic output is at risk. The study was designed to stimulate the conversation between business, governments and insurers on their collective responsibility to ensure appropriate steps are taken to promote awareness of risk, facilitate post-event recovery and build resilience.

As with other complex challenges, building in the ability to learn and adapt as quickly as possible is key to finding the right balance for addressing risk in each context. The infrastructure that underpins the world's cities performs an essential function in driving growth and wellbeing. The ability of city infrastructure to withstand and recover from shocks and stresses is tested by a diverse range of threats and revealed through increasingly complex exposures and vulnerabilities.

Urban environments are characterised by levels of uncertainty which can undermine even the most comprehensive efforts to address risk. Further uncertainty exists around demographic change, technological change and global resource markets. As a result, "worst case" parameters, performance thresholds, and user demand cannot always be reliably forecast in infrastructure design.

To explore these questions Lloyd's worked with Arup to develop a set of principles that can guide the design, construction and operation of some of the key components of city infrastructure in order to enhance resilience.

The study investigates four different critical infrastructure systems: energy, water supply, ICT and transport through three case studies. These demonstrate how infrastructure has been impacted by catastrophic events in the past and how stakeholders responded at the time – as well as indicate ways in which they could act in the future to effectively address risk and enhance resilience in the future.

## 2. Research approach

This report was developed through a structured research process, across four key stages:

### 1. Literature review

A comprehensive desktop review was undertaken to identify:

- How key threats (natural hazards and terrorism) manifest as risks to city infrastructure and may result in potential losses;
- Macro-level trends that may impact infrastructure risk and resilience outcomes, including climate change, demographic change, economic growth, technology change and urbanisation; and
- Existing global research and evidence relating to the evaluation of infrastructure resilience.

Based on key findings from this research, a high level model was developed as a basis to understand infrastructure system performance (see *Section 3.2 Figure 4, p17*) and resilience (see *Section 5.1, Figure 5, p42*). This model provided a framework for subsequent case study research and consultation.

### 2. Case-study research

Desktop research and a series of informant interviews were carried out to identify key events, infrastructure system performance, city resilience outcomes and lessons learned for three case studies:

- Hurricane Katrina
- The Bangkok floods
- The Mumbai terrorist attacks

Infrastructure system performance was evaluated based on the model developed in the previous stage of research. City resilience outcomes were assessed against the 12 goals and 52 indicators of the City Resilience Index (Da Silva and Moench, 2014).

### 3. Consultation with key infrastructure sector specialists

Arup delivered a workshop for senior infrastructure specialists from across transport, energy, water, ICT and integrated city planning sectors. The purpose of the workshop was to share initial research findings and identify established best practice and innovative approaches to enhance infrastructure resilience.

The sector specialists identified practical interventions to enhance infrastructure resilience through planning, design and operation through analysis of case studies and the infrastructure system performance model. Based on analysis of these findings, two sets of principles were identified to enhance infrastructure resilience:

- Cross-cutting principles (relevant to all infrastructure systems); and
- Sector-specific principles.

### 4. Insurance sector consultation

Lloyd's delivered a collaborative workshop involving city-sector experts and insurance practitioners to discuss key research findings and identify potential implications and considerations for the insurance industry.

This resulted in a series of recommended principles and next steps that could help move action forwards within the insurance industry.

### Research approach outcomes

Many of the resilience principles identified in this research are already actively promoted and implemented as “best practice” by planners, designers, and asset owners and operators across the world. Lloyd's and Arup hope this study adds to the knowledge base, stimulates new ideas and raises new research questions. Continued innovation, reflection and collaboration across sectors and industries are critical to address constraints in support of more resilient, inclusive, prosperous cities. This has resulted in a framework that Lloyd's hopes can guide all those stakeholders with an interest in ensuring that tomorrow's cities are built on resilient foundations.

## 3. Infrastructure risk and resilience

Cities around the world rely upon increasingly complex infrastructure systems that support the wellbeing and growth of cities, their communities and economies (Da Silva and Moench, 2014). Urban infrastructure plays a critical role in enabling communities and businesses to survive and flourish in the face of threats (Arup, 2014b). Yet, infrastructure systems are themselves subject to increasing levels of risk, driven by a range of critical trends that are shaping cities globally (see Section 3.1, Box 1, p14).

### Building a systems view

Traditional infrastructure risk management involves a “predict and prevent” approach to evaluate hazards and take appropriate action to mitigate asset risk. This approach is increasingly difficult in urban settings due to the diversity of hazards, size of assets, population and GDP at risk, human vulnerability, complexity of urban systems and future uncertainty.

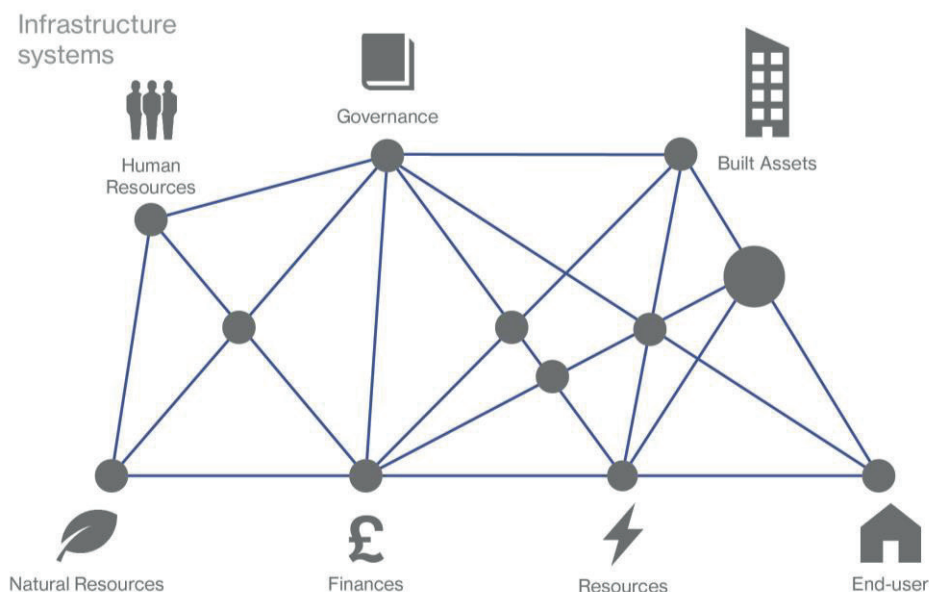
A “systems” view helps to better understand infrastructure-performance by looking beyond manmade assets to also consider natural resources, human

resources, finances, governance structures and behaviours (see Figure 2, below). Urban infrastructure systems can be understood across three main categories, according to the type of function they provide:

- **Protect:** Systems such as flood protection, landslide barriers and civil defences protect urban settlements from natural and manmade hazards.
- **Provide:** Systems that provide cities with resources to meet basic human needs, such as water supply, energy networks and public health infrastructure.
- **Connect:** Systems that support movement within and beyond city boundaries, including flows of people, goods and services (transport networks) and information (ICT).

These three functions are useful in understanding the role infrastructure plays in an urban system, and in identifying and enhancing the many interdependent factors that influence infrastructure performance and resilience.

Figure 2: Infrastructure systems



## 3.1 Infrastructure resilience

Resilience is defined as the ability of any system to cope, adapt and improve in response to chronic stresses and acute shocks they experience (Rockefeller Foundation, 2015). Infrastructure resilience embraces three key concepts:

- **Withstand and endure:** The capacity of infrastructure systems to continue to perform and provide their intended functions in the face of shocks and stresses.  
  
E.g. An 8.2 magnitude earthquake in Concepcion, Chile in 2010 was the sixth largest in recorded history, but fatalities remained under 1,000 – largely due to the rigorous implementation of building codes. A lesser magnitude earthquake in Haiti the same year caused around 220,000 fatalities – largely resulting from collapsed buildings (Petz and Ferris, 2011; Guha-sapir, Hoyois and Below, 2011).
- **Learn and adapt:** The ongoing process of evaluating and adapting performance (systems, processes and assets) to better cope with shocks and stresses. This can also be described as ‘adaptive capacity’.  
  
E.g. The city of Ho Chi Minh in Vietnam sits low in the Mekong River delta, and boasts a vast series of flood-defence measures including a major dam. However, rapid urbanisation and climate change have exposed the city to new flood vulnerability. Over recent years the city has retrofitted and adapted existing defences, incorporated ecosystem management and undertaken water supply interventions to improve existing water management; rather than build additional dykes (Arup, 2012).
- **Achieve transformational change:** Infrastructure functions evolve at system level to meet rapidly changing urban needs and better support city-scale resilience.  
  
E.g. The City of London has adopted a comprehensive transport mode shift strategy to address congestion and manage exponential growth in network demand. A shift towards public and passive transport modes prevented almost two million additional car trips per day during 2012 alone. Cycling is now the fastest growing transport mode in London (Future of London, 2014).

Arup’s City Resilience Index research also suggests that resilient systems also demonstrate certain qualities – inclusiveness, integration, reflectiveness, resourcefulness, robustness, redundancy and flexibility (Arup, 2014a). These qualities can be helpful to inform the design of infrastructure and other systems.

Insurance can make a significant contribution to resilience in cities, through incentivising robust risk management and providing financial and material support following loss events. In order to achieve these aims, insurers require qualitative and quantitative measures of risk, together with detailed analysis of potential concentrations of risk from extreme events.

## Box 1 – Global trends shaping infrastructure risk

### Transport infrastructure

Urbanisation is driving increased demand for city transport infrastructure (WEC, 2011), while the rise of private passenger transport and growth in global freight is contributing to congestion and pollution. Whilst many transportation modes are becoming increasingly energy-efficient, the sector is still dependent on oil for 96% of overall energy needs (European Commission, 2011). This presents an increasing challenge due to oil price volatility – some estimates suggest prices may double between 2005 and 2050. Current and future political instability in key oil-extracting regions such as the Middle East and Africa contributes to an already volatile market (Mitchell, Mitchell and Marcel, 2012). Other reports suggest that rapid technology change and COP21 commitments may leave up to US \$2.2trn of fossil fuel and mining assets stranded (Carbon Tracker, 2015).

Climate change is driving more extreme weather events (IPCC, 2014) that pose a threat of damage and interruption to transport infrastructure. Increased terrorism (The Institute for Economics and Peace, 2015) also poses a direct threat to infrastructure. Existing challenges are perpetuated by a combination of poorly designed, ageing and insufficiently financed infrastructure. Subsequent sections of this report explore the impact of social inequality on transport planning and delivery during the 2011 Bangkok floods (*see Section 4.2, p27*).

Urban policies that support diversification of transport options, mode-shift away from oil-reliant transportation (supported by increasing use of electricity and biofuel (US Department of Energy, 2013)) and drive an increase in active transportation (including walking and cycling infrastructure) can reduce congestion and provide significant co-benefits for human health and wellbeing (Oja et al., 2011; Panter, Heinen, Mackett and Ogilvie, 2016).

### Energy infrastructure

Population growth, globalisation and increased consumption place increasing demand on urban energy systems (Madlener and Sunak, 2011). The global energy sector will experience major transformation over the coming decades. The International Energy Agency projects a 30% rise in global energy demand to 2040, requiring a US \$44trn investment in global energy supply, and an additional US \$23trn invested in improvements to energy efficiency (International Energy Agency, 2016).

An increase in extreme shock events will play a significant role in the consistency and security of future energy delivery. Climate change will drive an increase in the intensity and unpredictability of climatic hazards (IPCC, 2014); events such as Hurricane Katrina demonstrate the potential impact on urban energy continuity. The rise of “smart technology” for energy distribution must accommodate increased risk of malicious intent and cyber-terrorism (US Department of Energy, 2013).

Global, regional and local economic shocks and stresses will continue to impact both energy demand and deficits in energy infrastructure investment (Ernst & Young, 2011).

### Water infrastructure

Temperature extremes driven by climate change will have an increasing impact on global water security. In many rapidly growing countries urbanisation is also placing increasing pressure on water resources, while unsustainable development pathways and governance failures affect the quality and availability of water resources (WWAP, 2012). Poor water-resource management can contribute to environmental impacts such as alteration of natural watercourses and permeability (WWAP, 2012). Affordability of basic resources has a direct impact on social wellbeing, and can lead to a loss of cohesion and community breakdown (Arup, 2014a).

Climate-driven shock events, social unrest and new types of infrastructure-focused terrorism will have an increasing impact on local water-system continuity (Field et al., 2014). For example, in February 2016 demonstrators protesting caste discrimination in Delhi forcibly closed inlet gates to one of the city’s main canals, causing seven treatment stations to shut down and triggering a water crisis across the city (Agence France-Presse, 2016).

Increased pressure on infrastructure that outpaces the capacity to maintain, update and improve ageing infrastructure will exacerbate risk unless national and local governments support sufficient infrastructure investment.

### Communications infrastructure

Smart technology is providing more sustainable and cost-efficient solutions to address some challenges of urbanisation, ranging from digital transport payment and operation to online healthcare services. City infrastructure increasingly relies on ICT for operation, while critical economic and financial services depend upon online technology. Service providers face the challenge of ensuring infrastructure keeps up with ever-increasing demand.

Shock events – both natural and malicious – are having an increasing impact on the performance of smart technology and online services. Customers now expect 24/7 reliable performance in ICT networks, and service providers are building extreme weather resilience into their operating systems to meet this (Business for Social Responsibility, 2010).

Cyber-terrorism is a continually evolving issue that law enforcement agencies are struggling to keep pace with. Attacks on ICT infrastructure can have significant impacts on global and local economies. In 2013, 81% of large corporations and 60% of small businesses in the UK reported a cyber-breach (The UK Cabinet Office, 2015).

Communications systems (including social media) can help enhance community empowerment, global education, and contribute to disaster preparedness, response and recovery (Arup, 2014b). However, such benefits are not available to all and in many countries (such as South Africa) fixed broadband access is unaffordable for the majority of the population (Research ICT Africa, 2012).

**Box 2 – Global trends shaping infrastructure risk**

*“City resilience describes the capacity of cities to function, so that the people living and working in cities – particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter.”*

(Rockefeller Foundation, 2015)

Arup, with support from the Rockefeller Foundation, undertook an extensive three-year research programme to establish an accessible, evidence-based definition of urban resilience – culminating in the publication of the City Resilience Framework (CRF) in 2014 and launch of the City Resilience Index (CRI) online platform in May 2016.

The CRF is made up of four dimensions – leadership and strategy, health and wellbeing, economy and society, and infrastructure and environment. These provide an organising framework for indicators and variables which provide a basis for measuring city resilience.

The CRF has informed analysis of city resilience outcomes throughout this report. In particular, the infrastructure & environment section of the CRF can support thinking about how infrastructure performance can support the resilience of a city as a whole.

Figure 3: The City Resilience Framework – Infrastructure & environment dimension



## 3.2 Infrastructure system performance

Before deciding whether or not to provide insurance cover an insurer will consider the circumstances surrounding a risk, such as the likelihood of occurrence, the steps already taken to reduce the risk, and the financial consequences. Understanding infrastructure performance – and how this performance might change during shock or stress events – can be approached in a similar way. Considering how the many components of an infrastructure system might respond under different conditions can help inform action to enhance resilience within and between systems.

### Infrastructure system performance can change under different conditions

Shocks and stresses such as natural disasters and terrorism can place additional strain on infrastructure systems due to direct damage, can change the role which an infrastructure system plays within a city, or can trigger demand for new and additional resources to maintain or restore functionality.

### Infrastructure systems do not exist in isolation

Any given infrastructure system can support a variety of urban systems and functions. For example: energy networks provide power to operate water pumping stations, sewerage treatment plants and hospitals. Similarly, any given system will be dependent upon other systems: energy systems depend upon public and private transport infrastructure for fuel supply and access and repair of critical assets.

