Editorial

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1 Introduction

The Emerging Frontier in Research and Innovation (EFRI) programme of the National Science Foundation (NSF) issued in 2007 a solicitation which, in its RESIN section, called for submission of proposals aims at addressing the resilience and sustainability of interdependent critical infrastructures. The following year, eight projects were funded by this programme. This work motivates the initiation of this special issue of the *International Journal of Critical Infrastructures*, which features seven papers summarising the most salient research findings of these projects.

During the duration of these projects, five yearly workshops were organised, where the project investigators had the opportunity to present their research activities to each other and to discuss and define the concepts of robustness, resilience and sustainability for interdependent critical infrastructures. The following definitions proposed by Mili (2011) were discussed:

Definition 1: The robustness of a system to a class of disturbances is defined as the ability of this system to maintain its function when it is subject to disturbances of this class.

Definition 2: The resilience of a system to a class of *unexpected* extreme disturbances is defined as the ability of this system to gracefully degrade and to recover its function once the disturbances ceased.

Definition 3: Sustainability is defined as the ability of a system to restore its intended function following a major breakdown while inflicting during its whole life cycle, from cradle to grave, a minimum damage to the earth ecosystem in terms of resource usage and waste disposal.

These definitions raise several remarks. Firstly, robustness and resilience are obviously complementary but not antinomic properties of a system. The robustness of a system is synonymous to resistance to disturbances by absorbing chocks while maintaining its function. On the other hand, the resilience of a system is its ability of preserving its backbone while avoiding a complete breakdown even at the expense of losing some degree of functionality.

Secondly, it is important to notice that robustness and resilience are not general properties of a system, but are relative to specific classes of perturbations. As pinpointed by Carlson and Doyle (2002), the more an engineering system is designed to be robust to a specific class of failures, the more it will become fragile and vulnerable to another class

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of failures. Hence, robustness comes intertwined with fragility. The example that they give to illustrate this duality is enlightening. They stress that the control systems of a modern airplane are made of an intricate hierarchical network of thousands of computerised feedback loops that provide high robustness to a variety of environmental perturbations, but by the same token, expose the aircraft to dangerous vulnerabilities to major power failures. This duality, robustness/fragility, also apply to critical infrastructures, including electric power systems. For instance, a bug in the software programme carrying out a key monitoring function or a vital control scheme can play havoc with the normal operation of these infrastructures. See for instance, the 2003 US-Canada Northeast blackout or the more recent deadly Metrorail collision in Washington DC that occurred in 2009. In the former event, the origin of the blackout can be traced back to a topology error in the database of the state estimator (US-Canada Power System Outage Task Force, 2004) while in the latter event, the accident was due to errors in the software programmes that automatically drive the Metrorail trains and control its emergency stop mechanism. Similarly, a system that is resilient to a certain type of failure may be fragile to another one.

The third remark is that robustness is a predefined characteristic of a system, embedded in its original blueprint envisioned by the designer or the planner whereas resilience is an emergent property of distributed agents that control a system of weakly coupled modules. Let us elaborate on this point. As resistance to disturbances, robustness requires strong coupling between the various components of the system. It is usually achieved either via an enhancement of the redundancy in the system by providing multiple paths to the input/output relationships or via conventional feedforward or feedback loops that have well defined responses to perturbations. By contrast, resilience requires flexibility, agility and adaptability to a changing environment that has not been envisioned during the design process. In other words, the control actions are to be specific to each situation that is new and unique. This is possible only if the controllers are agents endowed with a certain degree of self-learning, self-innovating and self-improvising abilities to generate novel actions called for by unexpected events whose occurrences come as a surprise.

2 The contents of the special issue

The first paper authored by Nguyen, Cai, Ouyan and Housh takes a complex system viewpoint to provide a unified definition of the concepts of interdependency, resiliency, and sustainability and proposes a mathematical framework to quantify them as system of systems. These concepts are demonstrated in a case study using a biofuel model.

The second paper authored by Chen and Mili applies a sequential Monte Carlo simulation approach to find the optimal placement and sizing of microgrids in composite reliability of a deregulated power system while accounting for the optimal coordination between renewable energy conversion, energy storage, and micro-turbine generation within microgrids. It is shown that microgrids contribute to the improvement of both the reliability and the resilience of a power system.

The third paper authored by Urken investigates the use of error-resilient data fusion systems based on multi-agent technologies and voting schemes to control in a coordinated manner a collection of microgrids connected to the feeders of a power distribution system. The aim of this control is to stabilise an electric power system subject to some disturbances. Scenarios involving centralised and decentralised communications network are being considered.

The fourth paper is authored by Ibanez, Lavrenz, Gkritza, Mejia-Giraldo, Krishnan, McCalley, and Somani. The paper develops a multi-objective optimisation approach based on network flow modelling aimed at long-term planning of the national electric power and transportation infrastructure. The interdependencies between these two infrastructures are unveiled and their impacts analysed under the assumption of the presence of a large fleet of electrical vehicles among cars, trucks and trains.

The fifth paper authored by Marshall, Bolon, Kelly and Keoleian investigates how adaptive behavioural responses of drivers of electric vehicles together with trip prioritisation can improve the robustness and resilience of the transportation infrastructure. In a case study using National Household Travel Survey data, two metrics of resilience, namely the realised travel factor and the ratio of competed to demand travel, are applied to quantify the transportation infrastructure resilience to gasoline supply disruption.

The sixth paper authored by Pandit and Crittenden develops a new composite network resilience index that integrates six characteristics of the topology of an urban water distribution infrastructure. This composite index is then used in a multi-objective optimisation approach to seek the best infrastructure topology that achieves some efficiency and resilience objectives. A study indicates that these two goals may conflict, which requires to carry out some trade-offs in the design process of the network flow.

The seventh paper is authored by Roe, Bea, Jonkman, Faucher de Corn, Foster, Radke, Schulman, and Storesund. The paper proposes a risk-based approach that assesses and manages human, organisational, and informational uncertainties of interdependent critical infrastructures. The approach is applied to the coupled critical infrastructure systems at the site and the regional levels in the Sacramento-San Joaquin delta of California.

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