

# Keeping an eye on infrastructure systems: 4 tactics

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Planning decisions have a long-term impact on the resilience of urban systems—and not just in Singapore. Credit: Colourbox

Even minor disruptions in infrastructure systems can have fatal consequences. Researchers and practitioners counter that risk by taking action on multiple levels. Four examples.

## Urban systems: increase resilience

By trade, Božidar Stojadinović is an expert in earthquake-proof construction. Now a Professor of Structural Dynamics and Earthquake Engineering, he specializes in [urban systems](#) and how to make them more resilient to earthquakes. "Systems engineering has become increasingly important in resilience research," he says. His combination of skills made him an obvious choice to head up a research cluster in the Future Resilient Systems program in Singapore—even though earthquakes are one of the few topics not on the agenda. Instead, the goal is to understand the resilience of high-density urban systems—of which Singapore is a good example—and to strengthen them in preparation for future challenges. The key challenges confronting Singapore are climate change and land scarcity. Responding to this will require long-term planning and timely changes to urban infrastructure.

Together with researchers from Nanyang Technological University Singapore (NTU) and the National University of Singapore (NUS), Stojadinović is developing a comprehensive computer model of the city that can be used to simulate urban systems as well as any challenges and their effects. In addition to incorporating all the buildings and associated infrastructure systems, such as power and water, this digital representation can be used to model user interactions with the systems. The model itself is based on a computer software framework originally developed for military war games and now widely used in gaming. The software lets users run multiple simulations of a variety of systems and exchange information between them. "That's a crucial feature," says Stojadinović. This is because of the sheer complexity of urban systems and the way that individual subsystems influence each other. "We're already pretty good at modelling and optimising individual systems, but often we don't fully understand how systems influence each other," he adds. The model that Stojadinović and his fellow researchers are developing aims to solve that problem and encourages experts to look beyond individual infrastructure systems and to perceive urban systems as a whole.

## Critical networks: manage risks

"Nobody could have predicted it" is an oft-heard response to [system failure](#). Giovanni Sansavini, ETH Professor of Reliability and Risk Engineering, works tirelessly to disprove that notion. An engineer by training, he studies risks in [complex networks](#) such as interdependent energy networks and large supply chains.

Risks in complex systems are hard to grasp in scientific terms. That's because systems tend to grow or shrink over time and change their structure. Many of them span the entire globe, and they often have no fixed mode of operation. Power grids, for example, are subject to diverse influences, and under load they respond differently than in normal operation. To address these challenges, Sansavini and his group experiment with computer models. They identify risks using the scientific method of uncertainty quantification, which allows researchers to capture a broad spectrum of conceivable impacts, errors and failures, and to observe how the modeled network behaves. Such Monte Carlo simulations make it possible to analyze the interrelationships between numerous failures. This opens the door to the discovery of hidden or "systemic" risks—the kind that can trigger the cascading failures that are often the cause of serious problems in complex systems. One example of this was a major blackout in Italy in 2003, which was caused by automatic systems shutting down one after the other as they came under increasing load.

Sansavini's models serve not only to identify risks, but also to quantify them. Thus, the researchers can determine which combinations of failures have the worst consequences for a system and how likely they are to occur. Understanding these scenarios is the basis for providing systems with adequate protection. In the case of energy grids, that might mean making them more flexible and less reliant on individual energy sources. Or setting up early-warning systems, introducing technical

improvements to address vulnerabilities, and helping the grid quickly return to normal after disruptions. "Of course, however robust we make the systems, people will still make mistakes, and unexpected things will happen," Sansavini cautions. The good news is that even these mistakes can be replicated in the virtual model. This means we can predict the system evolution and make it more resilient to disruptions in the future.

## **Complex systems: predict failures**

Olga Fink and her team conduct research on faults in complex systems, from aircraft and gas turbines to [infrastructure systems](#) such as railways. As Professor of Intelligent Maintenance Systems, Fink develops [intelligent algorithms](#) that learn from data collected by condition-monitoring devices. These algorithms address various challenges, from detecting system faults and diagnosing different failure types to predicting when the next failure might occur—or even implementing a prescriptive maintenance strategy. "Our goal is to predict the remaining useful life and then control the operation of a system to prolong its service life," says Fink. The intelligent algorithms learn from both historical and real-time operation and condition-monitoring data.

One hurdle is that machine-learning algorithms need a lot of data. "Failures are rare in safety-critical systems, so we don't really have enough data to learn from," says Fink. Fortunately, the researchers have some tricks up their sleeve: "One approach is to use data that represent the system's healthy state and train the algorithm to detect deviations." It can also be helpful to use condition-monitoring data from similar systems and adapt them to a specific system. Yet, in many cases, even these methods may not be sufficient. The researchers must then go a step further, by combining their algorithms with physical models that simulate the system they are monitoring or enriching the AI models with physical domain knowledge. This means the algorithms can work with less data and are easier to interpret by the experts who have to make

decisions based on the algorithm's outputs. In one project with NASA, for example, the researchers were able to predict the remaining useful life of aircraft engines. Olga Fink is particularly proud of this achievement: while early fault detection is now a mature process, predicting the remaining useful life of a system is a lot harder. It has been, she says jokingly, the "holy grail" of her area of research.

## **Critical research facilities: focus on redundancy**

Managing disruption is part of everyday life for Walter Iten, Head of Facility Management at ETH Zurich. His department is in charge of technical and infrastructure management for all ETH buildings and facilities. Iten says power failures are the biggest problem: "Nothing works without power!" That's why ETH relies on redundancy. Facility Management can draw power from two different substations for part of the Zentrum campus. And, in the event of a major power cut, the most important areas also have access to back-up diesel generators. For particularly sensitive research equipment, batteries are used to ensure an uninterrupted power supply.

But the jewel in the crown is the predictive maintenance strategy for all the facilities and buildings, which aims to prevent disruptions of all types from occurring in the first place. An IT maintenance tool keeps track of each system's operating hours and maintenance schedule, and triggers maintenance jobs as they become due. An increasingly important role is also played by sensors, which monitor systems to detect sudden failures. The Facility Management team can access these data remotely on a computer and intervene to a certain extent in the operation of the system. Currently, the facility-monitoring system and the maintenance tool are not connected—but, with the latest advances in sensor technology and AI, it is only a matter of time.

Provided by ETH Zurich

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