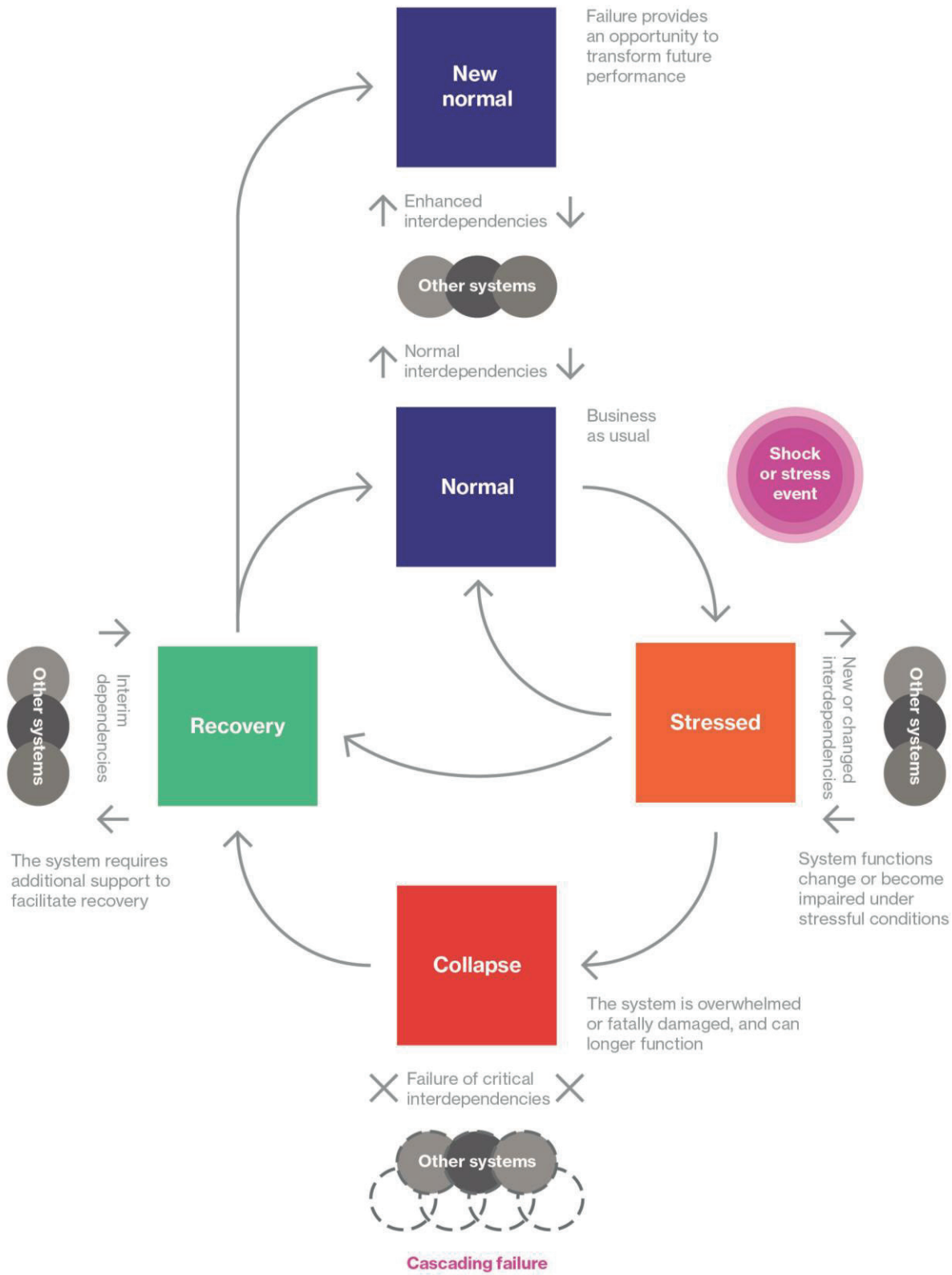
These interactions are commonly referred to as interdependencies. Understanding infrastructure system interdependencies can demonstrate how changes in performance under shock or stress events can have far-reaching impacts beyond a single infrastructure system.

The diagram overleaf describes a framework to understand how infrastructure system performance can change when impacted by shock or stress events. Changes in performance are described by five different “states” which have different characteristics:

- **“Normal” state**  
Business-as-usual operating conditions, where an infrastructure system is performing normally, or as expected.
- **“Stressed” state**  
Changes in infrastructure system performance can occur due to pressure from a shock or stress.  
  
Performance might be impaired due to direct impact (for example, disruption of rail services due to structural damage of tracks), or indirect impact (for example, mass evacuation might mean staff are unavailable for operations).  
  
Performance might change to meet new urban demands – for example, an energy system might prioritise supply to vital infrastructure and community services such as hospitals. Likewise, the system might depend on additional support – such as back-up generators and emergency plans.
- **“Collapse” state**  
Collapse occurs when an infrastructure system can no longer provide the key function(s) for which it is intended.  
  
Collapse of any one infrastructure system can have far-reaching impacts for other urban systems. For example, collapse of an entire urban energy system might cause major disruption to local industry, freight and international supply chains. These chains of impact are often referred to as “cascading failure”.
- **“Recovery” state**  
Infrastructure systems require additional actions or support to restore their performance after a state of stress, or on a much larger scale after system collapse.  
  
During recovery infrastructure systems often have additional or new dependencies – for example, reliance on skilled labourers, equipment, supplies and funding for reconstruction.
- **“New normal” state**  
In the wake of a disaster or disruption it can be tempting to focus solely on efforts to restore a system to “business as usual”. As a result, opportunities to reflect on past mistakes and successes may be missed.  
  
Achieving a “new normal” means reflecting, learning and doing things differently – in short, transforming into a new and more resilient state.



Figure 4: Infrastructure system performance



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## 4. Case studies

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Infrastructure can play an important role in protecting cities and supporting their continued function and recovery when disasters occur. Case studies in this section explore infrastructure performance and city resilience outcomes during three natural disaster and terrorism events in order to identify lessons for infrastructure planning, design and operation.

While individual learning points are identified, the lessons are often cumulative and have driven wider innovation that serves as a reminder that the insurance industry must constantly evolve and innovate as new challenges emerge.

Lloyd's and Arup hope that stakeholders and partners can use such lessons as they prepare to prevent failure, expedite recovery, and transform performance to increase resilience of the whole system.

It is also hoped they can recognise that change has happened reactively over time, and that there is potential to use the framework presented in this study to guide future action to be proactive rather than responsive.



## 4.1 Hurricane Katrina, 2005

### New Orleans, US

#### Energy infrastructure

Hurricane Katrina's final landfall hit the southeast coast of Louisiana and southern Mississippi on 29 August, 2005 as a Category 3 hurricane with sustained winds of 140 mph. The city of New Orleans was devastated by Katrina. Storm surge and battering wave action smashed the levees of the city, causing extensive flooding. Around 80% of New Orleans and surrounding parishes were inundated, and remained flooded for weeks after the storm had passed (The Associated Press, 2015).

One of the deadliest and most destructive hurricanes ever to hit the US, Katrina caused between 1,000 and 1,500 fatalities. An estimated US \$108bn of property damage and widespread infrastructure damage occurred, including extensive loss of power across New Orleans, wider Louisiana, and neighbouring states (Blake et al., 2007).

Just 26 days after Katrina's landfall, Hurricane Rita struck the coast of New Orleans, slowing recovery and placing additional pressure on already-depleted regional recovery resources (Electric Light & Power, 2006).

#### Energy infrastructure event timeline

29 August 2005 >>	30 August 2005 >>	1 September 2005 >>	10 September 2005 >>	15 September 2005 >>
Katrina affected an area of 37,000 square miles, around one third of the territory of energy distributor Entergy. Hurricane winds devastated transmission and distribution systems; approximately 3,000 miles of transmission system failed, amounting to around one fifth of the 15,000-mile system. More than 28,000 miles of distribution lines were impacted, in addition to 263 substations and 1,550 feeders.	Entergy put a recovery plan into action. Pre-positioned damage assessors identified areas where flood or debris blocked access to damaged infrastructure, and evaluated the optimal crew size, time and resources required. Crews then began restoring power to essential services such as hospitals, law, fire, sewer and water utilities. An "outside-in" strategy was adopted; restoring power on the perimeters of the impact zone, then working into more severely impacted areas.	Entergy had restored power to a number of critical facilities in the New Orleans area – including East and West Jefferson Parish hospitals, the Louis Armstrong Airport, Gretna's water facilities, the Emergency Operations Center, Jefferson Parish Sewage Plant and Gretna police and fire departments.	By restoration day 12 crews had restored electricity to nearly 750,000 customers in Louisiana and Mississippi. More than 340,000 Louisiana customers remained without power, mainly concentrated in the New Orleans metropolitan area and Chalmette, Hammond, Bogalusa and Amite.	Service had been restored to 861,000 of Entergy's 1.1mn affected customers. Service was also restored to six of the eight oil refineries between Baton Rouge and New Orleans, and to the remaining two soon after. Twenty of 25 of the large industry customers impacted returned to service by mid-September, and had resumed operations in some capacity. Transmission substations that were accessible and not flooded were put back in service, and restoration of the remainder of the distribution service was on schedule.

#### 4.1.1 Energy infrastructure performance

New Orleans' energy distribution system experienced near-instant collapse, largely due to the devastating physical damage to transmission lines, distribution lines and substations caused by high winds and the collapse of protective flood levees. Loss of electricity across much of the city caused cascading impacts to a range of already severely-damaged urban systems including health services, transportation and law enforcement.

While repair and recovery crews responded quickly due to good logistical planning and distribution of resources prior to the event, human resources, vehicles and materials were severely strained – particularly once damage was compounded by Hurricane Rita (Electric Light & Power, 2006). Entergy's financial reserves were also overwhelmed, resulting in the organisation's near-immediate bankruptcy (Henderson, 2009).



24 September 2005 >>	October – November 2005 >>	Longer term >>
Twenty six days after Katrina, Hurricane Rita hit southeast Texas and southwest Louisiana. Some 800,000 new power outages occurred, and restoration crews set about replacing almost 29,000 distribution poles, and returning 522 transmission lines and 715 substations (which had been affected by both storms) back into service. Rita was the second-worst storm in Entergy's history. The exhausted recovery workforce mobilised to address Rita's damage, while restoration management teams had to face overwhelming logistical challenges, including material shortages brought about by the post-Katrina restoration.	Forty two days after Katrina, power was restored to customers in Mississippi, Louisiana and the New Orleans area at the rate of nearly 26,000 customers each day. Distribution lines serving large blocks and neighbourhoods of customers were restored next. Individual services servicing fewer people were given lowest priority. Crews then moved to the more difficult phase of restoring service to severely damaged areas, especially around New Orleans and south of the city. Crews rerouted circuits around flooded substations. Ongoing flooding in south Louisiana sometimes required trucks and other equipment to be barged in. Even when trucks finally began rolling through this devastated area, they had to carry extensive stocks of vehicle maintenance and repair items due to hazardous road conditions. Restoration trucks frequently continued rolling with a dozen or more plugs in their tires; punctured by storm debris. Crews who entered flooded areas in south Louisiana were equipped by local morgues in anticipation of encountering human casualties.	Entergy New Orleans Inc. filed for bankruptcy shortly after Katrina. The company returned to business two years later in 2007, following federal aid and insurance payments.

## 4.1.2 City resilience outcomes

### Infrastructure and ecosystems

In addition to high winds, much of the destruction to energy networks and other city infrastructure occurred due to the structural failure and collapse of protective levees that surrounded the city. A series of investigations since 2005 have cited inadequate design and construction as the primary cause of levee failure (Sills, Vroman, Wahl and Schwanz, 2008).

In addition to rebuilding and enhancing manmade defences (US Army Corps of Engineers, 2017), the events have led city and regional actors to look more closely at the potential role of coastal ecosystems in providing storm protection and opportunities to undertake coastal wetland restoration (Tibbetts, 2006). Power outages caused disruption to many forms of urban mobility including ports, railroads, traffic lights and air-traffic control were disrupted by power outages (Grenzbeck and Lukmann, 2008). A lack of street lighting made it even more difficult for residents to navigate flood waters. Disruption to ICT networks across the city hampered search and rescue, and contributed to social panic as residents became desperate to make contact with friends and family.

It was suggested that some infrastructure might have been protected from hurricane impacts through actions such as burying electricity transmission and distribution lines (Henderson, 2009). A local study suggested this would have cost 10 times that of overhead cables, a price that would have been passed on to local customers (Entergy, 2008).

Since 2015, Entergy New Orleans customers have been paying a storm-reserve charge on their monthly electricity bills. The scheme looks to enhance continuity of future maintenance and repair by providing an immediately accessible pool of money for continuing operations and paying vendors (Larino, 2015a). The reserve fund reached US \$75mn by selling low interest, securitised bonds, which customers pay back over 10 years through the reserve charge (Larino, 2015b; Entergy, 2015).

Certain infrastructure remained operational after the hurricane. New Orleans' sewerage system has an independent energy supply which allowed the city to be pumped of floodwater (Arup, 2014b). Since Katrina, a trend towards decentralised energy networks has been observed across hurricane-prone US cities. This includes green reconstruction strategies that draw on renewable sources such as solar energy to increase storage diversity, capacity and redundancy (Arup, 2014b).

### Health and wellbeing

Due to extensive power outages, many citizens of New Orleans struggled to meet their basic needs. The city was plunged into darkness, adding to the chaos of extensive flooding. Food could not be stored or cooked in large quantities, and residents were deprived of air conditioning during peak summer temperatures. The black outs added to the misery of those already struggling to cope with casualties and loss (Henderson, 2009).

Power disruption also led to severe health outcomes. Direct hurricane casualties placed a huge strain on the emergency medical care systems, and this was exacerbated by further casualties arising from the loss of electrical power. Lack of air conditioning particularly affected the elderly, those with respiratory illnesses, and those who relied upon cold-storage medication due to the loss of refrigeration and failure of electronically controlled safe storage (Arup, 2014b).

A range of impacts to local livelihoods were also evident. Power disruption to business and industry caused ongoing disruption to income, across a community which was already severely affected by widespread loss of homes and possessions.

### Economy and society

Loss of power had a knock-on impact to security and the rule of law within New Orleans in the aftermath of Katrina. Police radios could not be recharged, meaning direct "on the ground" conversation was the only means of communication. This aggravated an already low morale, and 18% of police officers abandoned their posts (Sims, 2007). A lack of lighting also contributed to predatory crime and disruption (Arup, 2014b).

Nevertheless, positive examples of resilience were also seen across the city as energy systems failed. Community cohesion triumphed in some areas – buildings with uninterrupted power or emergency back-up supplies became community hubs and meeting places, where citizens exchanged news and provided material and non-material support (Arup, 2014b).

Economic impacts at city, regional and national scale were significant. The loss of power disrupted crude oil and natural gas operations in the Gulf of Mexico, including the shutdown of 11 petroleum refineries. Power outages also caused interruption to water and rail based freight logistics, and resulted in the bankruptcy of Entergy New Orleans Inc (Henderson, 2009).

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## Leadership and strategy

City Hall and other key buildings benefited from back-up power generators that allowed some degree of leadership functionality (Arup, 2014b). Some businesses and households also had generators, demonstrating some local community awareness and preparedness.

Strong coordination of infrastructure repairs between different sectors during recovery, such as coordinated repair of underground water pipelines and road infrastructure, facilitated more effective response times and use of resources.

Katrina exposed a number of conflicts between infrastructure and environmental planning in the city, highlighting the need for more integrated development planning. For example, insufficient distance between major oak trees and overhead energy transmission cables resulted in extensive windfall damage.

Energy system emergency plans were tightened as a result of Katrina, including better use of resources from private sector and neighbouring regions. More strongly implemented emergency infrastructure plans were evident when Hurricane Gustav hit the region three years after Katrina and energy system interruption was reduced (Arup, 2014b).

