Mathematical Disruption and Impact Models for Addressing Regional Resilience

Prepared for

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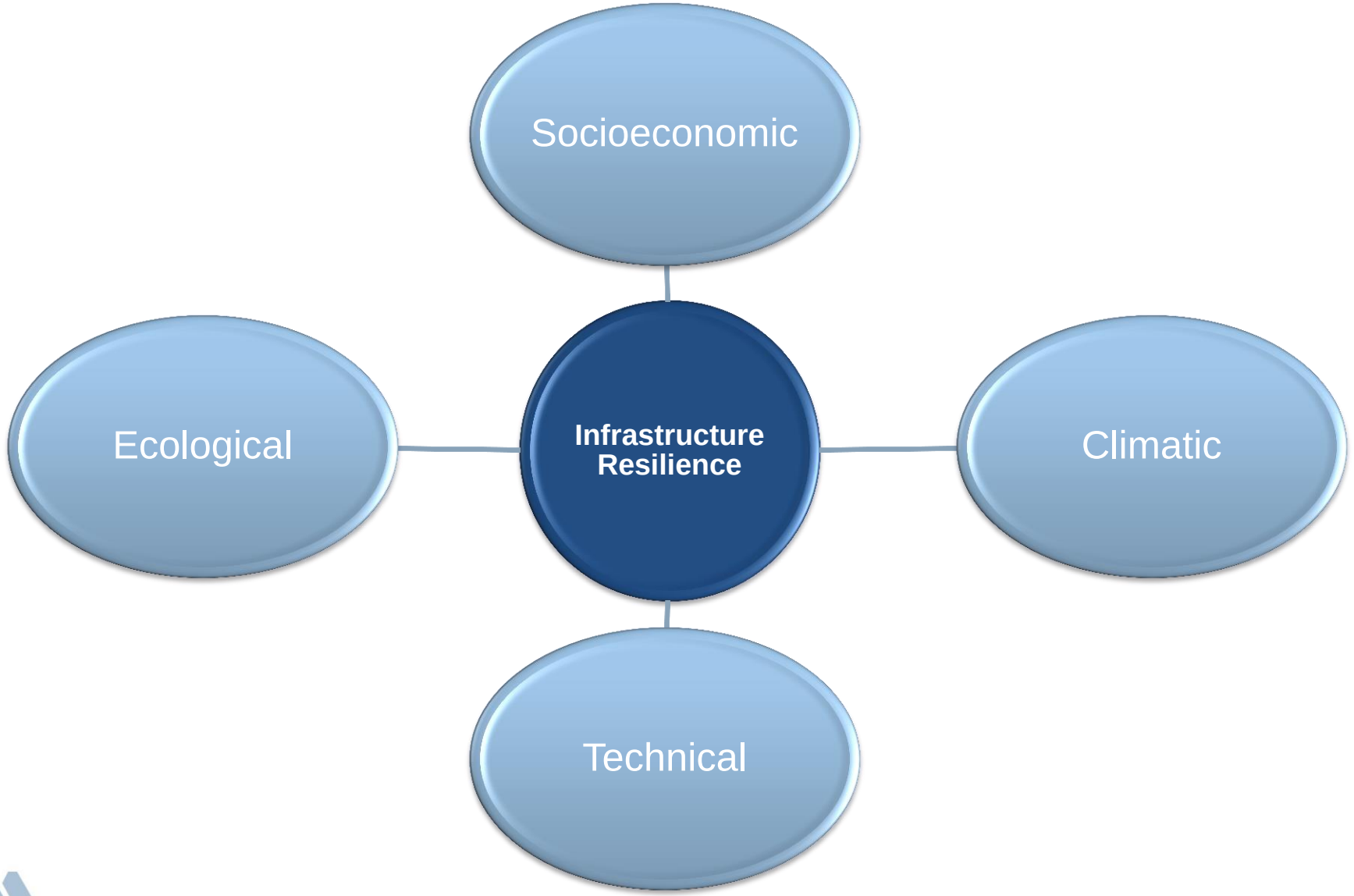
Recent Disasters

