Mathematical Disruption and Impact Models for Addressing Regional Resilience

Frederic Petit and Julia Phillips
Decision and Information Sciences
Infrastructure Assurance Center
Argonne National Laboratory, US
fpetit@anl.gov; phillipsj@anl.gov

Abstract - Assessing infrastructure resilience requires consideration of many interconnected socioeconomic, ecological, climatic, and technical elements. Sandy and other recent disasters have underscored the need to utilize a combination of mathematical tools and impact models to improve overall understanding of critical infrastructure systems and lay the foundation for enhanced resilience. The objective of this paper is to discuss three tools developed by Argonne National Laboratory: EPFast, NGFast, and Restore©.

The U.S. electric power system relies on numerous components to operate as designed to serve customers who consume electric power from the power grid. The system is designed to operate and serve customers under diverse operating conditions. In practice, natural events like storms, tornadoes, floods, and equipment failures can disrupt the operation of various components that produce or transport electric power to customers. For example, lightning can damage large substations, or fallen trees can sever significant power transmission lines. The disruption of these components can cause interruptions of electric power service to customers. On the other hand, there may be no impact on customers in other situations, even when system components are damaged and removed from service. Therefore, there is a degree of reliability and resilience designed into these electric power systems.

EPFast is a linear steady-state modeling tool for simulating the behavior of large power systems following power disruptions caused by the loss of power system components that consist of various transmission lines, substations, and generating plants. The model explores the possibility of uncontrolled islanding caused by successive (i.e., cascading) steady-state line overloads initially triggered by the disruption of a major power system component whether by manmade or natural causes. The tool identifies the substations and transmission lines that can experience a loss of power, as well as the quantity of power lost and the number of affected customers. As such, EPFast is sometimes called a power outage area estimation tool because it provides estimates of the extent (geographic size) and depth (amount load shed) of the power outage. The tool can also be used to identify post-event mitigation measures (e.g., required level of local load reduction) required in some regions to avoid transmission line congestion impacts that could be encountered during long-term asset outages caused by extended repair projections. EPFast can be used in a variety of ways to assist analysts examining the performance of the Electricity Subsector serving a facility or region of concern.

Natural gas supplies almost 25% of the nation's energy demands. Its usage is projected to continue growing, especially with respect to electricity generation, as natural gas is thought to be the most efficient and cleanest burning fossil fuel[1]. The nearly 1.2 million miles of transmission pipelines supply more than 68 million residential customers and 5 million commercial enterprises[2]. Natural gas is transported from production fields and import points to consumers nationwide via high-pressure interstate pipelines. In an emergency involving a pipeline disruption, whether it be natural or man-made, quick response is necessary to limit the impact of the event. Existing modeling systems can take days to provide essential assessment data following an event like a pipeline break or a reduction in pipeline flow (resulting from either compressor damage or a low-output condition in production fields brought about by hurricanes or freezing rain). Argonne's natural gas flow model, NGFast, allows for rapid, first-stage assessment of the impacts of major pipeline breaks and reductions in flow from import points and production fields.

NGFast is a stand-alone program designed to operate on a personal computer and has the capability of handling multiple natural gas pipeline breaks involving multiple pipelines across a number of states. The tool can also model a reduction in flow because of changes in pressure levels (e.g., due to outage of an upstream compressor station). NGFast was originally developed for quick estimation (less than 1 hour) of hurricane impacts on the U.S. natural gas infrastructure, both offshore and onshore, in both quantitative and qualitative terms. NGFast can be used as both an impact analysis tool and an information retrieval tool. It includes data on more than 80 interstate pipelines, over 1,800 LDCs, and nearly 800 State border points.

Within minutes of a break, NGFast can generate HTML-formatted graphics and tabular reports to supplement briefing materials for state and federal emergency responders. The model provides summaries, as well as detailed reports (pre- and post-disruption conditions). Impacts are measured in

[1] "About Natural Gas", American Gas Association, http://www.aga.org/kc/aboutnaturalgas/Pages/default.aspx [Accessed, 11 May 14]
[2] Ibid.

terms of extent of gas volume lost, States affected, utilities affected, number and type of customers affected, and amount of gas-based generation capacity affected.

NGFast can also be used to aid stakeholders in assessing the resiliency and reliability of an existing natural gas system of interest (e.g., evaluation of the availability of various supply sources to compensate for a postulated loss) and to assist first responders in formulating mitigation and recovery plans in anticipation of a pending threat or disaster (e.g., knowledge of the affected areas could help first responders plan for the right location of staging areas for their logistics and crews).

Restore© is a stand-alone program designed to operate on a personal computer. It models complex sets of steps required to accomplish a goal when the time required to complete a repair or the steps needed to repair or replace may be uncertain. For example, external conditions (i.e., the time of day, weather, and crew availability) may affect one or more of the steps required to accomplish a goal. Each step in a process is characterized by a probability distribution that captures the uncertainty in the time required to complete that step. Several Monte Carlo simulations are run to generate probability distributions that provide estimates on the amount of time needed to complete an entire multi-step process.

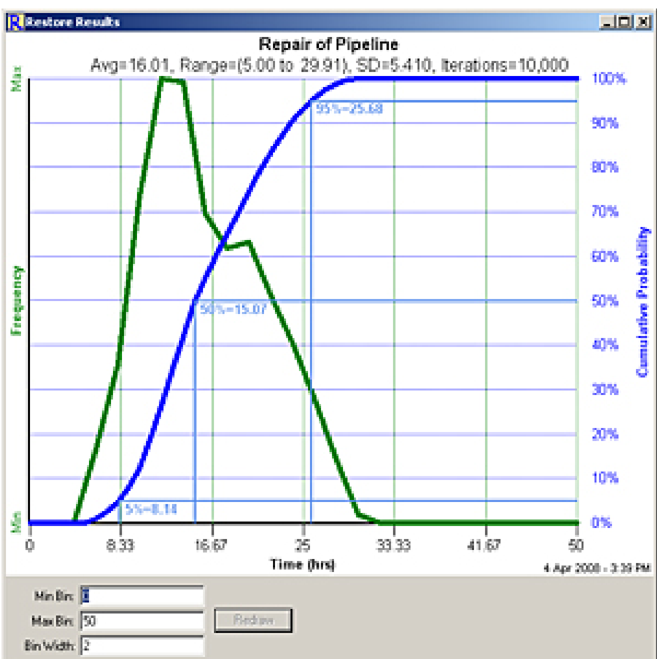

Figure 1. Sample output from Restore© showing a completion time distribution and its corresponding cumulative probability function[3]

These three models can be used in tandem with each other to provide a more holistic picture of infrastructure resilience. The growing interconnectedness between electric generation and natural gas supply necessitate a broader understating of resilience, beyond a single asset or system. While these three models provide insight on a small portion of community or regional resilience, they are an important step in creating a framework to better understand how connected our critical infrastructure systems are and the impacts of disruptions to these systems.

Keywords—restoration models; critical infrastructure resilience; critical infrastructure impact models

Disclaimer

[3] Restore©: Modeling Interdependent Repair/Restoration Processes, http://www.dis.anl.gov/pubs/67184.pdf.