Evaluation of Extreme Event Impact on Grid Operation and Recovery: A Probabilistic Risk Assessment (PRA)-based Approach

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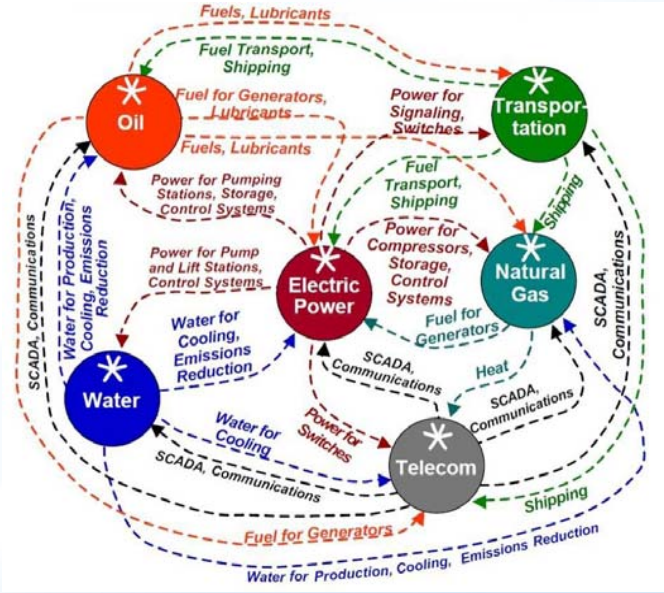
Background

- The grid is highly vulnerable to external extreme events that seem more prevalent than before;
- The occurrence and damage of the extreme events to the grid are better fit with a power-law distribution with a “heavy-tail”;
- The assessment of the extreme event impacts on the grid needs to cope with a large amount of uncertainties.

Objective

- To develop a probabilistic risk assessment (PRA) approach for analyzing the grid impact of extreme events based on the strong correlation between events and component failures and repairs;
  - Perform interdependency analyses to assess cascading failures across infrastructures up to the grid via grid-centric modeling;
  - Identify vulnerability and cost-effective mitigation based on probabilistic analyses and quantitative results.

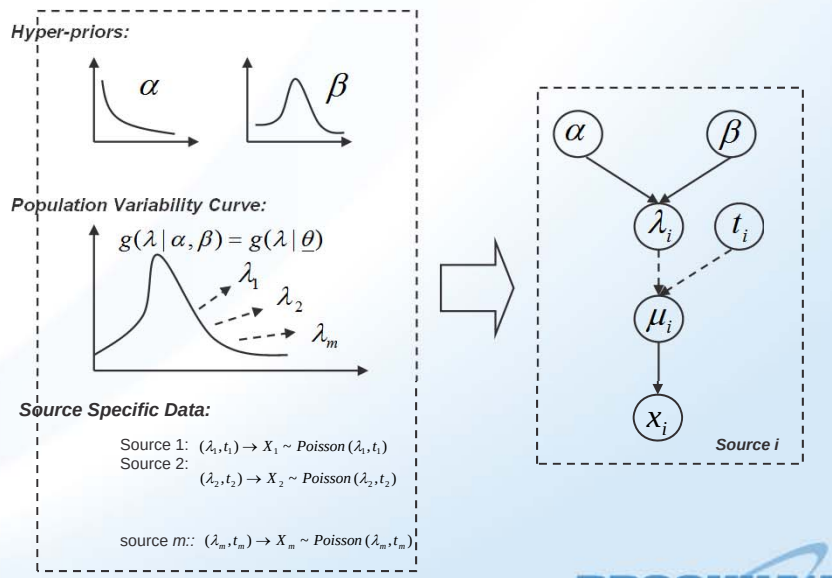


A PRA-based Approach to Extreme Event Impact

- Development of probabilistic model for extreme events;
- Development of correlation between the events and the component failures and repairs;
  - Dependence of failure rates of the grid components on the event;
  - Dependence of repair rates on the event and other infrastructures.
- Evaluation of the risk measures (or reliability indices) associated with the impact of the component failures and repairs on the grid condition.

Probabilistic Model for Extreme Events

- Identification of external event features (e.g., wind speed or temperature represented by vectors $\underline{x_i}$ here) influencing component failures and repairs;
- Collection and analyses of both generic data and regional or forecasting information for external events;
  - E.g., magnitude and frequency of the hurricane of different categories and their distributions based on the historic data;
  - A two-stage Bayesian method can be used to better account for both the generic and forecasting data.