## 4.1.3 Insurance outcomes

### Risk management

Three years before Hurricane Katrina, *The Times-Picayune* published a five-part series “Washing away” that highlighted the chance of a hurricane hitting New Orleans (McQuaid and Schleifstein, 2005; Lafrance, 2015). One of the segments involved scenario analysis from 2001 that predicted a potential future where the 1998 Hurricane George hadn’t shifted track and made a direct hit on New Orleans (McQuaid and Schleifstein, 2005). Scientists based at Louisiana State University (LSU) had designed a computer model that described the impacts of the event – the “New Orleans Scenario” – with results suggesting that a hurricane greater than category 3 was possible (Louisiana State University, 2000).

*“A slow-moving Category 3 hurricane or larger will flood the city. There will be between 17 and 20 feet of standing water, and New Orleans as we now know it will no longer exist.”*

(Ivor van Heerden, October 29, 2004)

The scientific experts further extrapolated that at that strength, levees would not be able to stand against the surge component, but their advice was not heeded. The levees were expected to withstand a Category 3 hurricane. Katrina was a weak Category 4 and some areas experienced conditions of a Category 1 or 2 storm, suggesting that the levee walls were under-engineered and this led to structural failure (NOVA, 2005).

### Claims

Loss adjusters were limited by the number of claim sites they were able to access due to the damage of the infrastructure (electricity, phone services, and physical damage) and the wide scale nature of the flooding, which made physical access impossible. In addition, displacement of business and homeowners further slowed down the claims process (Cooper, 2006). As a result, several class-action lawsuits were filed against insurance companies for failing to meet state-mandated deadlines for adjusting claims (Cooper, 2006).

Lack of access not only affected the claims process, but also increased the damage caused. While floodwater remained, damage from water saturation, mould, and exposure could not be repaired and so worsened (Gunturi, 2015). Insurers’ claims departments have since

responded by increasing their visible presence, with commercial policyholders seeking closer relationships with them. This partnership assists with the catastrophe loss-management discussion pre-loss, along with establishing clarity on the protocols and procedures to fund claims. As a result, there has been improvement in understanding how claims are dealt with, and a recommendation to make partial payments following losses to deliver quicker responses (Marsh, 2015).

### Underwriting

The wide-scale damage triggered by wind and storm-surge flooding led to coverage leakage where insurers were required to pay out because it could not be determined whether the proximate cause of the loss was wind or flood. This resulted in underwriters tightening policy wordings around the flood peril, with some explicitly deciding to exclude all flood or storm surge – especially for business interruption and contingent business interruption (Guy Carpenter, 2014). Further clarification occurred around the use of named-storm or windstorms with storm-surge clauses becoming more common, and more clarity on coverage limits and how deductibles were applied (Marsh, 2015).

Insurers have since asked for enhanced exposure data to establish a more complete view of potential impacts, as readily available information is often high level and of poor quality (Lambert, Milroy and Clark, 2009). Insurers request information such as the exact geographical coordinates, the number of floors and the type of construction, to capture risks at a more granular level.

### Modelling

Hurricane Katrina was a reminder of the importance of exposure management and that catastrophe models are only as good as the assumptions behind them (Lloyd’s, 2005). Questions were raised on the quality of data, how models were used, and how the outputs were used to make assumptions.

Models prior to Katrina did not give much attention to storm-surge risk as it was not perceived to be a major driver of overall hurricane losses (Willis, 2015), yet secondary effects were the biggest loss drivers, with a significant proportion coming from flood rather than wind damage (Gunturi, 2015). This also highlighted the need to record information on structures and their vulnerabilities in greater granularity. One example of this was the number of casinos built on barges along the Mississippi coast. Some casino barges were destroyed or heavily damaged at their docks (Stutz, 2015). Without specific information that these casinos were barges – a typical assumption at the time would be to consider

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casinos well built, concrete structures – the losses were in some ways unexpected. Today, there is much better recognition of the wide array of buildings that companies are insuring. The view of the vulnerability of assets has increased as a result of greater granularity of information.

Catastrophe models are not designed to give precise predictions of loss from a given event since event footprints are only ever approximations to the true intricacies of a real event. Nevertheless, important lessons were learnt from Katrina (Marsh, 2015). One example of this was the integration of a forward-looking view of risk within catastrophe models that took account of non-stationary features like multi-decadal oscillations and climate change trends in sea-surface temperatures. Incorporating such features – which had been highlighted in the academic literature for some time – was a step forwards. There was recognition across some industry stakeholders that improvements in scientific knowledge should be integrated within models on an ongoing basis, to reflect current understanding and catastrophe modelling firms amended their processes accordingly.

As a result of Katrina, catastrophe modelling has been widely integrated across different parts of the insurance industry, to support greater risk management and awareness of potential losses (Marsh, 2015). In the context of reinsurance purchasing, catastrophe exposures were generally modelled using aggregate portfolios but post-Katrina, they are modelled on a per-risk basis (Marsh, 2015).

### Stakeholders

Pre-Katrina, insurers and reinsurers were examined by credit rating agencies on the use of modelling for capital management strategies. Following Katrina, failure to demonstrate strong capital management for catastrophe risks meant (re)insurers faced downgrades of their credit and financial strength ratings (Marsh, 2015). As a result of Katrina, focus has changed from the traditional reinsurance capital base to make way for alternative capital, capital markets convergence and greater use of insurance-linked securities and catastrophe bonds (Marsh, 2015).



## 4.1.4 Lessons learned

The review of infrastructure system performance during the events of Hurricane Katrina – and its aftermath – highlights important lessons for future planning, design, operation, maintenance and the insurance of infrastructure.

### Lessons for planning, design and operation

- Effective business cases will weigh the cost-benefit dilemma between infrastructure robustness and day-to-day affordability of energy. In some cases, passing on additional costs to the urban poor can perpetuate their vulnerability by reducing energy access. In other cases, transparency and awareness-raising around pricing may help to ease the impact. Risk-management professionals have an advice and guidance role to play regarding demonstrating the value of action, as mitigating the risks may mean that insurance becomes available where it previously wasn't, or that pricing may be modified based on a lower loss risk to exposure.
- Redundancy and diversity are important qualities of city energy system design. This includes independent energy supplies for critical city infrastructure, city-wide back-up supplies and wider energy system decentralisation. Actions which increase storage capacity and spread risk can decrease the potential for city-wide energy system collapse.
- In addition to effective design and testing of protective infrastructure (such as flood levees) (US Army Corps of Engineers, 2017), natural ecosystems (such as coastal wetlands) (Coastal Protection and Restoration Authority, 2016) can play a role in protecting cities from natural hazards.
- Effective planning and coordination between disaster response and recovery agencies can enhance their capability, capacity and connectivity across regions and between sectors. Coordination is key to improve the speed and effectiveness of recovery, can provide access to additional response and recovery resources, and allows risk to be spread in a more manageable way across many systems and stakeholders. Disaster planning by the government and private industry has changed since Katrina. For example, the National Response Framework now defines how all federal agencies will respond to emergencies (US Department of Homeland Security, 2013). Nearly two-thirds of businesses checked and restructured their disaster recovery plans after Katrina according to FEMA (Marsh, 2015).

### Lessons for insurance

- Asset-specific insurance represents one strategy to address cost-benefit dilemmas around infrastructure safety and robustness. Access to sites and loss information is central to processing claims and releasing money, and is an area that requires greater consideration for the benefit of all parties. Contingency funds, such as those provided through insurance, can help to ensure repairs are implemented more efficiently and reduce disruption to customers. Lack of site access hampered stakeholder response and increase damages as a result of prolonged exposure. The scale of flooding and sustained inundation provided barriers to all.
- Katrina led to a focus on data quality that has since become a driver of risk modelling, with insurers asking for enhanced data to provide support a greater view of risks. This was highlighted by poor granularity of assets and their vulnerabilities.
- The way in which extreme events were modelled themselves led to innovation in how the industry evaluated potential impacts, and how potential loss scenarios are considered. This was supported by changes in technology and analytics, and now most risks are run through models (Marsh, 2015).
- In addition, the need to listen to scientific experts and integrate changes in the understanding of hazards was raised. Ensuring multiple views of risk from different stakeholders can help broaden understanding and present different scenarios for consideration.



## 4.2 Bangkok Floods, 2011

### Thailand

#### Transport infrastructure

During mid-2011 severe monsoon season flooding swept across Thailand, with devastating impacts to the northern, north-eastern and central regions of the country. By October the flooding reached Bangkok; inundating significant areas of the city. Floodwaters drove residents from their homes, shut down thousands of factories, and caused extensive damage and disruption to city infrastructure. Waters did not recede until January 2012.

The direct impact of Bangkok's flooding included many hundreds of deaths, and around US \$45.7bn in direct economic damages nation-wide (Aon Benfield, 2012) – only US ~\$12bn of which were insured losses (Acclimatise UK, 2016). Further afield, interruption to industry and manufacturing in Bangkok set back global industrial production by 2.5% (United Nations Office for Disaster Risk Reduction, 2012).

#### Energy infrastructure event timeline

July 2011 >>	20-24 October 2011 >>	26-28 October 2011 >>
Unusually high seasonal rainfall affected much of Thailand from July onwards (Aon Benfield, 2012).	<p>On 20 October, logistics operators asked government to seek cooperation from the military and Thai Airlines to help transport consumer goods upcountry amid rising floodwaters in the Rangsit area. Operators switched to indirect routes, resulting in shipment delays and double or triple fees (Fernquest, 2011).</p> <p>A limited supply of vehicles were available to transport shipments, as only large pickup trucks could be used in the high flood waters (Fernquest, 2011).</p> <p>On 24 October, a decision was taken to divert water through canals in Bangkok. As a result substantial areas of the city and surrounding suburbs were flooded (Hancocks, 2011).</p>	<p>Floods swept through Bangkok's Don Muang airport, causing its closure. The airport had been acting as an emergency shelter and national flood relief headquarters, meaning that operations and evacuees had to be relocated. Across town, Bangkok's international airport Suvarnabhumi International – protected by a 3.5m flood wall – continued to operate as usual and also took on some domestic flight services (Vedat, 2011; AP News, 2011).</p> <p>Northern districts of Bangkok were increasingly affected by flooding, with some areas up to 90% submerged. Evacuation orders were issued across the city. Soon after, city bus stations, train stations and many roads became jammed by crowds of people attempting to flee. In some areas residents resorted to bamboo rafts and army trucks as roads became fully submerged. Military and government agencies transported civilians from evacuation points to schools and other temporary shelters (AP News, 2011; Harvey, 2011).</p> <p>It was suggested by several private engineers that roads and bridges were in places perpetuating flooding by obstructed natural water flow. Engineers proposed that several major roads in eastern Bangkok could be blown up to promote drainage. This suggestion was later dismissed by government, which instead focused on dredging canals and waterways (Thin Lei Win, 2012; Marks, 2016).</p> <p>Media reports caused car owners to panic and relocate vehicles to elevated, flood-safe locations – including major roads – creating additional traffic problems. Some residents also slept on elevated road roads for safety (Channel 4, 2011).</p>

#### 2.1 Transport infrastructure performance

While stressed, Bangkok's transport system continued to function to some extent throughout the flooding events. As some transportation modes failed entirely, local adaptation towards other formal and informal modes provided an alternative means of connection – demonstrating the importance of infrastructure diversity and redundancy.

Overall, transport system operations were significantly reduced, and many areas of the city were impassable. The floods highlighted the critical dependency of civilians and businesses upon transportation systems in order to meet their basic needs (including food, shelter and healthcare).



7- 9 November 2011 >>	18 November 2011 >>	December – January 2012 >>	March 2012 >>
<p>Across the flooded northern districts of Bangkok residents relied upon boats and military vehicles for transport. Authorities experienced increasing difficulty transporting supplies to flood-stricken areas, as 55 roads around the city were blocked.</p> <p>Rama 2 Road – the last remaining route open to southern Thailand – served as a vital supply route for transport of goods from Bangkok south. It became clear that this road would soon flood. In response plans were mobilised to reclaim Highway 340, an alternative link submerged in parts by up to one metre of water (Fredrickson, 2011).</p> <p>Flood waters reached the outskirts of inner city, triggering further evacuations. Bangkok's subway and overground SkyTrain continued running as normal, but bus services – the only transit mode affordable to many residents (Thinphanga, 2016) – were suspended in flooded areas.</p> <p>The new flood headquarters – recently relocated to a government energy ministry building from the flooded Don Muang Airport – was now surrounded by water. Several major roads continued to exacerbate flooding by blocking natural drainage of water (BBC News, 2011).</p>	<p>Flood waters were receding in many districts of Bangkok. Areas still flooded in the Bangkok metropolitan area included suburbs in the east and west, the west bank of the Chao Phraya River, and districts in the northern part of the city (Vedat, 2011).</p> <p>In central Bangkok, businesses, hotels, shops and tourist attractions were open for business as normal. The BTS Skytrain and MRT subway were operating normally. Taxis and tuk-tuks are available as per normal. Some BMTA bus routes are still rerouted or suspended due to the flooding. Express boat services on the Chao Phraya River were also suspended, as were most water-related tourist activities (AP News, 2011).</p>	<p>Floodwaters finally receded from remaining districts between late December 2011 and early January 2012 (S and T, 2012).</p>	<p>Don Muang airport re-opened to commercial flights in March 2012, after substantial repairs. The president of Airports of Thailand reported that approximately US \$4.8mn was necessary to repair the airport's eastern runway (Aon Benfield, 2012).</p> <p>Bangkok's main Suvarnabhumi International Airport was largely unaffected, as a large dyke and water pump system surrounding the facility held firm (Aon Benfield, 2012).</p>

## 4.2.2 City resilience outcomes

### Infrastructure and ecosystems

Through the flooding events, elevated expressways and major roads circling Bangkok's inner city afforded an unexpected degree of protection as water naturally channelled along roads (Aye, 2012; Bulsk, K, 2011). Some effective continuity was also observed as alternative transport options took on a new role to absorb pressure from disruption to other services. However, major city roads also diverted the floodwater to other communities and obstructed the natural flow to the Gulf of Thailand. Expansive impermeable surfaces exacerbated drainage and run-off issues. Similar circumstances were observed in the districts surrounding the International airport, where 3.5 metre high flood defences protected the airport, but diverted water to surrounding communities.

Some hoped that a reduction in private transport use during the floods would lead to a more sustainable long-term change in behaviour towards public transport. However, this has not been the case and private transport is still dominant in Bangkok (Thin Lei Win, 2012). Recent international examples do exist to demonstrate how travel disruption can promote efficient transport usage. For example, a recent study revealed partial Tube strikes in London led to long-term behaviour change towards greater efficiency in commuter travel across the capital (Larcom, Rauch and Willems, 2015). Studies suggest that behaviour change and mode shift must be feasible in the long-term in order to become permanently embedded. In the case of Bangkok, a lack of sufficiently affordable public transport across the city has driven citizens to revert to private transportation (Thin Lei Win, 2012).

### Health and wellbeing

The Bangkok Floods represent a clear case of "winners and losers". Whilst those living and working in the key central business district managed to escape significant flooding, many poorer communities suffered the consequences of floodwater diversion away from the Central Business District (CBD) and key assets such as the international airport (Marks, 2015).

Residents in the worst affected northern districts suffered from a severe lack of mobility from mid-October through to early January. Restriction of transportation services meant it became increasingly difficult to meet basic needs and access supplies, particularly food (Bulsk, K, 2011).

Bangkok usually relies heavily on private transportation due to its spatial expanse, as public transport is not affordable to the majority of the population. Road closures and lack of access affected people's daily lives.

Many were unable to reach their regular livelihoods, others were charged exorbitant rates for boat travel with usual transport options diminished (Marks, 2016).

