



Toolkit for Resilient Cities

Executive Summary

A research project carried out by Arup, RPA and Siemens

California Academy of Sciences, San Francisco



Summary for Decision Makers

Between 2000 and 2012, natural disasters – including weather, health and seismic events – caused \$1.7 trillion (£1.1 trillion) globally in damages. This figure includes direct impacts on infrastructure, communities and the environment, together with reductions in business profitability and economic growth in affected regions.¹

Resilience is the ability of people, organizations or systems to prepare for, respond, recover from and thrive in the face of hazards. The goal is to ensure the continuity and advancement of economic prosperity, business success, environmental quality and human well-being, despite external threats. In a globalized world, only the most resilient cities will remain economically competitive and attractive for business growth, and capable of adapting to continually changing conditions.

This paper explores how the resilience of critical urban infrastructure systems might be

enhanced to prepare cities more effectively for major weather-related hazards² and the co-benefits resiliency actions have, e.g. environmental performance, energy efficiency, safety & security etc.

Our research has focused on physical infrastructure relating to energy, transportation, water and buildings. These systems were chosen because they underpin many other essential city operations and services, including sanitation, emergency response, and the delivery of food, fuel and other materials. Our research considers proven technology solutions applicable to emerging and established cities, and the enabling actions required from policy makers, utility providers and other city stakeholders to facilitate delivery.

Creating Resilient Systems

The creation of resilient infrastructure systems may require large scale changes to the way infrastructure is planned, designed, managed and maintained. In many cases, advanced technology and instrumentation can facilitate the development of systems with greater ability to withstand and respond to sudden impacts. Resilient technologies for energy, transportation, water and building

systems share common attributes, which are largely underpinned by advanced IT and communication services.

Robustness of new and existing infrastructure

Resilient infrastructure networks must incorporate components that will continue to function in an ever-changing environment. All equipment must be capable of handling stronger winds, more intense rainfall, higher temperatures, and other impacts. This implies improved specifications for new system components (including water and heat resistance) and the use of sensitivity analysis during system planning and design to take account of more extreme operating conditions. Revised asset management regimes are also required to ensure maintenance of acceptable performance. At the network level, utility managers may consider optimizing the location of new or redeveloped infrastructure to reduce exposure to hazards, including undergrounding or elevation of essential equipment.

Decentralized resource supplies and distribution networks

Energy, transportation and water infrastructure can be designed to operate both as part of a

large system and to serve a more localized community independently of the wider network. This relies on multiple connected microgrids that can either operate together or individually. During a major hazard event, microgrids can buffer local service users from impacts elsewhere. IT is the key enabler allowing service providers to switch operations from microgrids to integrated networks and vice versa. Besides contributing to resilience, local solutions can also improve the efficiency of water and energy supplies by reducing distribution losses.

Enhanced monitoring and controls

System monitoring and control is underpinned by increased application of IT networks and IT-enabled equipment (such as field devices and sensors), either embedded in new infrastructure or retrofitted into existing assets. Improved monitoring and control capabilities for all infrastructure can enhance resilience by providing detailed and rapid information to utility managers and city leaders regarding operating conditions and performance. This has the potential to minimize feedback loops and response times, enabling diversion of resources to priority areas while limiting the overall loss of system function. Furthermore, the proliferation of IT-based equipment across infrastructure networks leads to greater connectivity between systems. With greater ability to share information, performance can be optimized across all city network domains.

Creating Resilient Cities

Technologies alone cannot make urban infrastructure resilient. They will not be adopted without an appropriate climate for the required investments, and their potential benefit will not be secured unless system operators are equipped to use and act upon the information and controls that technologies can provide. Changing social, political and economic conventions is as fundamental to the success of city resilience initiatives as is upgrading physical assets. Implementation of technology solutions often requires a broader 'enabling' toolkit, which includes changes to urban planning, policy and regulation; governance; knowledge development; and financing models. No single piece of this toolkit can deliver resilience on its own but a number of actions must be taken.