- Natural Hazards

- Manmade Events

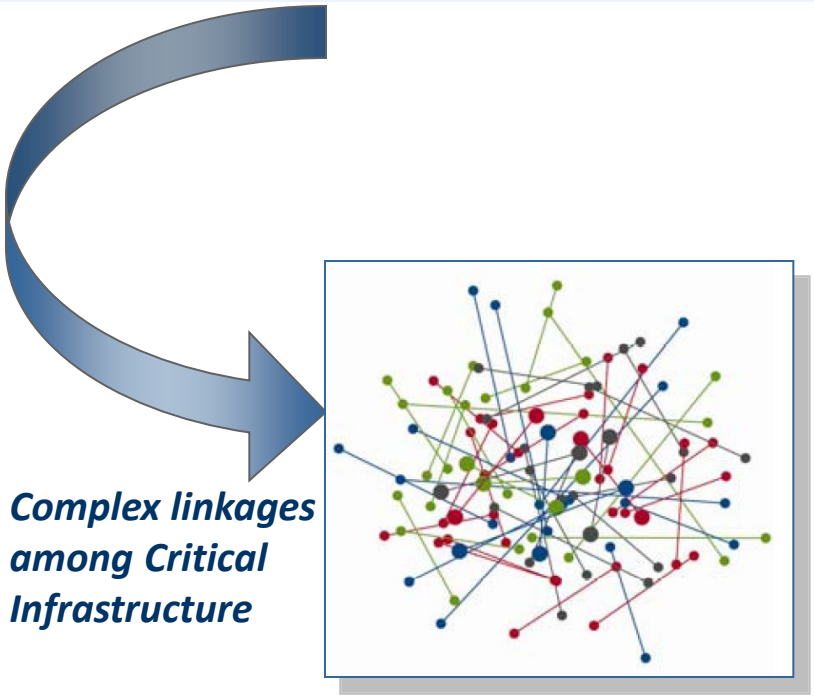
Many Interconnected Elements



Critical Infrastructure Systems

- **16 Critical Infrastructure sectors** in United States
- Primarily owned/operated by **private sector**
- Increasingly **interconnected** (physical and cyber)
- Operate in an **all-hazards** environment
- **Regulated** and **non-regulated**

- Agriculture and Food
- Banking and Finance
- Chemical
- Commercial Facilities
- Communications
- Critical Manufacturing
- Dams
- Defense Industrial Base
- Emergency Services
- Energy
- Government Facilities
- Healthcare and Public Health
- Information Technology
- Nuclear Reactors, Materials and Waste
- Transportation Systems
- Water