For the same reason, citizens struggled to access healthcare. Some fatalities occurred because regular hospital routes and transport options were not available (Bulsk, K, 2011).

### Economy and society

Economic impacts were unprecedented, including those arising from damage and disruption to transportation. The estimated national cost to repair roadways was US \$4.5bn, while a further US ~\$4.5mn was required to repair the runway at Don Muang (US Department of Homeland Security, 2013). Further costs were incurred due to significant disruption to the transportation of consumer goods. The Thai government sought cooperation from the military and Thai Airlines in support of regional and international logistics (Bulsk, K, 2011).

Floodwaters swamped thousands of factories in Bangkok. The resulting impacts to national and global economies were unprecedented, due in part to disruption of manufacturing and interruption of freight networks. For example, interruption to Western Digital's hard-drive production process caused unit sale costs to double globally (Acclimatise UK, 2016), and Toyota's car production slowed in several countries (Sills et al., 2008; Reed, 2011).

### Leadership and strategy

Leadership and strategic planning played a key role in determining how floods impacted Bangkok, its residents and economy. Key infrastructure, including certain transport hubs, were protected at the expense of other communities and parts of the city (Aye, 2012).

Many examples of effective emergency management were observed, in particular, contingency plans for continued operation of transportation systems and a shift to alternative transportation modes. However, the wellbeing of some communities was sacrificed for others. Many communities were isolated and lacked sufficient, timely support. Insufficient coordination of response meant that certain city districts opened flood gates to discharge water at the expense of others (Aye, 2012).

The design of roads and drainage that perpetuated the impacts of flooding also raised questions regarding the degree of consultative and integrated development planning.

## 4.2.3 Insurance outcomes

### Risk management

The industry generally believes that in order to match and balance risk, geographic diversification is necessary (Insurance Europe, 2014). This rationale is considered correct, yet it relies on the accurate representation of risk in every region covered. To address this problem there is a need for initiatives like the Oasis Loss Modelling Framework (Oasis LMF), to provide a framework for high quality, transparent models for existing perils, and new models for so-called “unmodelled” perils and new territories. Oasis LMF aims to create and foster links throughout the wide community of those interested in modelling catastrophic risk across business, academia, and government (Oasis Loss Modelling Framework, 2017b).

As a result of the Thai floods, reinsurers demanded greater transparency and control, especially over business interruption exposures. The floods led to insurance claims that were larger than expected by some insurers, due to a low granularity of data held. The Thai floods raised a lot of debate around extensions and view on the territory itself in terms of a catastrophe exposure (Sousounis, 2012).

There was also a greater emphasis put on understanding the implications of non-modelled risks with the Association of British Insurers study on “Non-Modelled Risks – A guide to more complete catastrophe risk assessment for (re) insurers” (Association of British Insurers et al., 2014), and modelling companies took steps to take this into account by working on solutions to help companies identify loss potential from so-called ‘non-peak’ zones (Sousounis, 2012).

### Claims

The Thai flooding event resulted in US \$45bn in economic losses and US \$12bn of insurance losses, with supply chain interruption of global manufacturing firms contributing noteworthy values (World Bank, 2011). Supply chain disruption occurred across industries simultaneously. This highlighted the importance of managing exposure aggregations in one region, and the potential for impacts to spread far beyond. For example, the supply chain disruption to hard disk manufacturers not only affected manufacturers with direct supply chain links to Thai facilities but also affected companies like Intel who had no Thai facilities in their supply chain (Jittapong, 2012). Like Hurricane Katrina, sustained inundation resulted in further damage, and a large portion of the machinery needed to be replaced. Stock was further damaged by humidity and mould (Aon Benfield, 2012).

Pressure was placed on reinsurers by the Thai insurers and reinsurers to pay claims promptly as Thailand has a short prescription period where insureds are required to bring proceedings within the two-year period from the date of loss. Brokers who placed business with international reinsurers faced pressure from Thai insurers to push reinsurers to resolve claims quickly to meet the two-year period (Lees, 2014). This timeframe left little opportunity to discuss the basis of the settlement where the “follow the settlements” wording had aggregating clauses (Lees, 2014).

### Underwriting

Insurers and reinsurers have since adopted practices such as exclusions and increasing prices in order to mitigate the risks they present (Lloyd’s, 2012). There were questions raised for insurers and reinsurers as the floods raised awareness of catastrophe risk, and a reduction in coverage for flooding followed. Despite some businesses having a CBI extension cover on top of their “Property Damage/Business Interruption” cover, the extension was written on an “All risks” basis only for limited perils namely fire, lightning and explosion – there was no flood cover. This demonstrated the importance for brokers and underwriters to check the policy wordings to ensure the risk transfer agreement follows the policy coverage and is appropriate for local markets (Echelon Claims Consultants, 2015).

The event also caused reinsurers to consider event limits to previously unlimited policies. Rates for fire pro-rata and excess of loss renewals increased due to the losses (Guy Carpenter, 2012). The demand for excess of loss cover has been increasing since. Previously, proportional cover had dominated in the Thai market.

### Modelling

The combined impact of the relocation of Japanese manufacturing to Thailand, following the March 2011 earthquake and tsunami, and the effects of the Thai floods on the insurance industry called for an increased need for accurate data and models to highlight total exposures in the region. Flood is complex to model and can give rise to varied phenomena. For the regions of Thailand there were no major flood-loss experiences prior to this event of prolonged standing water for such prolonged periods. This led to gaps in the hazard knowledge with assumptions made on what flood events could look like (Insurance Journal, 2012).

As well as the physical hazard, catastrophe models may not explicitly model additional coverages and/or sub-terms and conditions, and this was seen in the flood event where highly significant exposures were not

modelled (Association of British Insurers et al., 2014). As a result of this work by the ABI, Lloyd's "Minimum Standards" require Managing Agents to:

industrial estates that flooded in 2011 (Aon Benfield, 2012).

*“Have robust systems and processes whereby data outputs from Exposure Management systems and assessments of Non Modelled Risks are incorporated into the Internal Model.”*

(Lloyd's, 2017)

### Interacting with stakeholders

In total, 65 of Thailand's 77 provinces were impacted during this flood event. Damage was widespread and severe in many locations – the scale and number of bodies to coordinate with was extensive (Sousounis, 2012).

Flood coverage became essentially unavailable in the Thai market after the catastrophe. The Thai Government has since instituted several measures following the floods including an insurance fund to enable companies and individuals in Thailand to protect themselves against future named events. The Thai Government made a promise to provide for better flood defences to cover future events, by issuing government bonds (Aon Benfield, 2012).

The Thai Government scheme, the 'Catastrophe Insurance Policy' offers coverage for flood, earthquake and windstorm, and if conditions are met, covers THB 100,000 (US \$3,000k) for residential property damage and 30% of SME and commercial cover (National Catastrophe Insurance Fund, 2012). Coverage becomes effective when:

- The Cabinet declares the event has escalated to a "Catastrophe"; or
- The total claim for damages exceeds THB 5bn (US \$143mn) within a 60-day duration and a minimum of two claimers; or
- Hazard magnitudes equate to seven on the Richter scale or 120kph wind speeds.  
(Office of Insurance Commission, 2012)

The Thai Government also announced water management and flood projects to better prepare for flooding along the Chao Phraya River Basin. However, it will take some time for flood defences to be built and in some areas these defences are to be managed separately by private entities, and these entities will be responsible for their own financing; hence, implementation of these plans may vary between the

## 4.2.4 Lessons learned

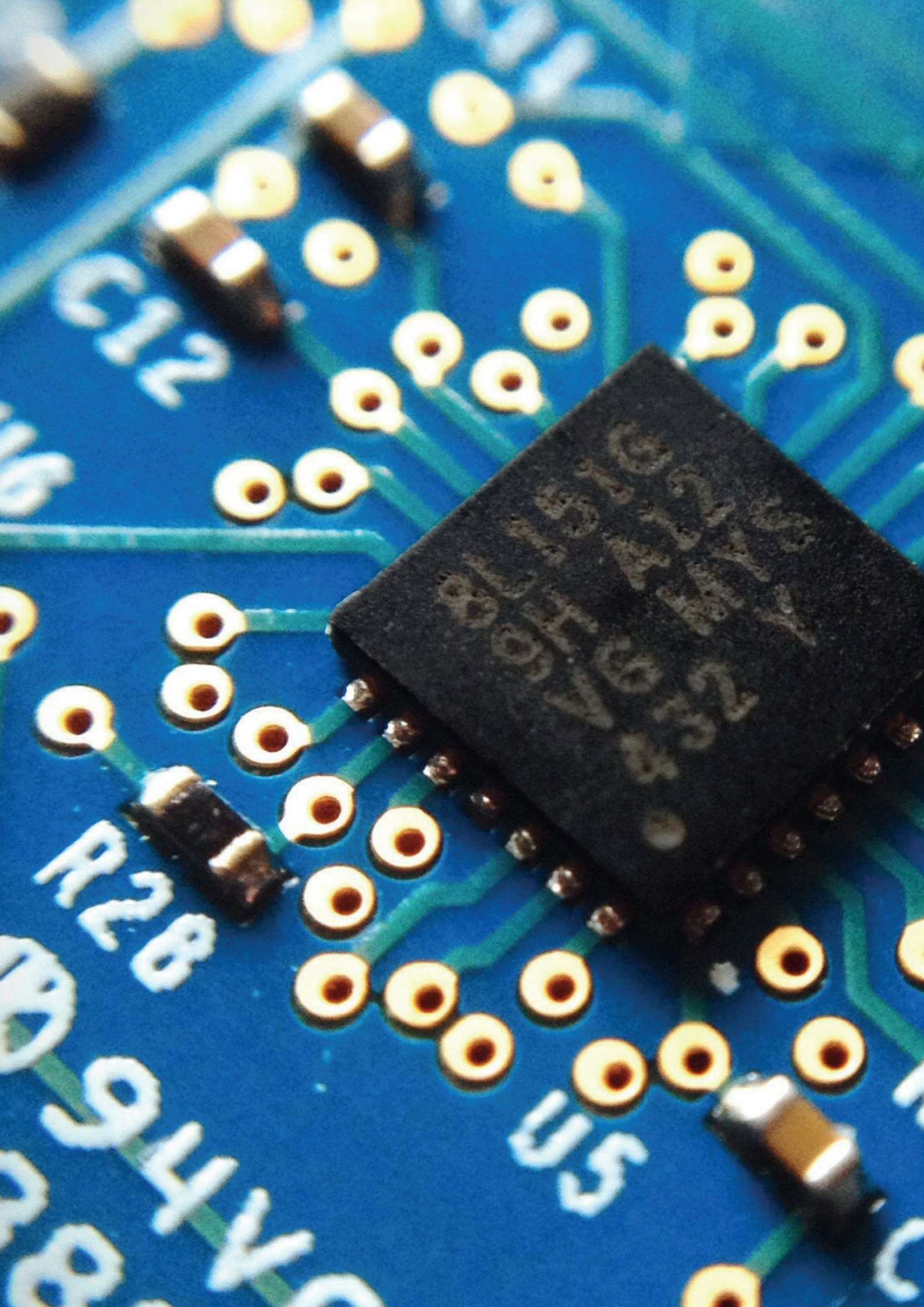
This case study highlights a number of key lessons with regards to future planning, design, operation and maintenance, and insurance of infrastructure:

### Lessons for planning, design and operation

- Integrated approaches to planning transportation infrastructure will take into account impacts of infrastructure on the wider urban catchment – including drainage and surrounding land uses.
- City transport networks that are sufficiently flexible, diverse and supported by comprehensive contingency planning can experience better function and continuity during a major shock or stress event.
- Many critical city services depend on transportation. Effective emergency planning will account for the need to maintain service accessibility and continuity. This is particularly important for vulnerable communities and individuals.
- Most cities are made up of many municipal authorities who control various local aspects of disaster response. Effective, integrated planning, coordination and management across municipal boundaries (for example, decisions to open or close local flood gates) is critical to ensure decision-making considers the collective interests of the wider urban catchment.
- In some cases, there is a need to weigh decisions to protect one city system or location (for example – stringent flood protection of the international city airport and central business district) against the potential for negative consequences elsewhere (in this case – damage and disruption to vulnerable communities within flood plains). Disaster scenario planning and modelling can help to better inform these choices ahead of time.
- Disruption provides an opportunity to improve and transform the way in which communities engage with infrastructure systems. Public and private sector have a role to play in supporting the long term success and sustainability of changes in patterns of use and mode shift.

### Lessons for insurance

- Given the inherent uncertainty around supply chain and business interruption, the emergence of more frequent and severe “non-modelled” risks across a broad range of classes of business could present substantial challenges to insurance firms and warrants further consideration.
- As well as the physical hazard, catastrophe models may not explicitly model additional coverages and/or sub-terms and conditions, and this has seen changes to Lloyd’s “Minimum Standards”. This has also led to development of the analysis and consideration of non-modelled risks to provide a better understanding of risk, and to provide an incentive to further build in-depth probabilistic models. These models should consider the effects on contingent business interruption insurance including supply chain disruption.
- Policy wording is a key issue for understanding exposure, pricing and terms and conditions changes. Insurers and reinsurers have since adopted practices such as exclusions and increasing prices in order to mitigate the risks they present. The Thai floods raised debate around extensions and views of the territory itself in terms of a catastrophe exposure. The event also caused reinsurers to consider event limits to previously unlimited policies.





## 4.3 Mumbai terrorist attacks, 2008

### India

#### Communications infrastructure

A series of 12 coordinated shooting and bombing attacks were carried out in Mumbai over a four-day period between the 26 and 29 November, 2008. Ten attackers from Lashkar-e-Taiba, a militant Islamist organisation, targeted establishments that were either unguarded or had light-armed security that could be easily defeated. Attackers operated in three groups, carrying assault rifles and grenades. The groups targeted a variety of city locations including cafés, a train station, petrol station, hospitals, hotels and leisure and community centres.

The attacks lasted more than 60 hours and resulted in 175 fatalities, including civilians, security forces members and nine terrorists (Bhandarwar et al., 2012). The attack caused wide-scale disruption across the city, with major interruption to businesses, schools, hospitals, and the stock exchange (News18, 2008). Estimated economic damage from total business losses amounted to US \$100bn, and insured losses were US \$111mn (Lloyd's, 2015d).

#### Energy infrastructure event timeline

26 November 2008 >>

In the evening of 26 November 2008, 10 terrorists travelling by inflatable boat arrived at various locations along the Mumbai city shoreline. Prior to the attacks, they had undertaken reconnaissance of various targets using technology including Google Maps (Shachtmann, 2008). A variety of locations were targeted, including many popular public locations (Shankar et al., 2011):

- Firearms attacks on community centres – including a local Jewish Centre, Nariman House.
- Firearms attack on a petrol station.
- Firearms attack on the Leopold and Bade Miyan city cafés.
- A 90-minute firearms attack at the Chhatrapati Shivaji Terminus (CST), Mumbai's central commuter train station.
- Gunfire at the gates of the Brihanmumbai Municipal Corporation of Greater Mumbai (BMC), and at the neighbouring Times of India office.
- Attack of the Gokuldas Hospital, Cama & Albless Hospital, and Metro Big Cinema.
- Sieges of the Oberoi and Taj Mahal Palace hotels and Nariman House. (Al Jazeera, 2009; Shankar et al., 2011)

27 November 2008 >>

In the early hours of the morning, terrorists successfully hijacked a police van at Dhobi Talao. Coordinated attacks continued at several locations across the city including major explosions and fire at the Taj Hotel.

At 02:00 Indian military forces arrived at the Taj Hotel, and subsequently launched a counter-assault at 09:15. A military counter-assault was launched simultaneously at the Oberoi Hotel.

Around this time there was a great deal of media attention and social media activity. This information was advantageous to attackers (Shankar et al., 2011) and TV coverage was restricted by authorities.

At 17:30 in the evening, the National Security Guard (NSG) arrived at Nariman House (BBC News, 2008).