Urban planning and land use policies can direct development in ways that protect people and structures from harm

Every city has its own planning constraints related to topography, historic patterns of growth, land ownership or tenure, and land values. Well entrenched planning 'norms' can deter proactive change and impede progressive adjustments to changing external conditions. Nevertheless, effective planning and land use policies can reduce the loss of life and property in the event of a disaster. Buffers, building codes, easements,

transfers of development rights, and no-build and no-rebuild zones can aid in this goal. Inadequate or poorly performing infrastructure may not be easily adapted to meet resilience criteria, while the lack of space may inhibit relocation or renewal of at-risk assets.

Resilience practices should be adopted in policies, planning and construction across all city districts, to ensure that resilience of the whole city is increased and not enhanced in one community at the expense of another.

Governance should take a whole system approach to city management

Governance needs to take a whole system approach, taking advantage of the interdependency between sectors through greater coordination and communication. Collaborative planning should be normal behavior, not just a crisis response strategy. Decision making should extend across disciplines and progress should be monitored using shared metrics.

Collaboration is important throughout disaster preparation, relief, recovery and rebuilding. Different parts of the process require different skills and expert knowledge, which can only be gained through an interdisciplinary approach.

Improved knowledge and capacity can help city stakeholders plan for and recover from emergency situations.



There can be an information gap at many levels in city decision making from the top level of government down to individual households. Knowledge and the capacity to act influence the types of infrastructure that a city is willing or able to adopt. A strong understanding of a city's dependence on systems, the interdependencies between systems, regional convergence and coupling is needed to optimize the selection of new technologies and equipment

Data can be used to provide a sound evidence base for decision making. Hazard preparation and response can be inhibited by a lack of data and information about at-risk assets. Where data exists, it is often sector focused and not widely available to decision makers who need it. Furthermore, misinterpretation of data is common and can mean it is not

utilized effectively. Lack of sound evidence can undermine public confidence in governance organizations.

Cities should create a data clearinghouse to help identify and monitor structures, systems and places that are exposed to hazards. The clearinghouse should be supplied with data from all key sectors and the community.

Appropriate financing mechanisms are needed to support investments in resilient infrastructure

City resilience strategies require sustainable financing, both for capital and operational investment. This can be a particular challenge under limited city budgets, especially in low income countries.

Investments should be appraised against longer timescales to match the lifecycle of most infrastructure assets. This would ensure that the full scope of short term costs and long term benefits are taken into account in investment decisions. City budget allocations should prioritize investments that amass the most benefits over the long term, based on both present and anticipated future conditions. Where possible, resilience criteria should also be integrated within normal city maintenance and upgrade routines, thereby entirely avoiding the need to justify unusual project investments.

Where upfront capital is required, innovative financing mechanisms may be needed to support resilience investments, including new economic incentives and revenue sources, such as grants, taxes and fees that help build redundancy, flexibility and reduce consumption.

New York City: increasing the resilience of the electricity grid

The city of New York is an international icon, offering an attractive environment for businesses and residents. The city has established a strong identity as a global enterprise hub; a center of commerce, highly connected to trade and industry throughout the world.

But with great strength, comes great vulnerability. During just a few hours in October 2012, Superstorm Sandy brought winds of up to 85mph (38 m/s) and a peak storm surge of 9 feet (2.7 meters), which occurred on top of a 5 foot (1.5 meter) high tide. The storm caused widespread loss of power to residents and businesses across the metropolitan region, and rapidly focused New York City on some very basic needs.

We undertook a high level review of the vulnerabilities in the New York City electrical grid and the steps that could be taken to mitigate risk. Impacts of four types of natural hazards (drought, heat wave, wind and flood) on the generation, transmission and distribution of electricity were explored, in order to extrapolate how.

From the analysis of the threats to the grid, we developed a range of investment options.