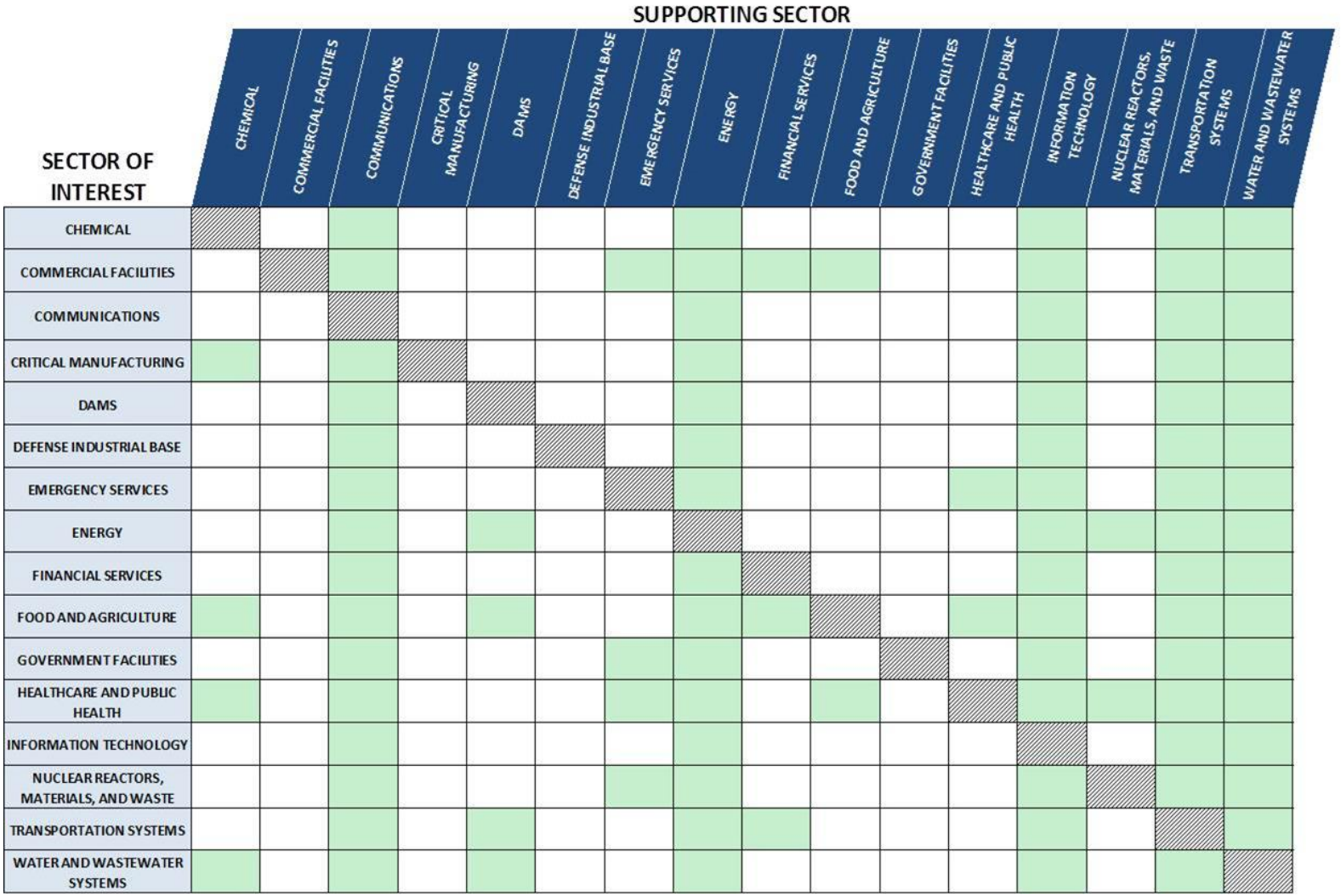
Complex linkages among Critical Infrastructure

Enhance Resilience

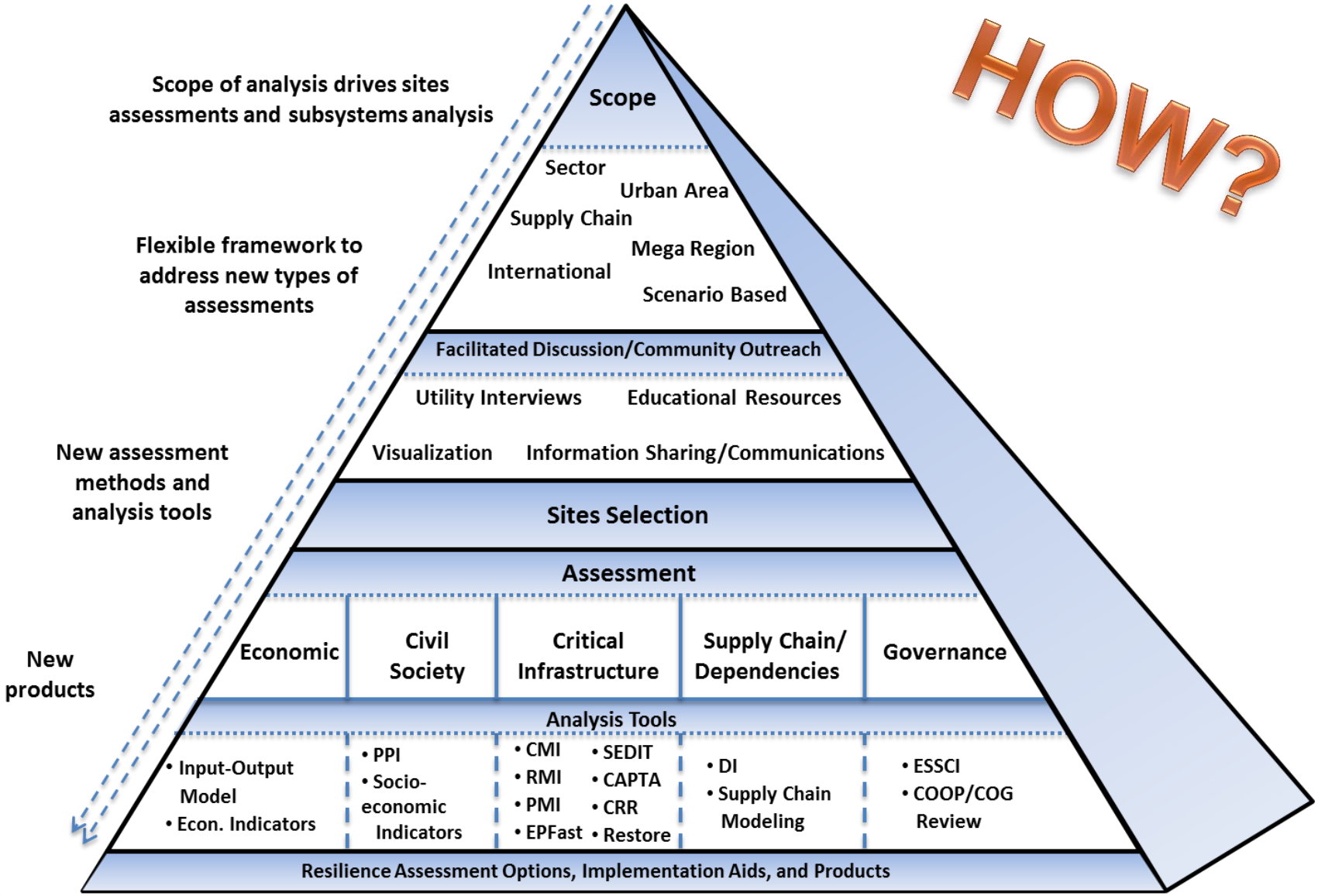
Ability of an entity (e.g., asset, organization, community, region) to **anticipate**, **resist**, **absorb**, **respond to**, **adapt to**, and **recover** from a disturbance