#### 4.1.1 Energy infrastructure performance

In contrast to the previous case studies from New Orleans and Bangkok, the city's communications systems appear to have performed well in response to changes in use and demand during the attacks.

This case study demonstrates how an infrastructure system can play a critical but contrasting role in both enabling a disaster and supporting the response by city authorities. Digital technologies employed by attackers to facilitate the attack included mobile phones, email, global positioning systems, and social media (Kolås, 2010).

*"...the death they delivered was facilitated by state-of-the-art technologies – on ones and zeros flying, as it were, through cyberspace. Mobile phones and voice-over-internet protocol links connected the Lashkar fidayeen to satellite phones used by their controllers in Pakistan; hacked internet servers were used to set up fake email addresses; money was electronically transferred half way around the world; and global positioning systems guided the perpetrators to their targets."*

(Shankar et al., 2011)

In such cases, infrastructure performance may increase or aid the threat itself – and it might be desirable to take action to shut down some system functions.



28 November 2008 >>

At 07:30 in the morning, the NSG begin their counter-assault of the Oberoi Hotel. The siege was declared over at 14:40, with reports of hostages released. At this time, the NSG also reported that the new section or wing of the Taj Hotel was clear of attackers.

At 18:00 an end to security operations at Nariman House was reported (BBC News, 2008).

29 November 2008 >>

In the early hours of the morning, further reports emerged of gunfire and explosions at the Taj Hotel, followed by another fire.

Finally at 08:50, Indian security forces declared the Taj Hotel siege over (Scott-Clark and Levy, 2013).

Longer term >>

Following the attacks, new legislation was implemented enabling the government to prevent the media from showing news real-time or delay the news of an incident due to national security concerns (Ibrahim, 2009).

The Oberoi hotel undertook reconstruction and increased the number of CCTV cameras from 15 during the attacks to 150 and also the number of security personnel to 50 from 10 during the attacks. The hotel also installed a vehicle gate where all vehicles are searched. The glazed façade of the hotel lobby was also redesigned so that it has anti-shatter film applied to the glass. Security upgrades also took place at the Taj Hotel (Bajaj, 2010).

The events at Mumbai drew a range of international scrutiny over the years following, regarding the unexpected ways in which the attackers leveraged ICT technology, and insufficient or untimely response from authorities (Shankar et al., 2011).

## 4.3.2 City resilience outcomes

### Infrastructure and environment

Communications technology played a pivotal role in the attack, particularly from a security perspective. Prior to the attacks terrorists used online resources such as Google Maps for reconnaissance of targets. During the attacks terrorists drew upon a combination of satellite phones and mobiles utilising VoIP (voice-over-internet-protocols) telephony to communicate. As mentioned, Twitter and 24/7 television coverage provided the attackers with real-time updates that assisted their coordination (Fitsanakis and Allen, 2009).

Following an order by the Deputy Commissioner of Police of Mumbai, all television news channels in the south of Mumbai were blocked for approximately 45 minutes at one point during the siege. The New York Police Department conducted a post-attack analysis which concluded that the only effective interference method would have been a shutdown of mobile and wireless communications over the entire area (Angel Rabasa et al., 2009).

Since the attack, legislation has been introduced to provide India's Government with greater control over the media to prevent journalists from showing real-time news, or to delay the news for national security concerns.

### Health and wellbeing

The events had an immediate, direct impact on health and wellbeing in Mumbai. In addition to direct injuries, the events caused community unrest and acute stress (Balasinorwala and Shah, 2009). Impacts were felt long-term by residents and the business community, with secondary short-term effects on local livelihoods (Ramesh, Pepper and Balakrishnan, 2008).

The purpose of the Mumbai terrorist attacks was primarily to inflict casualties and gain media attention (Kolås, 2010). In addition to the direct fatalities and disruption the attacks were successful in spreading fear around the city.

### Economy and society

International media coverage throughout the attacks undoubtedly helped to raise the attackers' profile, acting as a fear-multiplier as coverage played out in real-time. This publicity contributed to negative short-term impacts on tourism and other activities important to Mumbai's economy. Growing fear of terrorism was felt as far afield as Europe as a result of the events (Finseraas and Listhaug, 2013).

Discontent with international media coverage was also apparent within India. Strong opposition was observed in relation to the way the media sensationalised the attacks, spreading fear and insecurity (Neelamalar, Chitra and Darwin, 2009).

During the siege, the Maharashtra State Government unsuccessfully attempted to shutdown Twitter as attackers followed public tweets to track the movements of responding agencies. Subsequent terrorism incidents (such as the 2016 Brussels bombings) have seen citizens participate in mass Twitter 'hashtag' disruption, flooding feeds used by attackers to monitor live police movements. This demonstrates actively engaged citizens and an innovative community-level response to misappropriation of social technology.

### Leadership and strategy

This government attempt to shutdown Twitter raised questions regarding stakeholder empowerment and the ability of citizens to communicate in an emergency. This is a tension between the public right to communicate versus malicious use by attackers.

The communication and organisational infrastructure in place to coordinate efforts between Mumbai's local emergency services, the Maharashtra State Government and central Government in New Delhi and other emergency management stakeholders was poor. While shut-down of television stations during the incident suggests certain emergency protocols existed, emergency support was slow to arrive (Finseraas and Listhaug, 2013; Shankar et al., 2011; Rao and Nair, 2014).

Overall, the response was disjointed. The attack included several elements that were absent from India's terrorist response plans – including multiple locations, extended siege and the co-ordinated use of high-powered firearms (Rao and Nair, 2014).

### 4.3.3 Insurance outcomes

While this use of ICT infrastructure did not bring about many insurance claims outside possible pricing and risk selection at a high level, there remains a need to seriously consider the performance and security of this aspect for city resilience. Responding to terrorism remains a priority for businesses in India. Mumbai experienced another attack in July 2011 (National Consortium for the Study of Terrorism and Responses to Terrorism, 2017).

A statistical foundation for risk analysis requires losses. In comparison to other hazards event – windstorms and earthquakes – there are fewer terrorism events worldwide, which provides a challenge for risk modelling.

The nature of terrorism events is changing, and what constitutes a terrorism event is expanding. Cyber-attacks and social disruption are types of emerging attack that require consideration (BBC News, 2016). There are also challenges in being able to accurately model human behaviour, which can affect terrorism risk (National Research Council, 2010).

This complexity, alongside limited historical records for quantification, presents a modelling challenge that needs to be explored. Terrorism modelling is still developing compared to natural hazards modelling, which has experienced decades of development by the insurance sector and other industries (Grossi, Kunreuther and Windeler, 2005).

A counterfactual analysis approach could be used to extrapolate for past events, asking how they could, plausibly, have been worse. This enables insurers to consider what has not yet happened, but could, would, or might have under differing circumstances (Woo, 2015). Analysts could build a dataset of potential losses to move this topic forwards.

Data required to build knowledge about the threat includes attack frequency, attack methods, targets and perpetrators. Expertise is also needed to understand:

- The geopolitical situation involved;
- Instigator motivations, capabilities, and causes; and
- The potential for mitigation.

#### Integration and reliance on ICT systems

What is important to note is how quickly the reliance and integration of ICT systems has developed since 2008, and the potential for cyberterrorism to harm or shut down critical national infrastructures (such as energy, transportation, government operations) is a very real concern (Weimann, 2005).

This has created a wider network of exposures and impacts, and it is not inconceivable to think that a well-planned cyber-attack could catastrophically affect a nation's services and its infrastructure (Timms, 2016). Cyberterrorism attacks have the ability to cause failure, or at least disable, the military, financial, and service sectors of advanced economies (Weimann, 2005).

Unlike other perils, cyber has the theoretical ability to produce claims in almost any insurance class. This undermines (re)insurers' ability to model losses confidently, allocate capital and therefore accurate pricing for insurance products (Pool Reinsurance, 2016). The gap between the available global insurance capacity and market exposure has become increasingly stark: market capacity stands at approximately US \$500mn, but the exposure is estimated to be more than US \$130bn (Pool Reinsurance, 2016).

Cyber insurance not only provides a financial pay-out after a cyber-attack, but also offers expert consultancy to improve security and on-the-ground support during the crisis period.

Working with underwriters who understand this risk from the beginning will benefit an insureds security strategy. Underwriters can help businesses identify risks and vulnerabilities, and can therefore mitigate the likelihood of a breach happening in the first place.

Exposure to cyber terrorism extends beyond the coverage traditionally offered by cyber insurance. For example, cyber-attacks against operational technology may result in physical property losses and personal injury. Such cyber terrorism events could result in claims against the lines of insurance covered by the Terrorism Risk Insurance Program Reauthorization Act of 2015 (TRIPRA 2015 or TRIA) – such as property and workers' compensation (Lloyd's, 2015a; Aguirre, Bansal, Douglas and Millicia, 2015).

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Another approach to look at cyber coverage would be by asking how cyber-risk is considered within a traditional terrorism insurance policy. Terrorism insurance policies are already widespread; nevertheless, an examination of the coverage provided for a cyber-event within such policies points to significant gaps due to either a lack of a clear definition or explicit exclusions of such risks from the policy coverage. Cyber-policies usually cover costs such as customer-notification expenses, credit monitoring, identity-theft monitoring, and privacy and security liability; it is unlikely that terrorism insurance would cover these types of losses stemming from cyberterrorism. However, if a cyber-terrorist attack resulted in damages covered under traditional terrorism policies, coverage disputes would likely arise, and ultimately, under current policy language, these losses may be covered. This highlights another area that has yet to be tested and is currently an issue of debate (Aguirre et al., 2015).

### 4.3.4 Lessons learned

A number of lessons can be drawn from this case study that have implications for infrastructure system planning, design, operation and maintenance and insurance:

#### Lessons for planning, design and operation

- Reliance and integration of ICT systems has developed since 2008, and the potential for cyberterrorism to harm or shut down critical national infrastructures (such as energy, transportation, government operations) is a very real concern.
- This has created a wider network of exposures and impacts, and it is not inconceivable to think that a well-planned cyber-attack could catastrophically affect a state's services and its infrastructure. Cyberterrorism attacks have the ability to cause failure, or at least disable, the military, financial, and service sectors of advanced economies.
- ICT infrastructure (including social media) provides a basis for emergency management stakeholders to effectively communicate with the public during a major incident, but can also be used maliciously by terrorists for reconnaissance and live-incident monitoring. ICT infrastructure planning, design and operation has a role to play in anticipating and preventing criminal activity.
- Similarly, city authorities have a role to play in ensuring urban risk management planning and emergency management protocols maintain pace with rapidly evolving ICT technology, and prevent or respond effectively to its misappropriation.
- The private sector (including ICT companies and media outlets) is a key stakeholder in communications system emergency response. Effective protocols require strong communication and collaboration between public and private sector.
- Communications infrastructure underpins public awareness, communication and warning systems during an emergency. The public can play an active role in mitigating malicious appropriation and assisting emergency agencies to respond effectively (for example, through hashtag disruption).

#### Lessons for insurance

- Unlike other perils, cyber has the theoretical ability to produce claims in almost any insurance class. For example, cyber-attacks against operational technology may result in physical property losses and personal injury. This makes (re)insurers' ability to model losses and allocated capital confidently more challenging.
- Insurers could consider counterfactual risk analysis as a technique to augment sparse loss data for risk modelling. By considering what could, would, or might have under differing circumstances, analysts could build a potential loss dataset.

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# 5. Enhancing infrastructure resilience

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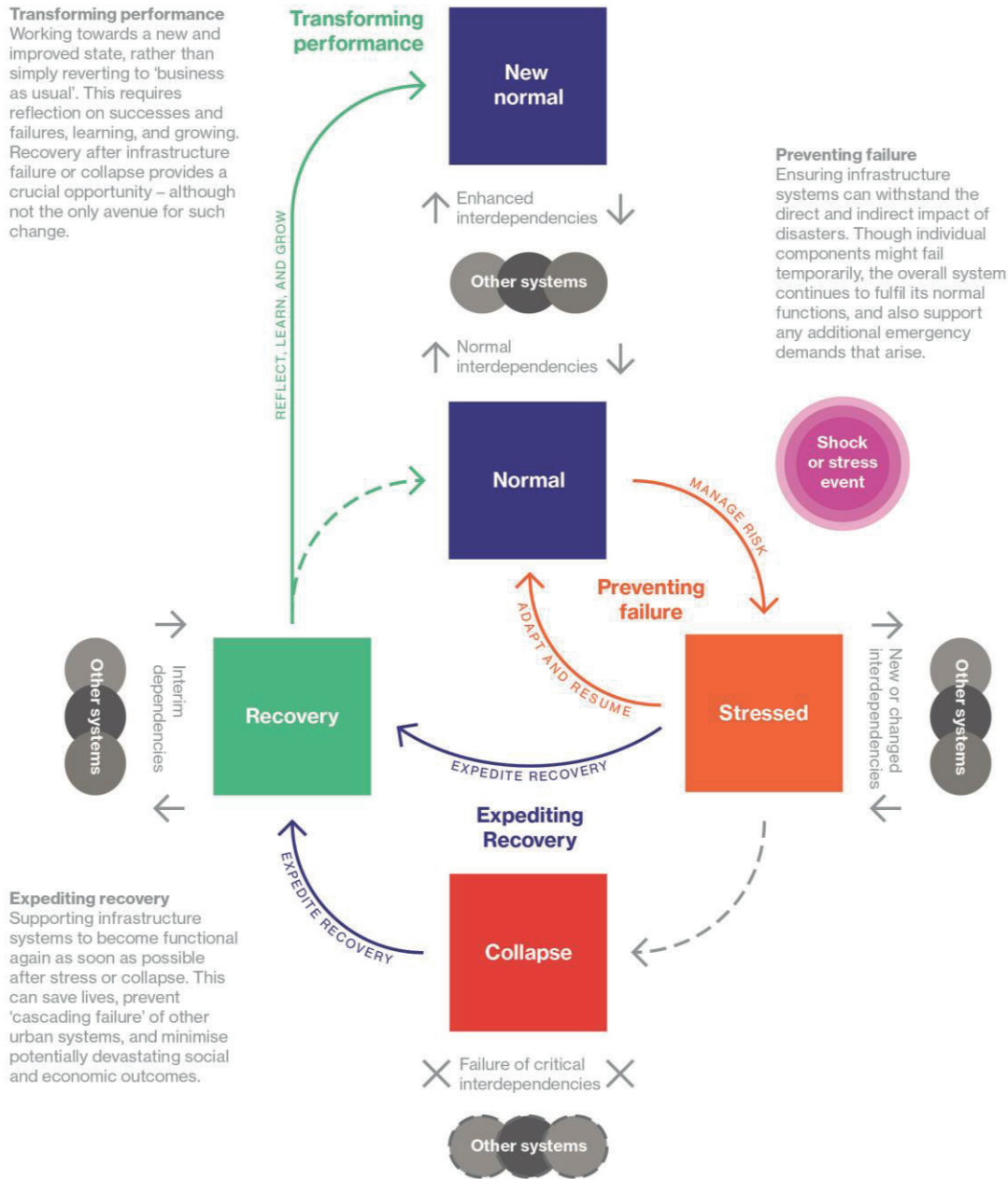
## 5.1 Infrastructure resilience pathways

Events in New Orleans, Bangkok and Mumbai demonstrate how infrastructure can influence a city's ability to withstand, adapt, and recover quickly when a disaster occurs. Infrastructure failure can impact human lives, urban assets, and economic activity at a local, regional and national scale. In each city infrastructure risk management proved inadequate in the face of unpredictable and compounding events.

In order to better manage risk and recover quickly from future disasters infrastructure owners and operators must move beyond asset-by-asset risk management to build resilience within and between infrastructure systems. This requires consideration of how infrastructure performance might change when a shock or stress event occurs. New approaches are needed that recognise fragility, complexity, and interdependencies between infrastructure and wider urban systems (*see Box 3, p43*).