Making equipment more robust

In the short term, technologies that promote robustness will be essential. Protection measures include flood-proofing and waterproofing substations and installing submersible equipment, undergrounding critical overhead lines, adding hydrophobic coatings on overhead lines, and installing fuse-saving technologies.

Expanding demand reduction programs to reduce peak demand and network congestion

Demand response programs are typically voluntary programs with incentives that are initiated by the utility contacting the customer but there are greater opportunities with advanced metering infrastructure (AMI) and Energy Management Systems (EMS) at the building level for automated demand response through the internet.

Developing a smart grid for greater flexibility and responsiveness

In the medium term, investing in AMI will provide detailed, real time information to help manage the large and dynamic power grid. Smart meters communicate with a wide range of user control systems, and securely and reliably communicate performance information, price signals and customer information to the utility.

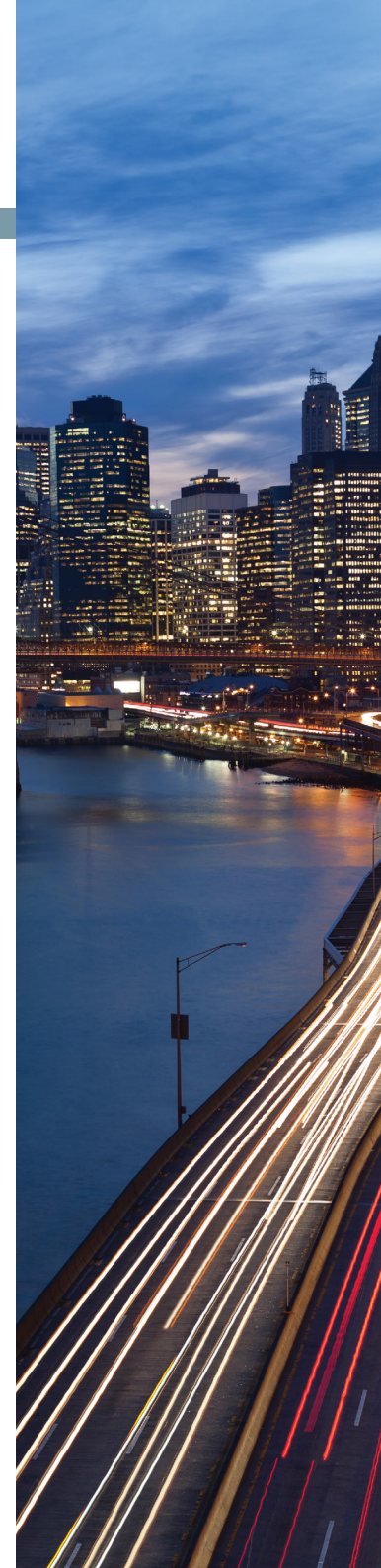
Distributed automation of the systems will integrate smart technologies and provide a monitoring and control function to allow for system performance optimization. Intelligent feeders and relays, voltage/Voltage Ampere Reactive (VAR³) controls, and automated switches are essential to enable this function.

In the long term, investments such as increased deployment of distributed generation, Automated Demand Management (ADM) – which connects buildings to the grid and reduces grid load by automatically powering down non-critical appliances – and vehicle-to-grid (V2G) technologies will all make the grid more resilient by increasing the diversity of supply, creating system capacity at times of peak demand, and enabling flexible means of energy storage.

Economic benefits for New York City

An economic analysis was developed to demonstrate the business case for investing in technologies that enhance resilience and help to manage risk by improving robustness, redundancy, responsiveness, flexibility and diversity to the grid, while also increasing capacity and efficiency in normal times.

Our analysis projected a cost of \$350 to \$450 million (£225-290 million) every three years, based on the damages caused by recent events and their projected frequency in the future.⁴



If this scenario prevails, the city and the tax/rate payers will pay up to \$3 billion over 20 years just to repair the damage (in red in graph labeled as 'no action').