(Carlson et al., 2012)

Understand Critical Infrastructure Interdependencies



Regional Resilience Framework



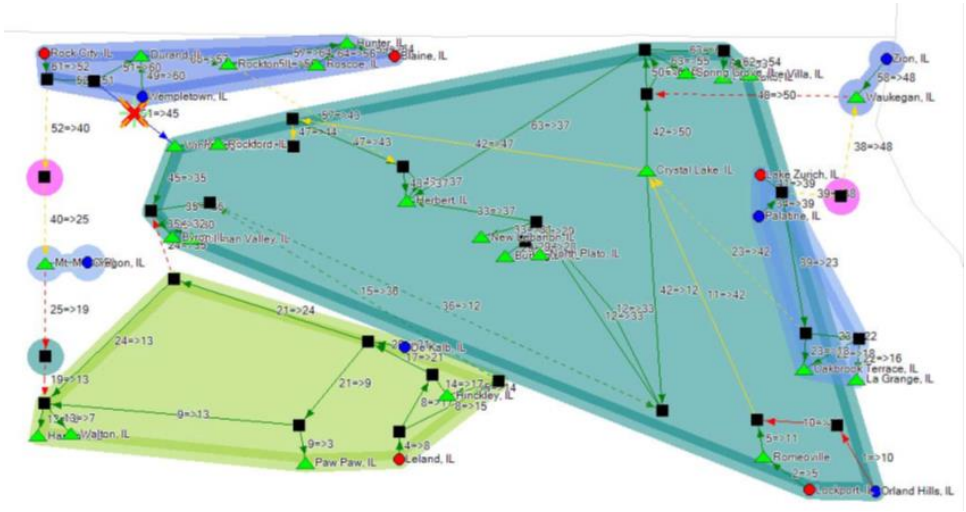
(Carlson et al., 2012)