The diagram overleaf identifies three approaches or "pathways" to enhance infrastructure performance following a shock or stress event. Building on infrastructure performance states described in Figure 4 (*see p17*), these pathways seek to prevent failure under stressed conditions by adapting and resuming normal functions, expedite recovery if failure or total collapse occurs, and reflect, learn and grow to transform towards new and improved state of performance. Each pathway can support the identification of specific strategies to enhance infrastructure resilience through planning, design and operation.

Figure 5: Infrastructure resilience pathways



- "Normal" state: business-as-usual operating conditions, where an infrastructure system is performing normally or as expected.
- "Stressed" state: changes in infrastructure system performance can occur due to pressure from a shock or stress.
- "Collapse" state: collapse occurs when an infrastructure system can no longer function to a level above minimum support.
- "Recovery" state: infrastructure systems require additional actions or support to restore their performance after a state of stress, or on a much larger scale after system collapse.
- "New normal" state: in the wake of a disaster or disruption it can be tempting to focus solely on efforts to restore a system to "business as usual". As a result, opportunities to reflect on past mistakes and successes may be missed.

**Box 3: Understanding and managing interdependencies**

Any given infrastructure system is connected to many other urban systems (including other infrastructure systems, as well as social, economic and governance systems). These relationships are not static – they may change over time, and under different urban conditions. For example, a public transportation network might provide basic community mobility under normal conditions, but in a disaster it might be repurposed to provide a vital evacuation service. Understanding how interdependencies change in times of stress and recovery is essential to preventing failure, expediting recovery and achieving transformation.

In Arup's professional opinion, infrastructure owners and operators can make better policies and decisions when they understand system interdependencies, allowing them to develop plans and take action to protect or prioritise critical services, thereby enhancing city-wide continuity during times of crisis. However, identifying and understanding interdependencies presents a significant challenge – one which can be magnified as cities grow and accommodate formal and informal systems. As a starting point, it has been suggested that infrastructure dependencies can be categorised across four groups:

- Physical: Where one component relies on outputs from another (for example, water distribution on energy supply).
- Cyber: Where the operation of infrastructure relies on information and communications technology.
- Geographic: Where different infrastructures are exposed to the same hazards due to proximity.
- Logical: Which relate to economic association (for example, market prices), legislation or human behaviour (Rinaldi, Peerenboom and Kelly, 2001).

Developing detailed interdependency models can be difficult, due to the extent to which relationships are complex, constantly evolving and locally specific. Instead, a comprehensive approach to resilience can protect interdependencies by building a system's overall capacity to cope with shocks and stresses; alongside processes to identify critical interdependencies and act accordingly.



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## 5.2 Overarching principles to enhance infrastructure resilience

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A number of common overarching principles can help inform the planning, design and operation of infrastructure systems across sectors. These principles relate to the three resilience pathways: preventing failure, expediting recovery and transforming performance.

Principles relate both to enhancing the performance within individual infrastructure systems, and understanding, promoting and protecting the interdependencies between urban systems.

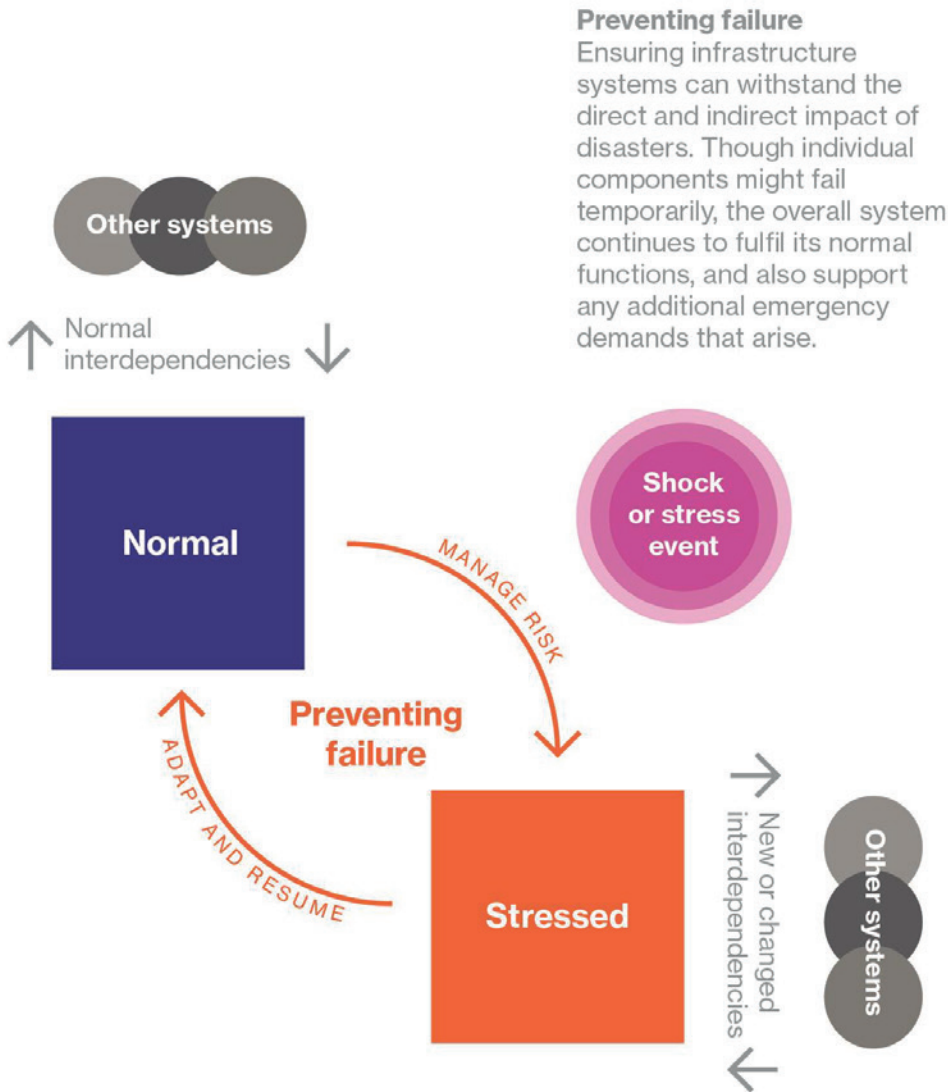
The idea is to allow these pathways to facilitate the implementation of a series of principles that will support, enhance, and protect city infrastructure resilience.

The appendices of this report also provide a series of further sector specific principles for:

- Energy
- Water
- ICT and
- Transport infrastructure

## 5.2.1 Preventing failure

Figure 6: Preventing failure



### Planning and design principles

#### 1. Promote integrated planning

Planning and design can account for surrounding land uses to ensure compatibility, avoid compounding environmental risk, and enhance digital and physical connectivity with other systems and resources. Integrated planning also means promoting cooperation across sectors to improve asset management, develop joint contingency plans and build resilience on a city scale.

#### Relevance to insurance

Integrating the insurance sector into the planning aspect could serve to establish cooperation early to facilitate partnerships, as well as introducing risk quantification in to the procurement process. Regional and national insurance markets hold relevant expertise and are able to draw on main company office resources where needed.

## 2. Value ecosystem services

The simplest, most shock-resistant and cost-effective design approaches can leverage the vital contribution of ecosystem services. For example, retaining and protecting vegetation to regulate water run-off, and harnessing coastal buffer zones for storm-surge protection.

### Relevance to insurance

By quantifying the economic value of natural defences such features can be more effectively included in risk models and coastal management (Lloyd's, 2016). The protection natural defences provide is often implicitly incorporated in industry risk models, but these benefits are often pooled with many other factors and then not clearly recognised by model users, (re)insurers, brokers, clients and others. If these factors are captured explicitly in indices or directly in models it will help insurers and other stakeholders appreciate their value.

## 3. Prioritise emergency preparedness

Integrated, holistic emergency preparedness requires good governance (ensuring up-to-date contingency plans are in place), finances (adequate emergency funds) and human resources (ensuring staff are trained, aware and accountable). Comprehensive early-warning, risk monitoring and scenario planning are essential. The private sector has a critical role to play in breaking down traditional perceptions that responsibility for urban risk management sits entirely with government.

### Relevance to insurance

Integrating the insurance sector into the emergency planning stage could unlock administrative red tape and confusion in the wake of events. Adopting shared scenario processes and risk models could help develop a broader systems model for all parties to coordinate and plan their responses.

## 4. Design for robustness

Robust design often requires new and existing infrastructure to go beyond legal codes and standards towards best practice. Standards are often inadequate in many developing countries. Robust design anticipates failures in systems, making provision to ensure failure is predictable, safe, and proportionate to the cause. This could include considering future scenarios for climate change, resource scarcity and cyber security.

### Relevance to insurance

The insurance industry has experience, guidance advice, and in some cases patented technology that can be used to enhance robustness. Insurers' catastrophe models should incorporate failure of mitigation.

## 5. Incorporate redundancy

This refers to spare capacity that supports systems to accommodate increasing or changing demand. Redundancy can exist within the components of an infrastructure system, or in external systems which support the same function (for example, diesel generators or back-up water tanks).

### Relevance to insurance

This is important when considering the potential for business interruption, and ways to limit systemic effects of events. Insurers should play their part in demonstrating the value of redundancy as a factor for enhancing resilience.

## 6. Increase diversity

While individual components of an infrastructure system might fail, the system as a whole might continue to function if adequate diversity exists. Diverse systems are less likely to experience mass failure, as different components will not fail under the same conditions. For example, drought might cause a hydro-electric power plant to fail, but a city's energy system might continue to function as usual – supported by sources such as solar and geothermal power.

### Relevance to insurance

Scenarios are a tool for exploring risks. Working with cross-sector experts to explore potential futures in extreme but plausible ways can challenge thinking and improve understanding of risk. Where available, diversity indices should be incorporated into risk modelling and underwriting.

## Operations principles

### 7. Invest in information management

Understanding and enhancing infrastructure system performance requires accurate, up-to-date performance data. “Smart design” techniques can integrate data management systems within assets. Performance can be assessed from construction stage onward through “Building Information Modelling” (BIM) (Davidson, 2014).

#### Relevance to insurance

Holding a central directory for a building that contains all information needed to evaluate design, maintenance, and vulnerabilities, is something of great interest to the insurance industry. There can be a lack of data at granular levels and risks can vary from building to building. Finding a way to reduce smoothing of values across geographic areas could allow greater consideration of risk variation from asset to asset. If each building had a standardised data file containing agreed exposure information, this could be consumed directly by insurers.

### 8. Maintain assets

Ongoing maintenance of infrastructure assets (refer to ISO 55000) can be considered from the earliest stages of business case to ensure sustainable funding models are in place, along with contract structures which incentivise maintenance (such as PPP or PFI). “Low maintenance design” can be particularly beneficial in harsh environmental conditions, or where funding is scarce. “Designing for maintenance” ensures infrastructure design supports access and maintenance. Effective maintenance requires properly trained human resources and systems for accountability.

#### Relevance to insurance

Insurance companies can offer risk-based premiums to asset owners or managers who have mitigated risk and in some cases even make this a condition for insurance. Demonstrating risk management processes to maintain and enhance assets is an area where insurance services could play a role, and is a potential service area that could be developed for the industry. If the level of asset maintenance is contained in an index then this can be incorporated into modelling.

### 9. Expand disaster risk management

This involves identifying threats and evaluating and mitigating risk (both natural and manmade) across entire infrastructure systems. Risks are addressed from the earliest planning phases, then assessed and reassessed throughout operation (based on accurate data and probabilistic modelling), and action taken accordingly. Contingency/scenario plans and processes are tested, evaluated and updated regularly.

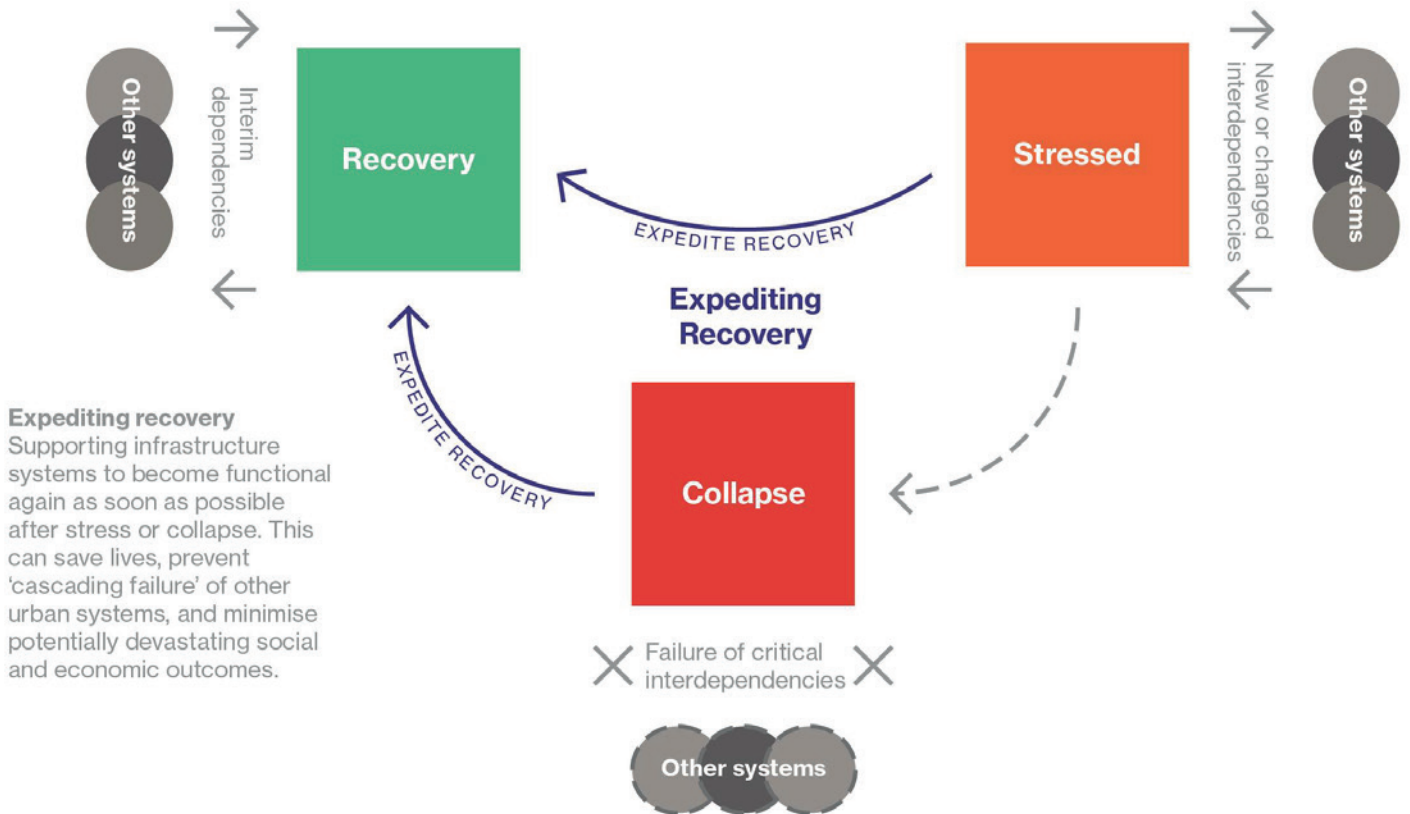
Effective risk mitigation may need to consider competing hazards where reducing the impact of one hazard could bring about unintended consequences and vulnerabilities to another. For example, buried ICT lines are protected from storms but can be prone to flood damage. A lighter roof may prevent the pancaking of buildings in an earthquake but may detach and damage surrounding property in strong winds.

