Towards Resilient Communities: Strengthening Infrastructure for Critical Service Provision under Severe Weather Conditions

by Laiz Souto[1], Maria Pregnolato[2], and Philip C. Taylor[1]

1 Department of Electrical and Electronic Engineering, University of Bristol
2 Department of Civil Engineering, University of Bristol

Emails: { laiz.souto, maria.pregnolato, pvc-research } @bristol.ac.uk

What? Methodology aimed at enhancing infrastructure resilience to extreme weather events while ensuring provision of critical services at community level.

Why? Critical infrastructure should be designed and operated to ensure a satisfactory provision of critical services while being resilient to extreme weather events. Accessibility to critical services is conditioned to the availability of critical infrastructure.

How? The selection of appropriate planning and operational measures for resilience enhancements is made with the objective of ensuring provision of critical services under severe weather conditions subject to technical operating constraints within a mixed-integer linear programming model.

Methodology

Minimize reduction in the provision of a critical service (out-of-service customers)

$$\min \sum_{s\in\mathcal{S}}\sum_{t\in\mathcal{T}} C_{s,t} - c_{s,t},$$

subject to operating constraints (flows, damage status, and resilience enhancements) of critical infrastructure systems:

$$\alpha_{n,t} = \sum_{r\in\mathcal{R}} \lambda_{r,n,t}\Delta_{r,n,t}, \forall n\in\mathcal{N}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$\alpha_{e,t} = \sum_{r\in\mathcal{R}} \lambda_{r,e,t}\Delta_{r,e,t}, \forall e\in\mathcal{E}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$0 \le \beta_{n,t} + \alpha_{n,t} \le 1, \forall n\in\mathcal{N}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$-\left(\beta_{e,t} + \alpha_{e,t}\right)\overline{F}_e \le f_{e,t} \le \left(\beta_{e,t} + \alpha_{e,t}\right)\overline{F}_e, \quad \forall e\in\mathcal{E}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$g_{n,t} - d_{n,t} = \sum_{e\in\mathcal{E}_i|OR(e)=n} f_{e,t} - \sum_{e\in\mathcal{E}_i|DE(e)=n} f_{e,t}, \quad \forall n\in\mathcal{N}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$0 \le g_{n,t} \le \left(\beta_{n,t} + \alpha_{n,t}\right) G_{n,t}, \forall n\in\mathcal{N}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

