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Enhancing Resilience Of Critical Infrastructures By Optimal Allocation Of Redundant Interdependencies

Andrea Bellè[a], Zhiguo Zeng[b], Marc Sango[c], Anne Barros[b]

[a]*Thales Research & Technology, Palaiseau, France*
[b]*Chair on Risk and Resilience of Complex Systems, Laboratoire Génie Industriel, CentraleSupélec, Université Paris-Saclay, Gif-sur-Yvette, France*
[c]*SNCF, Direction Technologies Innovation et Projet Groupe, Innovation & Recherche, Département Physique du Système Ferroviaire, Equipe Sécurité Système, France*

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Critical infrastructures (CIs) represent the backbone of highly advanced societies and the socioeconomic wealth of any population strongly depends on its system of CIs. In fact, CIs are responsible for supplying basic and essential commodities and services, such as energy, water, telecommunications, and transportation, and any failure or disruption within these systems can have catastrophic negative consequences (Buldyrev et al., 2010).

CIs are generally complex systems, composed of several heterogeneous and interconnected components. In addition, CIs are often interdependent on each other with various relationships of interdependencies between their components (Rinaldi et al., 2001; Ouyang, 2014). We refer to the ensemble of interdependencies as the *coupling interface*. When CIs are interdependent on each other, failures can propagate back-and-forth through the coupling interface, causing multi-sectoral disruption (Bellè et al., 2022). A typical example is the 2003 Italian blackout, where a cascading failures process involving power and telecommunications networks resulted in a power outage of the entire Italian peninsula (Buldyrev et al., 2010).

Given the importance of CIs, their resilience must be guaranteed and optimized. As CIs are often interdependent on each other, and their coupling interface plays a key role in determining the failures propagation between different systems, the allocation of interdependencies and the design of the coupling interface are crucial factors for the resilience of interdependent CIs. While the importance of this topic has been acknowledged in the existing literature (Ouyang et al., 2011), it is considerably underexplored. In our previous works (Bellè et al., 2023a, 2023b), we proposed a robust optimization framework for designing coupling interface between CIs in order to maximize their combined resilience. Leveraging on this model, we investigate how robust optimization can be used to optimally allocate redundancies within the coupling interface of interdependent CIs. Specifically, assuming that a coupling interface is already present, we propose a robust optimization method for allocating redundant interdependency links in order to maximize the combined performance of the interdependent CIs under the worst-case feasible failure scenario that can possibly happen.

The case study of interdependent power and gas networks (IPGNs) proposed in (Bellè et al., 2023a, 2023b) and shown in Figure 1 is used in this work. We present and discuss preliminary results, demonstrating the potential of redundant interdependencies in terms of resilience enhancement, as well as the validity of robust optimization for this purpose.

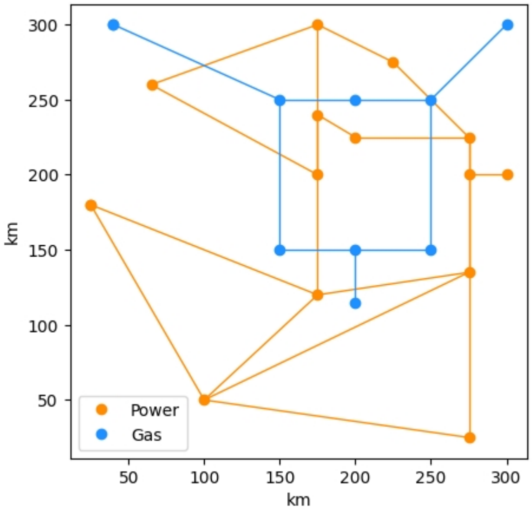

Fig. 1. Interdependent power and gas networks (IPGNs). Figure adapted from (Bellè et al., 2023a, 2023b).

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