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Parameter Inference of Component Failures and Repairs (1)

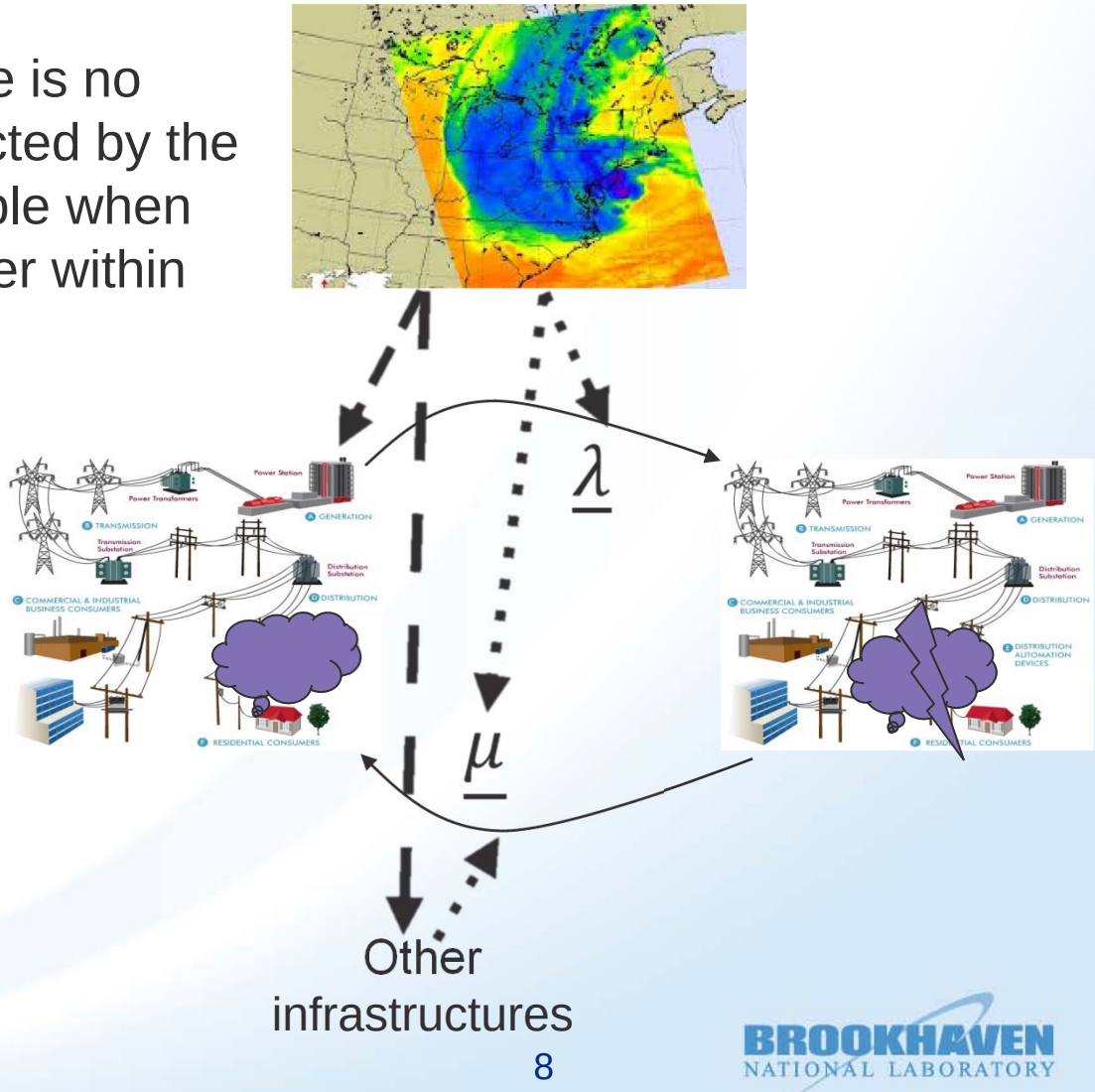
- The correlation between the external events and (1) **the failure rates of components within zone j of the area being affected by the event** and (2) **repair rates**

$$\lambda \sim F(\underline{x_{i,j}}),\ \mu \sim G(\underline{x_{i,j}})$$

- The failures of other infrastructures may affect both the failures and repairs of the grid components;
- A large amount of real data of both events and grid components need to be collected to develop a mapping for representing the correlation between them.