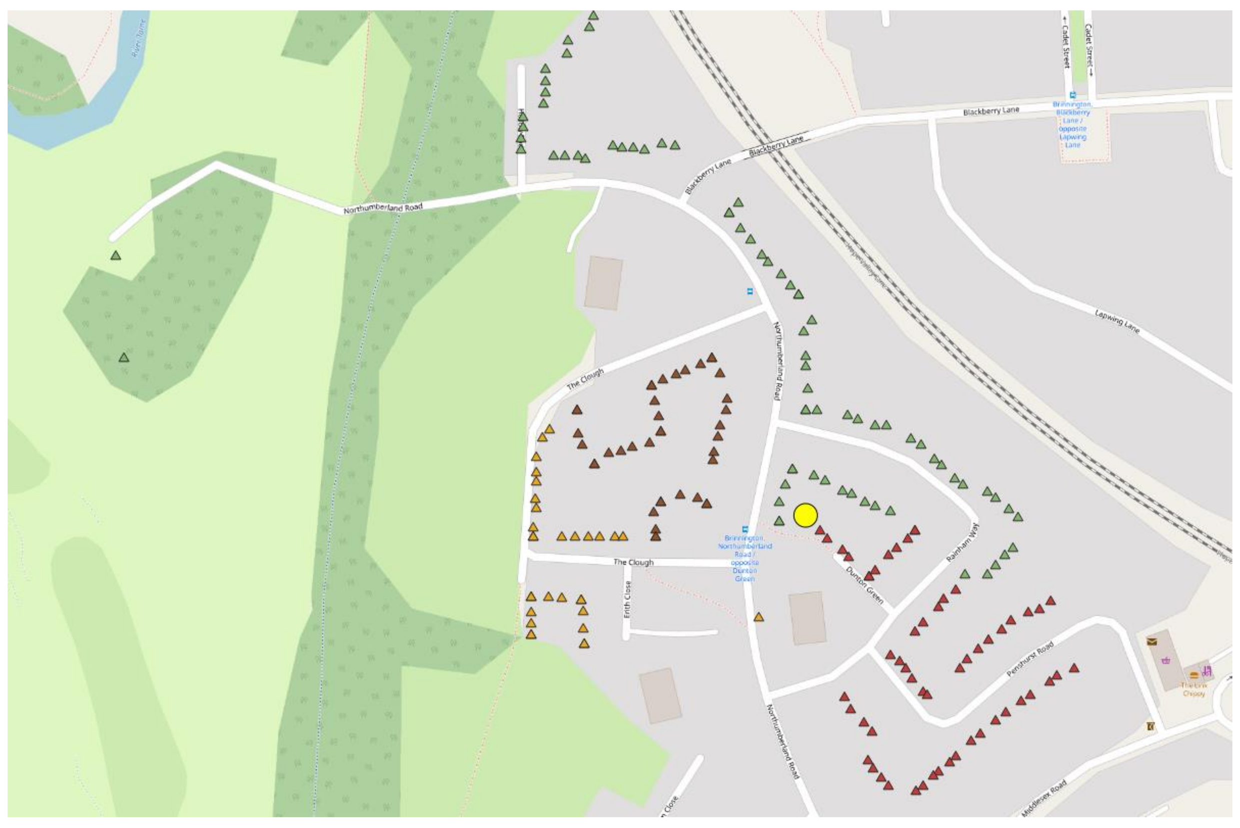
$$0 \le d_{n,t} \le D_{n,t}, \forall n\in\mathcal{N}_i, i\in\mathcal{I}, t\in\mathcal{T},$$

$$\sum_{n\in\mathcal{N}_i} \rho_{n,s,t}\left(D_{n,t} - d_{n,t}\right) = C_{s,t} - c_{s,t}, \quad \forall i\in\mathcal{I}, s\in\mathcal{S}, t\in\mathcal{T},$$

$$\sum_{n\in\mathcal{N}_i} \Lambda_{n,t} + \sum_{e\in\mathcal{E}_i} \Lambda_{e,t} \le \Lambda_{i,t}, \forall i\in\mathcal{I}, t\in\mathcal{T}.$$

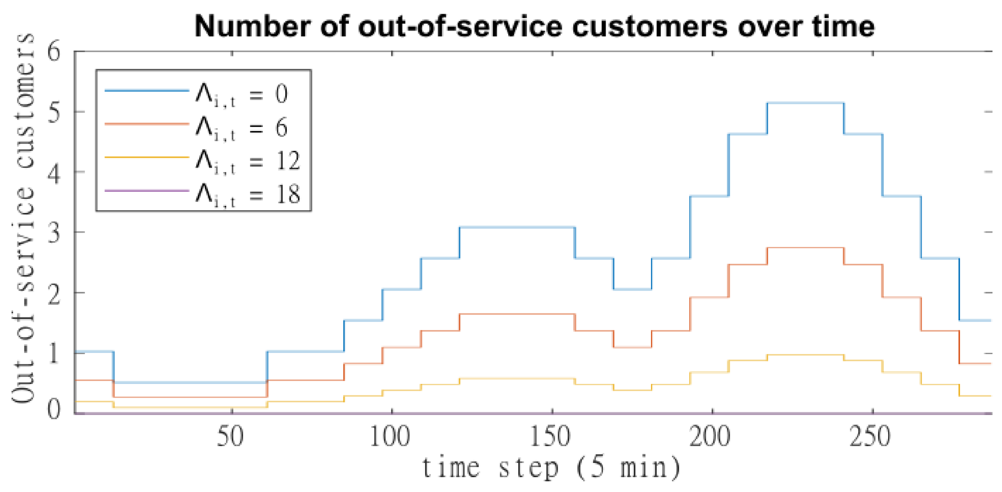
Acknowledgment: This research was supported by the UKRI Engineering and Physical Sciences Research Council under the auspices of Supergen Energy Networks Hub, grant EP/S00078X/2.