#### Relevance to insurance

Risk modelling of a range of risks in the design phases of infrastructure could allow assessment of assets to hazards. Without quantification it is difficult to assess resilience and how effective action might be taken to enhance it. Information within contingency plans will be of interest to risk modellers.

## 5.2.2 Expediting recovery

Figure 7: Expediting recovery



### Planning and design principles

#### 1. Plan the emergency response

Understanding how a system will perform (and fail) during different disaster scenarios can ensure effective plans are in place to respond accordingly, and inform advance distribution of resources (such as first responders, repair crews and spare parts) to repair and reinstate infrastructure quickly.

Effective response-preparedness will consider interdependencies and multiple failure scenarios – for example, a storm event that damages power lines might also interrupt road access, preventing repair crews from accessing damaged infrastructure.

#### Relevance to insurance

Risk modelling of a range of risks in the design phases of infrastructure could allow assessment of how assets respond to hazards. Without quantification it is difficult to assess resilience and how effective action might be taken to enhance it. This will have an impact on the length of business interruption. Indices that track expected recovery time could be incorporated into risk models.

### 3. Design with recovery in mind

Infrastructure design can enhance the speed and efficiency of repair and recovery following a disaster or major damage. Key strategies include ensuring critical components can be readily accessed for repair, and using standardised, non-specialised parts and materials across a system which can be quickly replaced from local sources.

Furthermore, ensuring the design doesn't exceed the capacity of local skilled labour to deliver repairs by adopting locally-appropriate technologies and up-skilling local labourers during the construction process.

#### Relevance to insurance

Pre-agreed plans could be used to speed up the recovery efforts. There is an opportunity to offer "build back better", but only if building codes mandate this in advance to level the playing field. Catastrophe models already take demand surge in to account; pre-agreed service costs are a method to control this.

### 4. Allow fail "soft" options

Failure is always a possibility to be considered and accounted for. "Fail-soft" design, planning and response aims to ensure failure occurs in a selective way, allowing the shut-down of non-essential pre-determined functions, while maintaining the primary function at reduced capacity.

#### Relevance to insurance

Supply-chain modelling is an area that requires further research to establish what primary functions require enhanced resilience, and to establish what this may look like. Any planned failure options should be shared so the risk can be established and taken in to account.

## Operations principles

### 5. Promote inter-agency coordination

Integration and alignment between city systems promotes consistency in decision-making. Case studies from around the world demonstrate how better communication, coordination, and pooling of finances and resources between sectors (public and private) and across institutional and regional boundaries can significantly improve the efficiency and effectiveness of response, and reduce the burden of risk by spreading it across multiple stakeholders.

#### Relevance to insurance

Scenarios are a tool for exploring risks. Working with cross-sector experts to explore potential futures in extreme but plausible ways can challenge thinking and improve understanding of risk. Insurers have a role in these discussions.

### 6. Map critical resources

Good resource mapping – both before an event and during recovery – can save lives, money and limit further damage. This means making sure that crucial, basic information (such as the location of critical assets and spare parts) is readily available, ensuring information is backed up and can be readily accessed by responders.

#### Relevance to insurance

If the level of critical resources can be converted into a metric, this can be tracked and used in risk quantification.

### 7. Create independent recovery systems

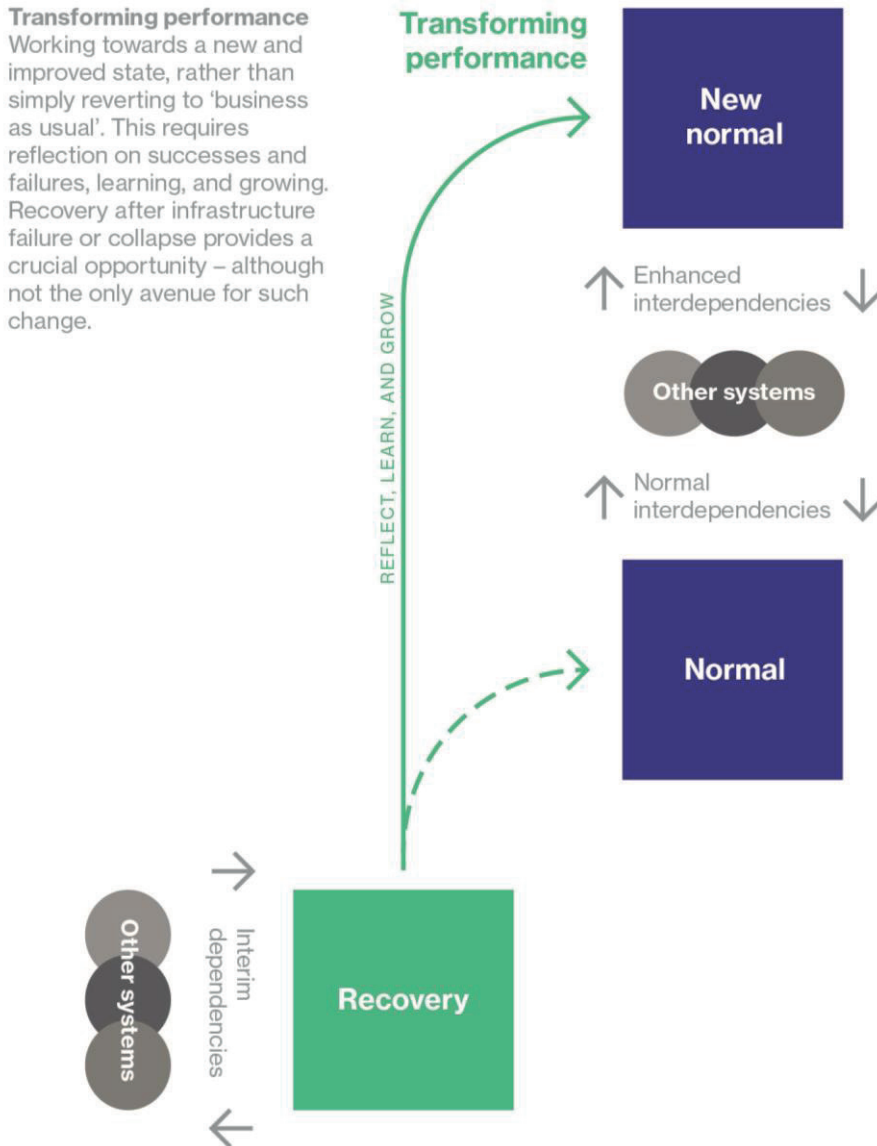
Given the complex nature of infrastructure interdependencies and in the event of cascading failure, recovery can be initiated or enhanced if essential recovery systems contain some level of independence. These are also referred to as "skeleton systems", which avoid dependency on advanced technologies. For example, many police forces have battery-operated short wave radios and wind-up walkie-talkie systems on hand for scenarios where both power and communications networks fail.

#### Relevance to insurance

If the level of independence of systems can be indexed, a view of the system fragility can be used in risk modelling.

## 5.2.3 Transforming performance

Figure 8: Transforming performance



### Planning, design and operation

#### 1. Build in flexibility

Flexibility in design and operation implies that the systems can change, evolve and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure. These largely unpredictable forces – including new knowledge and technology – can drive gradual or sudden change in our demand for infrastructure, and the functions and products they provide.

#### Relevance to insurance

Engineering research and network studies could help to identify the gaps between current standards for resilience, and the standards required under increasingly connected risks. Insurers' risk models could be used to make the business case for flexibility by conducting "what if" scenarios.

## 2. Reflect on the past, plan for the future

On a day-to-day basis, adapting and improving requires having systems in place to monitor performance and implementing continual improvement. In addition to monitoring past performance, foresight initiatives such as scenario planning can help to anticipate and address weaknesses before they affect performance.

In the event of infrastructure system collapse, the natural reaction is often to seek a return to business-as-usual as quickly as possible. Achieving true resilience requires a shift in thinking to embrace change and harness recovery processes as an opportunity to build back better.

### Relevance to insurance

Claims experts from insurers could be part of such “lesson learning” exercises, as they can assimilate and share information from multiple claims. A possible development could be the emergence of a “resilience service”, which could draw on aspects of facilities management, crisis management, disaster recovery, ‘build and operate’ contracts, and insurance.

## 3. Consult widely

Understanding stakeholder needs and expectations can help to ensure infrastructure systems continue to adapt and grow. This includes consideration of stakeholder needs and demands outside of “normal” operations. For example, ensuring emergency services and first responders are consulted in transport network design can enhance the network’s functionality in disaster evacuation.

### Relevance to insurance

Insurance should be involved in such consultations.

## 4. Drive a culture of safety

Land-use planning and design codes and standards are often cited as a universal remedy for risk. However, focusing on these measures alone can remove emphasis from the complexity and compounding nature of threats in urban environments. Risk management is only effective if it forms part of a culture of safety that includes education, community awareness, and enforcement of codes and standards.

### Relevance to insurance

The challenge remains in making change happen at scale – ultimately insurers are competing entities and coverage levels may differ in the approaches taken, so there is real importance in making collaboration happen in the precompetitive space. One way to do this could be to work with a city to develop a proof of concept framework that could be tested with the goal of applying the framework at a replicable, worldwide scale. Insurers’ risk models can be part of the education process.

## 5. Develop incentives

While the benefits of reducing asset-scale risk can often be accounted for, managing compounding risk and building system-level resilience can be more difficult to justify, particularly where any different owners exist, where benefits are indirect, and where benefits are distributed unevenly across the system or weighted outside of the system (for example, benefit to community health or property prices). Truly building resilience for all stakeholders means finding new ways to bridge silos within and between government, private sector and the community to measure and account for the benefits of resilience (direct and indirect), and to incentivise resilience-building activities.

### Relevance to insurance

One way for the insurance industry to incentivise policyholders to take risk mitigation measures, is through risk-based premiums. This will only be possible if the level of resilience is captured in readily consumable indices. Insurance companies can also communicate to customers the advantages of retrofits in hazard-prone areas and consider offering inspections and retrofit recommendations.

## 6. Reduce demand

Asset-owners and operators have a role to play in building system resilience by managing demand – often by promoting behavioural change and improving resource efficiency – rather than simply building more infrastructure. For example, after severe droughts in 2006 the state of Victoria in Australia significantly reduced long-term strain on its water resources through industrial and residential awareness, conservation programs, restrictions and new legislation to support more effective price-setting (Low *et al.*, 2015).

### Relevance to insurance

Insurance risk models can highlight the view of risk in a region, but only if national risk assessments and plans are made available by governments to provide the current understanding in a timeframe that is useable and useful to society.



#### Box 4: Constraints to implementation

While the principles outlined in this chapter reflect the key to future infrastructure resilience, their effective application has challenges grounded in often political, financial and behavioural realities.

Both general and sector-specific principles highlight the importance of effective infrastructure emergency planning and the creation of a culture of safety. Implementing these ideas can be expensive, and may not be perceived as important in developing countries as promoting economic growth and development gains. In locations with moderate or low-frequency hazard profiles, complacency towards efforts can be greater (Da Silva *et al.*, 2016) and this compounds the challenges of expensive planning. Emergency planning approaches that prioritise protection or support of certain infrastructure systems in an emergency scenario may also be controversial and difficult to negotiate, as demonstrated in the Bangkok case study around transport.

Improving resilience often requires significant capacity and resources beyond business-as-usual, for example innovative urban design or up-to-date quality infrastructure maintenance. Many cities will face challenges to effectively mobilise additional finance, and source appropriate local skills and knowledge.

Where most national and city governments serve relatively short terms of 3-5 years, the political cycle can be disruptive to long-term cohesive planning and robust, sustainable infrastructure. Without committed and engaged political and/or wider multi-stakeholder collaboration, the effective implementation of long-term strategic planning is difficult.

Inclusive approaches require overcoming structural barriers presented by departmental and fragmented management practices. For example, inclusive service access requires many different parties involved in delivery and operation of infrastructure, each with varying interests and objectives. Developing inclusive infrastructure systems requires strong leadership, effective infrastructure planning, strong sector regulation and enabling finance. Related to leadership is the need for effective multi-stakeholder communication and collaboration, including between regional and national parties, and across systems such as water bodies or energy networks that are transboundary in nature, potentially posing wider political challenges.

Reducing demand, effective land use and infrastructure planning are crucial across all sectors. Rapid urbanisation and urban sprawl pose significant challenges to these objectives, and emphasise the need for effective urban and regional planning and innovative technological and planning solutions.

Whilst sector diversification reduces the likelihood of complete system failure, this approach can lead to greater difficulties in addressing technical and institutional problems, as issues are spread across multiple locations and stakeholders.

Ensuring an appropriate level of infrastructure redundancy can come at the expense of efficiency and an appropriate balance needs to be found, particularly within energy and water systems.

Smart technology can contribute to the resilience of all infrastructure sectors identified in this report. Whilst this technology might enhance awareness, control and efficiency of system operation, it also creates additional dependency on ICT infrastructure. Furthermore, without appropriate supporting programming, transition to technology-based systems needs to be delivered in a way that is inclusive, providing proper skills and training, and avoiding access constraints for those that cannot afford technology.

The challenges outlined above are not insurmountable. Actively seeking to identify and acknowledge constraints enables more effective planning, education and the identification of appropriate actions. Over the past 50 years cities have witnessed dramatic and successful changes in the way that infrastructure is delivered, with significant improvement to quality reliability, safety and continuity through technological advance, effective planning and learning. As with other complex challenges, building in the ability to learn and adapt as quickly as possible is key to finding the right balance for each context. Many of the principles outlined in this research are already actively promoted and implemented as “best practice” by planners, designers, and asset owners and operators across the world. Continued innovation, reflection and collaboration across sectors and industries are critical to address constraints in support of more resilient, inclusive, prosperous cities.

## 6. Recommendations for enhancing city infrastructure resilience: implications for the insurance industry

To facilitate the pathways for infrastructure resilience identified in this report, there are a number of areas where Lloyd's believes the insurance industry can work in partnership with other stakeholders. Local insurance markets will have an important role to play in starting meaningful dialogue with governments, businesses, and asset owners, and to take these infrastructure pathways forwards in their own city perspectives.

### 1. Shared understanding

There is a need to understand how all the components and stakeholders of cities interact, and what the key areas and concerns are for each stakeholder. The role of education and shared understanding is fundamental to facilitating action and incentivising change.

Crisis management and disaster response are significant parts of what the Lloyd's market specialises in, but with most of the world being either uninsured or underinsured there are too many disasters where the (re)insurance industry suffers little loss and does not play a significant part in the rebuilding (Lloyd's, 2015c). For the insurance industry, there remains an education challenge.

Public and policymaker understanding of risk is critical, and governments, insurers and other stakeholders should work together to ensure there is a greater understanding of the role of all parties in the economic and social consequences of poor risk management, and to allow the development of appropriate solutions.

One way to do this could be to work with a city to develop a proof-of-concept framework that could be tested with the goal of applying the framework at a replicable, worldwide scale. This concept is described in "Next steps" (see p58), in this section.

### 2. Data for decisions

Improved data collection, hazard mapping and other tools to manage and quantify increasing catastrophe risks in our underwriting processes will allow more accurate risk based pricing. Additional data collection, tools and research are important to identify future trends and anticipate future risks, as well as to better understand current risks, and the insurance sector is not alone in this.

Over the past five years the world has reached a point where some aspirations of resilience could be met by fully embracing the technology of today. There has been an exponential increase in data availability. In 1906 airships were used to survey damage from the San Francisco earthquake to be studied by people to make damage assessments (Taylor, 2016).

Today, satellites can capture imagery in a variety of image bands to derive various datasets (Bulter, 2013), which can then be processed by automatic classification software to detect access roads, damage patterns and the extent of the damage (Jean et al., 2016; International Disasters Charter, 2017; Satellite Applications Catapult, 2012).

