PhD Proposal 2017

School: CentraleSupélec	
Laboratory: LGI	**Web site: http://www.lgi.ecp.fr/**
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Collaboration with other partner during this PhD: **In France:** Possibly Electricité de France, EDF	**In China:** Center for Resilience and Safety of Critical Infrastructures (CRESCI), School of Systems Engineering and Reliability, Beihang University (BUAA), Beijing.

Title: Risk, Vulnerability and Resilience Analysis of Critical Infrastructures by Information Theory
Scientific field: Engineering
Key words: risk, vulnerability, resilience, critical infrastructures, interdependences, modeling, information theory

Details for the subject:

Background, Context:

The welfare of modern society relies on the continuous operation of Critical Infrastructures (CIs) that are essential in providing goods (such as energy, water, data) and services (such as transportation, banking and health care) across local, regional and national boundaries [Kröger and Zio, 2011]. Examples of engineered, physically networked CI are those providing services of:

- energy (including generation, transmission, distribution and storage, in regard with electricity, oil and gas supply);
- transportation (including rail, roads, aviation and waterways);
- information and telecommunication (including information systems, industrial control systems (SCADA), Internet, fixed and mobile communications and broadcasting).

These infrastructures are getting more and more automated, and strongly interconnected due to their increasing extension on large scales and the pervasive introduction of information technology. If, on one hand, these advances have increased their efficiency, on the other hand, they have created new vulnerabilities to component failures, natural and manmade events. Actually, in the last decades an increased number of disruptive events (natural external events, malicious acts, large scale blackouts) affecting CIs has occurred: for example, World Trade Center attack (New York, 2001), North American blackout (eastern USA and Canada, 2003), Mw 9.0 earthquake and subsequent tsunami (Japan, 2011), etc.

To conduct a comprehensive review on CIs and recommend a national policy for protecting and assuring their continued operation, the President's Commission of Critical Infrastructure Protection (PCCIP) was created in 1996 [PCCIP, 1997]. Other international federations and countries followed with some delay, such as the European Union that introduced the European Program for Critical Infrastructure Protection (EPCIP) of 2004 to "assure the continued functioning of Europe's critical infrastructure" [COM, 2004]. The infrastructures defined "critical" are those "whose services are so vital that their incapacity or destruction would have debilitating impact on the deface or economic security of any state" [COM, 2004].

CIs are complex systems made by many interacting components assembled by design to provide optimal, consistent and reliable operation, and functional safety. Emergent (unexpected) behaviors may arise in CI systems in response to changes in the environmental and operational conditions of its components. As a result, large uncertainties exist in the characterization of the failure behavior of the elements of a CI, which make CI failure predictions difficult [Zio and Aven, 2011].

For ensuring adequate protection and resilience of CIs, their vulnerability and risk must be analyzed and assessed in order to prepare to address them by design, operation and management.

When analyzing such complex systems, the following challenges tasks must be addressed:

- The representation and modeling of the system.
- The quantification of the system model.
- The representation, propagation and quantification of the uncertainty in system response.

In this context, modeling and analysis by reductionist methods are likely to fail to capture the behavior of the complex systems that make up the CI, and new approaches are needed that look into these systems from a holistic viewpoint to provide reliable predictions of their behavior for their safe control. Furthermore, large uncertainties exist in the characterization of the failure behavior of the elements of a complex system, of their interconnections and interactions.

The analysis of these systems cannot be carried out only with classical methods of system decomposition and logic analysis; a framework is needed to integrate a number of methods capable of viewing the problem from different perspectives (topological and functional, static and dynamic, etc.), under the existing uncertainties [Zio, 2015].

Research subject, work plan:

The PhD candidate will tackle the challenges of system representation, modeling and simulation accounting for the presence of uncertainty to evaluate system vulnerability.

In this respect, he/she is strongly encouraged to perform a system analysis based on Information Theory (IT) that has been recently applied in the ecological field showing interesting insights of ecosystem behavior [Ulanowicz et al., 2009]. Since ecosystem and CI networks are complex systems presenting similar characteristics, it is expected that IT can provide important insights also in the analysis of CIs. The idea behind the use of IT is to account for both system characteristics that are present (i.e., that contribute to the order of the system) and absent (i.e., that contribute to the lack of order of the system in the form of diversity of processes). The absence can be crucial for system vulnerability, similarly to the ecological field where the absence of a specie can have impacts on the persistence of other species. IT allows (i) quantifying the positive contributions that lacunae can afford a system in its response to disturbances and (ii) evaluating the system sustainability by balancing the effective performance / efficiency (due to the presence of order) and the reserve capacity (due to the absence of order) of the system.

These factors are seen to be in opposition: when the efficiency of the system increases, its reserve capacity decreases and vice versa. As a consequence, if efficiency and reserve capacity are not properly balanced the system collapses due to the lack of resources to withstand unexpected disruptive events (too much efficiency) or it stagnates due to the increase of flexibility and connectivity (too much reserve capacity).

This analysis can give important insights on the structural and dynamic behavior of CIs, in support to their design and operation.

The thesis aims at preparing the PhD student to become a risk expert with the capability of handling with scientific rigor the complexities and uncertainties associated to complex technological systems. In doing so, the student will gain fine expertise in specific mathematical techniques for computational modeling and analysis of complex systems. This type of expertise is highly valued by industries and governmental organisms dealing with complex system (energy, gas, transport, aeronautics, …).

The study will focus on risk, vulnerability and resilience analysis of CIs (e.g. the electrical grid).

References:

COM. (2004). Communication from the Commission to the Council and the European Parliament: Critical Infrastructure Protection in the fight against terrorism. COM(2004) 702 final, Commission of the European Community, Brussels, Belgium.

Kröger, W., and Zio, E. (2011). Vulnerable Systems, Springer, London.

PCCIP. (1997). Critical Foundations - Protecting America’s Infrastructures. Washington, DC.

Ulanowicz, R. E., Goerner, S. J., Lietaer, B., and Gomez, R. (2009). Quantifying sustainability: Resilience, efficiency and the return of information theory. Ecological Complexity, 6(1), 27-36.

Zio, E. (2015). Challenges in the vulnerability and risk analysis of critical infrastructures: the need for an extended risk assessment and management framework for critical infrastructures protection and resilience. submitted to Reliability Engineering & System Safety.

Zio, E., and Aven, T. (2011). Uncertainties in smart grids behavior and modeling: What are the risks and vulnerabilities? How to analyze them? Energy Policy, 39(10), 6308-6320.