Parameter Inference of Component Failures and Repairs (2)

- It is often assumed that there is no repair in the area being affected by the event but the repair is possible when the components are no longer within the range of event impact;
- There exist different techniques that can be adopted for the inference
  - Regression method
  - Bayesian network
  - Fuzzy expert system
  - Other methods



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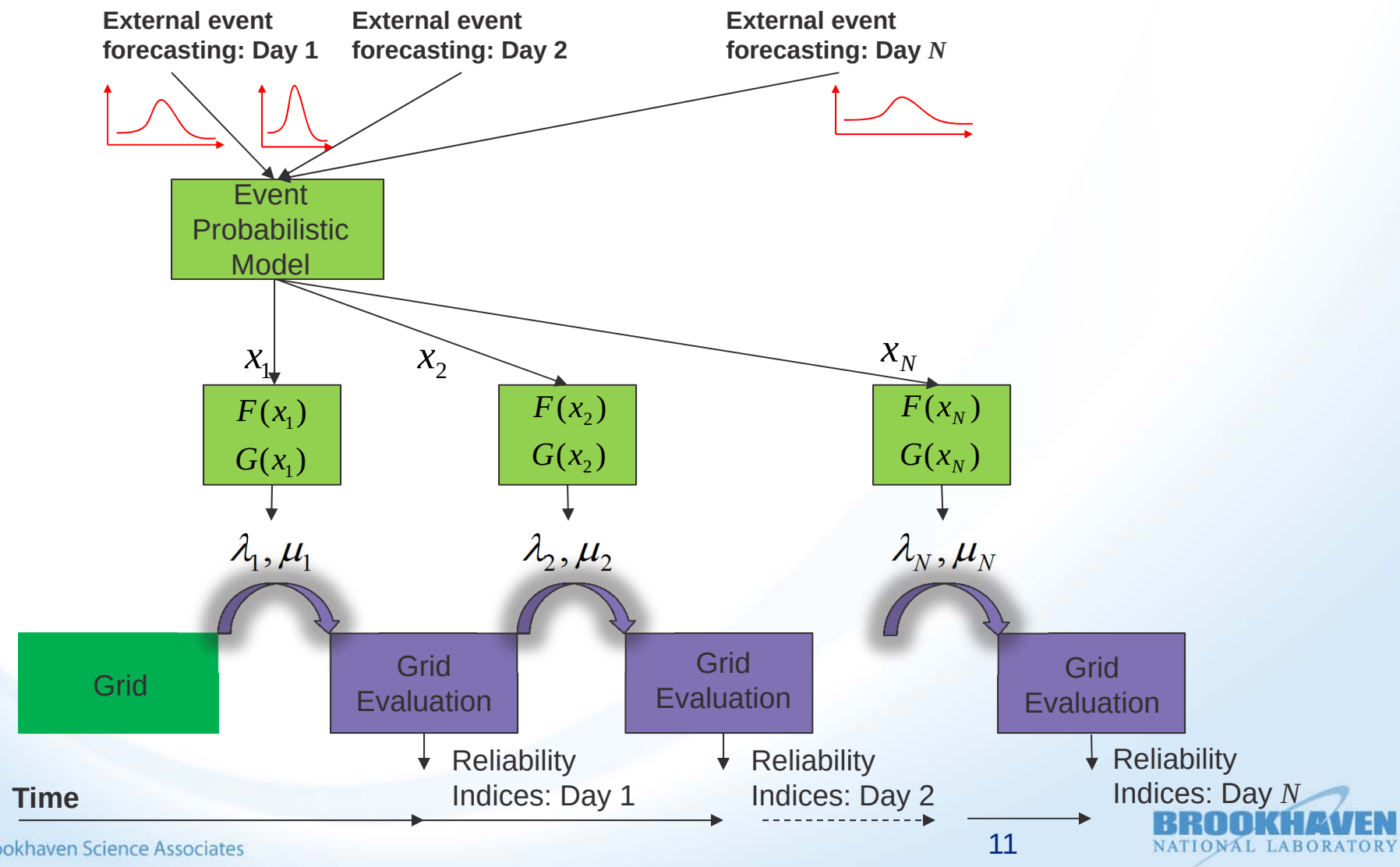
Grid Impact Analysis

- Many external events affect mainly distribution network but may also affect transmission system also;
- There are various methods for the grid impact analysis and example methods:
  - For transmission network: Optimal ac or dc power flow or minimal cut-set method may be used to minimize the losses of load given the grid component states and topology;
  - For distribution network: distribution network power flow, minimal path and zone partitioning, or minimal cut-set method to calculate the reliability indices for distribution systems;
- Time series analyses can be performed based on the progressive evolution of the event.

Progressive Analysis Using the Approach



Summary

- The approach can be implemented using the Monte Carlo simulation, i.e., calculating the reliability indices of the grid based on failure rates and repair rates of the components inferred by using the event samples of the event data and other infrastructure models;
- The approach enables sensitivity analysis for identification of vulnerabilities under the event;
- The unique features of this approach include
  - A two-stage Bayesian method to account for both generic event data and the forecasting information to better model the external event;
  - The repairs are explicitly modeled as functions of both the event and the states of other infrastructures;
  - The method enables the progressive analyses of the grid status as the event evolves;