This technological capability has the potential to be pushed forwards again with the rise of the "Internet of Things"<sup>b</sup> (Meola, 2016). By using new sources of data, insurers may be able to alert clients of potential losses before they occur, assess damage in real time, speed up the claims process and prevent false claims, reduce

<sup>b</sup> A network of internet-connected objects able to collect and exchange data using embedded sensors (Meola, 2016).

administration through automation, and allow more personalised products and services to be developed (Gasc, 2016), aiding overall response. City officials might also be able to track maintenance, manage responses and model impacts for more integrated decision-making. Assigning responsibility at the lowest key stakeholder during multi-stakeholder scenario and response planning could unlock administrative red tape and confusion in the wake of events.

### 3. Establishing metrics

This report considers many areas in which resilience can be enhanced. In many cases we have suggested that indices be created to track the current level of resilience. If such indices are created then they can, in principle, be used in models and underwriting processes as well as by city planners and other stakeholders.

Ensuring that any metrics, such as those involved in the Sendai Framework for Disaster Risk Reduction, are useful and useable by stakeholders will be key to their uptake. Conversely the absence of such indices will severely affect the degree to which insurers can actively incorporate resilience into our process given the level of complexity and number of locations involved.

If each building had a standardised data file containing agreed exposure information this could be consumed directly by insurers.

This report has called for indices in the following areas:

- Efficacy of natural defences
- Degree of diversity
- Asset maintenance levels
- Emergency response times
- Levels of critical resources
- Levels of independence of recovery services.

These could be combined into a single index or better still made available individually. Indeed indices relating to any of the items included in the Rockefeller Foundation City Resilience Framework would be useful.

Any data collection would need standards to ensure it is collated in a usable and useful format. Ensuring that data is available at greater granularity on a city-wide level is important, given there can be high levels of spatial variation. In the workshop held as part of information gathering process for this report, one of the attendees commented that the UK's Department for Environment, Food, Economic and Rural Affairs (DEFRA) flood models take a mean value across the data available.

This can result in information that is not usable as the actual risk underwriters are being asked to take isn't always at the granularity needed for an asset-level decision.

Insurers should work with government to administer policies aimed, for example, at improving construction standards or discouraging building in inappropriate areas. Better risk management could lead to lower pricing, reducing the overall cost to economic growth.

Initiatives such as Building Research Establishment Environmental Assessment Method (BREEAM, 2017) and Building Information Modelling (BIM) (Davidson, 2014) demonstrate the potential to generate demand and incentivise action by pushing initiative adoptees to engage in the design criteria. The next stage of BIM, level three, aims to get people working together and sharing data through defined processes, metrics and technology by using a single, shared project model that is held in a central repository (NBS, 2017).

If each building had standardised data files containing agreed exposure information, this could be consumed directly by insurers, banks, asset managers and facilities managers.

### 4. Developing models and tools

Models are often created on a case-by-case basis in response to requests. Finding a way to take a strategic view to allow proactive development for countries – such as the Vulnerable Twenty Group (V20c) – so they can be taken off the shelf, ready to use, is an area currently being explored by the Insurance Development Forum.

There is a need to provide tools that could offer a more transparent and comprehensive approach for analysing and pricing risk from extreme events. Ensuring that models are developed and maintained in a collaborative way is also an area to consider. As was seen in Hurricane Katrina, levee failure wasn't fully understood and accepted by some stakeholders but was well recognised by others. The scale of the risk was underestimated, and the response was insufficient to prevent or limit the impacts that unfolded.

Modelling potential scenarios and their impacts may also help in the debate on sustainability and general risk management in the built environment. The role of tools and models in informing actions to prevent failure and improve recovery is clear, but their potential role in

<sup>c</sup> The Vulnerable Twenty (V20) Group of Ministers of Finance of the Climate Vulnerable Forum is a dedicated cooperation initiative of economies systemically vulnerable to climate change.

supporting insurers and decision-makers to support long-term transformation towards improved practice might also be considered.

Ensuring these tools or their outputs are in an agreed format that can be integrated into other stakeholder systems will allow integration. The greatest need for this work is in developing countries and areas with low insurance penetration. A suggestion could be made to pool resourcing through initiatives such as the Insurance Development Forum to build the knowledge and capacity of developing and emerging countries, to allow them to manage and implement sustainable financing, and resilient investment.

The Oasis Loss Modelling Framework (Oasis LMF) is one initiative looking to support the use of catastrophe models beyond the (re)insurance industry to facilitate risk-informed planning and decision-making. It aims to generate an open marketplace for models and data, to lead to wider access to understandable tools for catastrophe risk assessment (Oasis Loss Modelling Framework, 2017a).

The framework provides “plug and play” data interfaces and web services that enable members to calculate the economic and insurance consequences of catastrophe events. The open-source aspect means that the latest thinking on natural disasters and climate change can be incorporated into Oasis’ models. For example, government agencies could use the Oasis LMF to build their own flood model and work with an engineering firm to model the financial impacts of building mitigation infrastructure (Lloyd’s, 2014).

If initiatives such as this are adopted and used by a wider set of stakeholders it could demonstrate the potential for insurance models to be used by all sectors to provide common understanding and a shared knowledge base to understand cities and risks as systems to help inform action to enhance resilience.

## 5. Use models to quantify risks

With the increase in the model availability and amount of data available comes the potential to use that information to make assessments about risks and to anticipate the potential impacts of hazards. This would help governments, communities and individuals to make informed decisions about resilience, insurance, investment, and wider policies and interventions. Quantification is the key to this.

Models can be used to help make transparent statements, such as:

- *“This asset is currently resilient to 1 in 10 risk of flooding.*
- *To be resilient to a 1 in 200 risk the following is recommended...”*

This kind of explicit disclosure of risk could act as a way to encourage stakeholders to understand and maintain their own detailed risk registers, and to hold open dialogue on the risks under consideration. Initiatives such as the “1-in-100 Initiative” are working towards this (United Nations, 2014a). It could also allow understanding about the differences between return periods and security.

Models are only as good as the data they are based on, and the insurance industry needs improved data collection, hazard mapping and other tools to assess increasing natural catastrophe risks in its underwriting processes. These overlap to some extent with what local and regional adaptation planners require to plan, and make recommendations for government-funded or mandated risk mitigation and adaptation measures.

Improved resilience to some risks is likely to result in more residual risks becoming, or remaining, insurable. This is an area to develop, as increasing resilience in one area can adversely change the resilience of others; for example, improvements to energy performance through insulation products led to unacceptable fire loads that could lead to a total loss (Zurich Municipal, 2011).

## 6. Design resilient assets

Infrastructure lasts a long time and risk levels are changing due to many megatrends, therefore it is important to create building codes that are robust to both current and future risks. Engineering studies will be necessary to achieve this since past data will not always be a good guide to the future.

Common building codes that incorporate resilience provide a level playing field for insurers and other stakeholders and make homes and buildings less vulnerable to the effects of hazards with less need for public or private disaster relief.

The study illustrates a range of tools and methods that could be relevant to the planning stage; the challenge is building them into the process, and establishing where they could be integrated. Equipment and other infrastructure components may be replaceable and upgradeable but many aspects of infrastructure performance that are set out at the design stage can be expensive and difficult to change.

Foundations and other parts of building envelopes can typically be in place for 50 years or more (Vaughan and Turner, 2013) – what meets current building and design codes of today may not meet future requirements to prevent infrastructure system failure.

Even if the impact of future catastrophes were known with certainty, it would not necessarily be understood exactly how the standards would need to be adjusted to reflect new levels of stress and resilience. Engineering research and network studies could help to identify the gaps between current standards for resilience, and the standards required under increasingly connected, human driven risks.

When stakeholders can rely on common sets of codes for planning, design, construction, and modelling, it is easier to assess and track appropriate metrics to understand critical infrastructure. Common building codes that should be applicable after a disaster strikes can encourage a “build back better” system but, at the same time, provide a level playing field for insurers. If this is only offered as an option within policies it can lead to low take up since premium rates are often higher, as a consequence of the costs of delivering increased resilience.

## 7. Incentivising investment

Finding ways to finance or support investment is a key challenge that often comes back to what information is available, and the way that knowledge is presented and used.

The ability to rate the resilience of assets would also be of use on the investment side, and resilience ratings could enable investors to integrate resilience considerations into all aspects of their portfolio-management activities. For example, if credit-rating agencies start to look at resilience as a measure of performance and factor this in to their assessments, this could provide an incentive to take action.

Underwriters can integrate indices and metrics into their assessment of risk. Ensuring that information is in a useful and usable format will be the key to effective adoption in the risk-assessment process.

This is an area that has received increasing attention from financial regulators in the past 18 months with initiatives such as the Financial Stability Board Taskforce on Climate-related Disclosure (FSB-TCFD). The group is working towards developing voluntary, consistent climate-related financial risk disclosures for use by companies. This information would provide information to investors, lenders, insurers, and other stakeholders to aid their decision-making processes by classifying risks (Sitt, 2016).

There is also a need to improve the risk/return profile of investment in green growth in this space, which can include adaptation (Climate Business Group, 2012). By focusing on reducing and managing the risk side of investment, this could facilitate the deployment of other forms of capital at the scale needed for growth.

The challenge of getting investors to commit funds has been recognised at the highest level by the G20 Green Finance Study Group. The group is working with the private sector and centres of excellence to develop a forum on environmental and financial risk, to facilitate knowledge on risk analysis and management within the financial sector (Cambridge Institute for Sustainability Leadership, 2016).

This is a complicated area that requires further research and dialogue as there is the potential for short-term moral and ethical questions for those with poor resilience ratings if they become unattractive risks. Yet this process could also help cities in the long-term to understand and communicate their risk and resilience strategies to stakeholders.

## 8. Incentivising resilience

It is in the interest of policyholders and governments to implement risk-mitigation measures, thereby potentially reducing both the damage from natural catastrophes and the cost of insurance.

One way the insurance industry incentivises policyholders to introduce risk-mitigation measures where local regulation prevails, is through risk-based premiums for implementing appropriate mitigating actions (Lloyd's 2011).

Another method is for insurers to give policyholders the option to share a greater proportion of the risk through offering policies with higher deductibles. Other things equal this reduces the costs of insurance but leaves the policyholder exposed to more risk, as such they may they are incentivised to take action to reduce their residual risks.

By offering risk-based premiums to asset owners or managers who have mitigated risk, the premiums would tend to be lower than average, other things being equal. In some cases this could even be made a condition for insurance.

Another option is for policyholders to share a greater proportion of the risk through choosing policies with higher deductibles. This provides a financial incentive for policyholder to implement cost-effective risk-mitigation measures in order to keep losses as low as possible below the full deductible amount. The incentive is also

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provided in part through savings in insurance premiums in return for them bearing more of the risk.

It is important to note that not every loss is recoverable under an insurance policy or may be a loss inside the deductibles. As such, individuals and businesses may experience resilience benefits if city policymakers and Administrators take action to enhance their resilience to events.

#### Offer resilience services

Consistent with the ClimateWise “Investing for Resilience” report, insurers could offer “resilience services”, which could include aspects of facilities management, disaster recovery, “build and operate” contracts, and insurance (CISL 2016). This could include upgrading the property covered by the service to improve its resilience, carrying out regular maintenance, recovery and repairs, and providing financial compensation in the event of a disaster.

This point was raised in a recent ClimateWise report (CISL 2016), raising a key innovation and development area for those working in the resilience space. The foundations of resilience service provision can be seen in the risk-management advice and assistance already provided by many insurers and brokers.

Resilience services could potentially be attractive to small and medium enterprises (SMEs) and larger corporates alike, who are accustomed to outsourcing parts of their operations. It could also be of interest to governments to help illustrate the value of insurance and how it can be integrated into government finance budgets as a value delivery aspect.

Providers of resilience services could also be incentivised to improve the resilience of the broader environment surrounding a property. These providers might be insurers, or might include other service providers. In this instance, risk transfer becomes one part of the overall service for risk that cannot be managed through other means.

## 7. Next steps

This report promotes a continual process of reflection, learning and action to promote infrastructure system improvement and transformation towards a “new normal” state; responding to global trends such as climate change, demographic change and technological advancement that can alter risk, demand, and performance requirements over time. However, there are challenges of implementation and adoption as the insurance industry is often presented with a final risk for assessment, rather than having been involved in the design, planning and procurement stages where change can reasonably take place.

There are many examples of individual initiatives that have tried to solve these issues, including but in no way limited to:

- 100 Resilient Cities
- African Risk Capacity
- Insurance Development Forum
- G7 InsurResilience
- My New Home
- R4 Rural Resilience Initiative

The challenge remains in making change happen at scale – ultimately insurers are competing entities and coverage levels may differ in the approaches taken, so there is real importance in making collaboration happen in the precompetitive space.

Insurers often assume that they can get in to a loss site swiftly and start the assessment process to get insureds back on their feet, but this can be a bottleneck point where access is prevented and that halts forward momentum (Thomson, 2016). In the Fort McMurray wildfire of 2016, due to the shifting fires insurers were not allowed onsite until day 26 (Edmonton Sun, 2016). This access issue saw a number of stakeholders, not just insurers, investigating innovative satellite technology to capture imagery to be used for remote damage assessment (Mogg, 2016).

This effect – also known as the duration effect – where insurers and other stakeholders cannot access loss sites is one of the key issues to solve, and can be more effectively explored in the “expediting the recovery pathway” (see *Section 5.2, p48*). The use of remote damage assessment technology, either via satellite or drone aided, is an innovation space that is rapidly developing, and is an opportunity for action, not only for insurers but all those involved in and responsible for the recovery of cities and communities.

### Establishing a demonstrator city

Emergency response and disaster relief agencies often hold live exercises to test their plans, and adopting a shared scenario process and risk models could be used to develop a broader systems model for all parties to coordinate and plan their responses. Local offices should explore partnerships in their cities that run these exercises to ensure insurers’ views are heard, and can demonstrate the tools and expertise that could be used to develop contingency and operations plans with agreed standards and guidelines, and expected responses by stakeholders with assigned ownership and responsibilities (African Risk Capacity, 2017).

Assigning responsibility for actions at the lowest key stakeholder level – e.g. defining who exactly is responsible for what in a city Department, such as planning teams distributing building information – during multi-stakeholder scenario and response planning could cut red tape and confusion in the wake of events. Partnerships are the only way this will happen.

Establishing answers to the following basic questions could help processes flow to get cities up and running – something that all stakeholders are working towards:

- What is needed?
- Who is responsible for what?
- Who gets access when?
- Where resources and data can be shared between stakeholders with common goals?

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A single demonstrator city could be chosen to explore this framework so a template approach can be applied to cities around the world. This kind of scenario approach could also be adopted and expanded to cover other pathway responses. All parties – government, private sector, communities, etc – should be involved to see what is possible under each pathway, and through the process of building common understanding and building relationships in advance identify what would help during of the first critical hours of disaster response.

This common understanding could also enhance the development and value of coupled models<sup>d</sup> to understand the flow of impacts and reactions, such as what and where the costs are for cities, and how systems respond to changes, to test the impacts and effects. This could facilitate better pricing for investors and more informed decisions by policymakers, and ensure a smoother journey to a more resilient future.

<sup>d</sup> State-of-the-art computer simulations of past, present, and future states.



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## 8. Overall conclusions

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Enhancing resilience at a city and global scale will require action at many levels to move from reacting after disaster strikes, to create a world where failure to plan in advance is unacceptable.

This study brings together a clear picture of how infrastructure resilience can be practically addressed with a set of innovative principles for planning, design, and operation. Many of the resilience principles identified in this research are already actively promoted and implemented as “best practice” by planners, designers, and asset owners and operators across the world.

Truly building resilience for all stakeholders means finding new ways to bridge silos within and between government, the private sector and communities to measure and account for the benefits of resilience (direct and indirect), and to incentivise resilience-building activities.

Lloyd’s and Arup hope this study can stimulate that discussion and, where appropriate, prompt innovation among insurers, governments and city stakeholders to help improve resilience, mitigate risk and protect infrastructure.

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