The simplest course of action to avoid these costs is to increase infrastructure robustness. Flood and wind protection measures for critical assets can be implemented relatively quickly (within three years on an accelerated schedule) with a cost in the range of \$400 million (£258 million). Implementing these measures should reduce the cost of repair and response in the next 20 years by approximately \$2 billion (£1.3 billion) (in blue in graph labeled as 'partial investment').

However, the robustness investments provide only a defensive solution which can at best reduce losses. Meanwhile, full investment in protection together with smarter infrastructure solutions will not only reduce the impact of future events event, but will also provide long term added benefits to the city, its residents and its businesses. On an ambitious 12-year investment program, city agencies and utilities will need to spend approximately \$3 billion (£1.9 billion) to introduce an effective system of smart technologies.

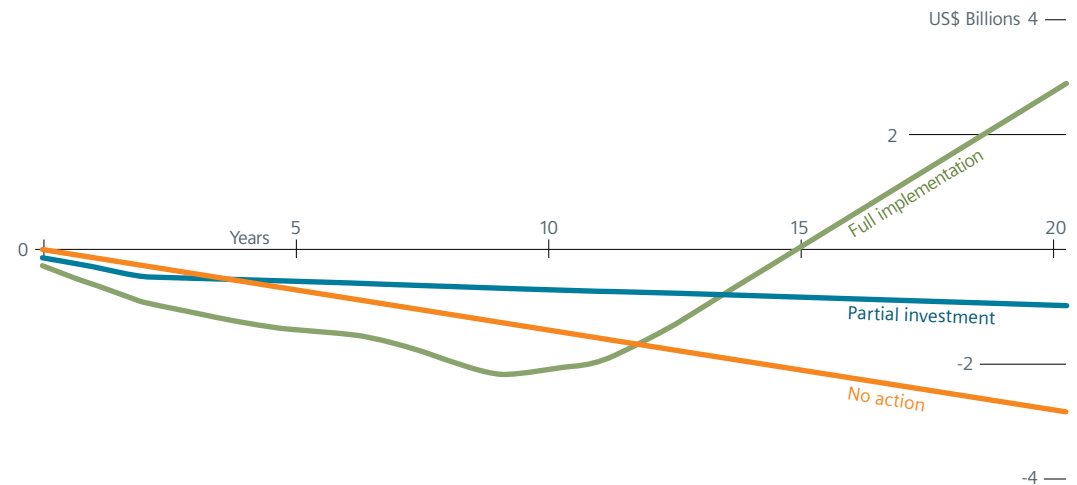
This is a significant cost, but these investments should lead to:

- Fewer outages and increased reliability for the utility and the customer
- Decreased transmission and distribution losses, with consequent system cost reductions
- Reduced need for additional generation capacity due to improved system energy efficiency

- Reduced disruption to priority energy consumers, including medical and emergency services, businesses and industry
- Reduction of greenhouse gas emissions and other pollutants
- The continued ability of the city to maintain its global competitiveness.

The financial value of these benefits may reach \$4 billion (£2.6 billion) (in green in graph labeled as 'Full Investment').

Economic analysis of future scenarios for New York City electrical grid



References

- ¹ United Nations International Strategy for Disaster Reduction, 2012
<http://www.unisdr.org/we/inform/disaster-statistics>
- ² Man-made risks such as terrorism, economic downturn and cyber attacks are outside the scope of this particular research, but should form part of a comprehensive strategy for resilient cities. It should be noted that the benefits accruing to cities from resilient infrastructure also extend to man-made disasters and accidents. The concept of resilience therefore allows cities to have an integrated approach to all hazard types.
- ³ VAR controls help distribution feeders to maintain acceptable voltage at all points along the feeder and help to maintain power. VAR is highly important to reduce transmission losses.
- ⁴ Con Edison offers plans to protect customers and energy systems from major storms, Con Edison Media Relations, January 25 2013

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