Case study: Impact assessment of disruptions to power and transportation infrastructure systems caused by flooding on a grocery store in Stockport, UK.



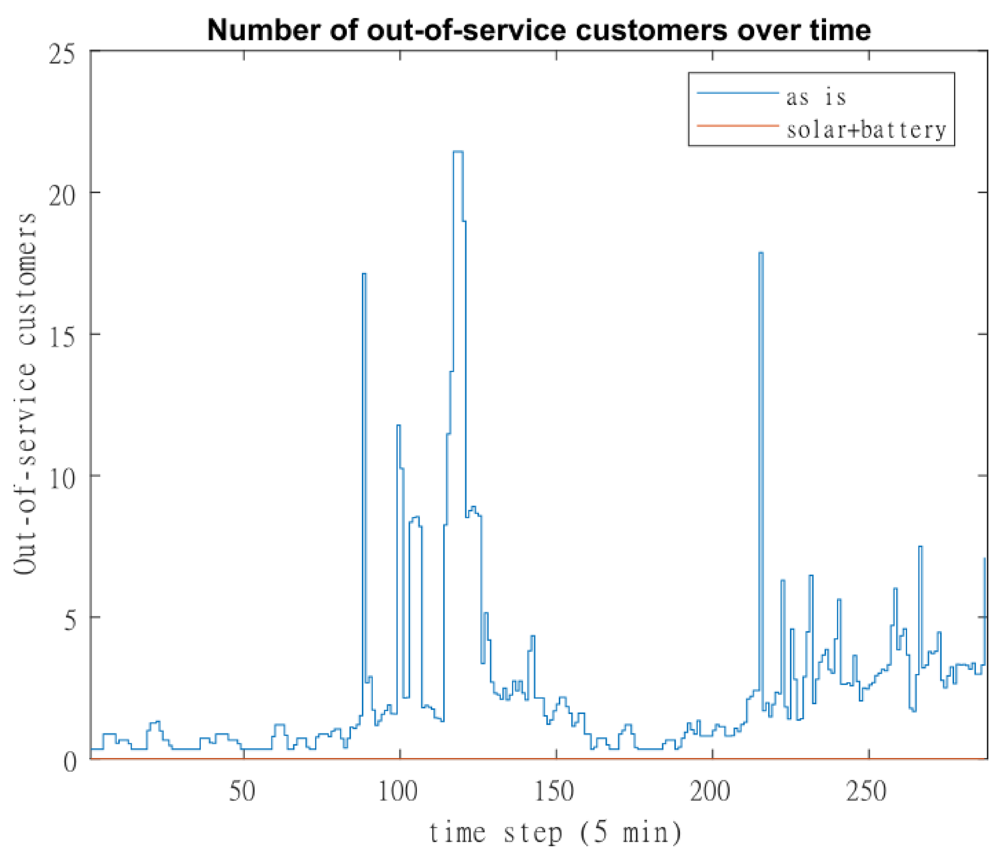
Map of Stockport, UK, showing the roads in the transportation network, the grocery store on the bottom right, the distribution substation (yellow circle), and the loads connected to the 4 secondary feeders (colored triangles) in the power network (inundated area)

Results



Number of out-of-service customers of the grocery store over time calculated as a function of disruptions to the transportation network for different values of $\Lambda_{i,t}$ defining improvements in water drainage (top) and

Map of the roads where improvements in water drainage are implemented when Λi,t = 6 (numbers in red), Λi,t = 12 (numbers in orange + red), and Λi,t = 18 (numbers in black + orange + red) (bottom)



Number of out-of-service customers of the grocery store over time calculated as a function of disruptions to the power network

Conclusions

The results have shown that the methodology can mitigate the impact of extreme weather events on critical infrastructure and its effects on the provision of critical services. The results are encouraging for the benefits of strengthening infrastructure resilience to extreme weather to the provision of critical services at community level.