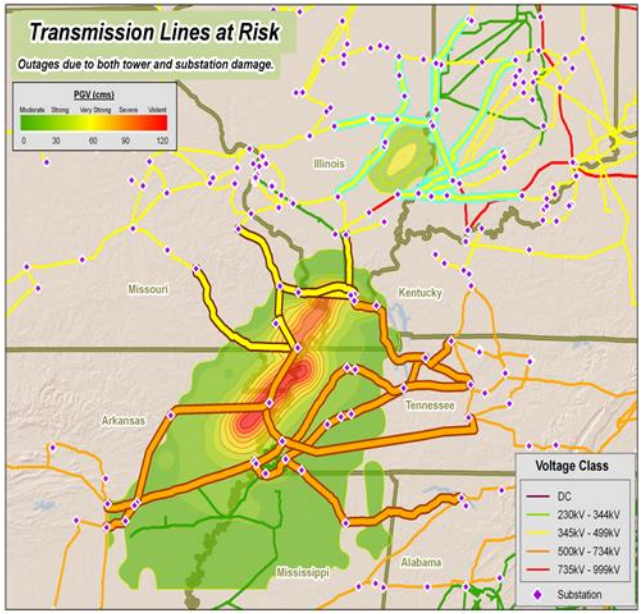
EPfast

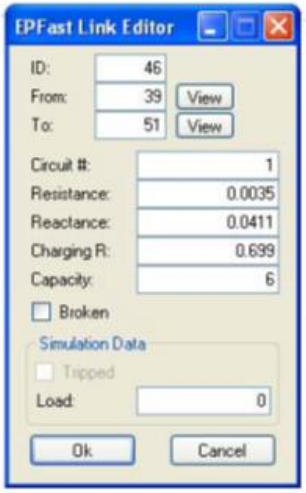
- Assess the **potential electric power outage impacts** on a particular facility or region of concern **following disruptions to infrastructure components**

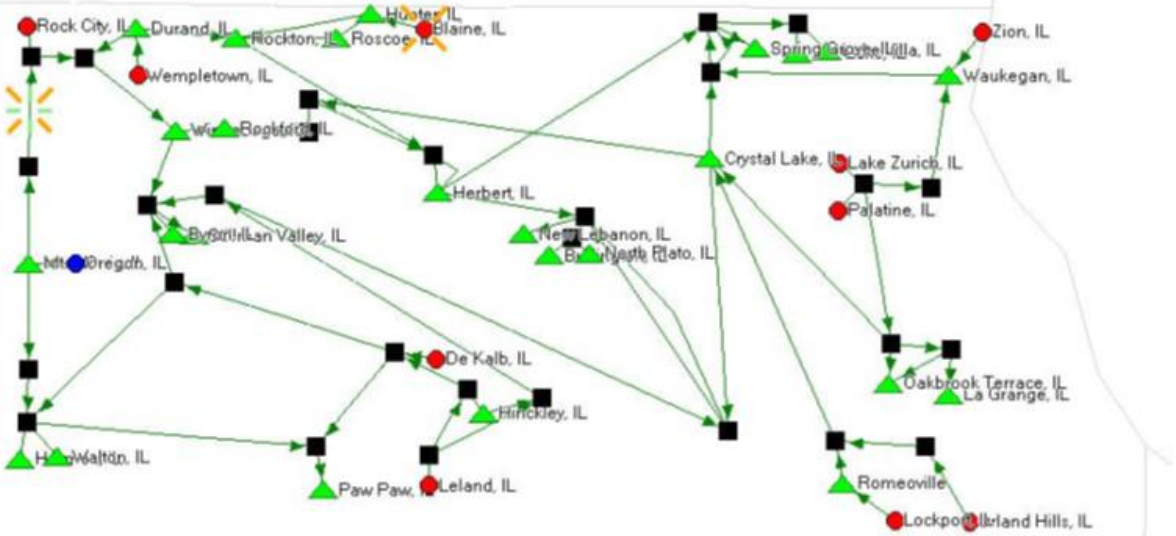
- **Multiple simulation modes** (e.g., load flow, islanding analysis, or network connectivity analysis) allow the user to **evaluate the system** and **conduct** meaningful **“what-if” scenarios**

EPfast









(Portante et al., 2011)

NGfast

- **Quantify the impacts** of manmade or natural disasters **on natural gas systems**, specifically those due to **pipeline breaks** or **loss of pressure**

- **Linear model** that uses a **progressive forward pipeline ownership identification** and **flow quantification process** to **track lost flow volumes**

NGfast

Name: NJ

	Predisruption	Postdisruption
Flow In (MMcf/D):	1205.79	289.6227
Flow Out (MMcf/D):	243.82	58.5639
In-state Delivered Vol(MMcF/D):	961.97	231.0588 Lost: 730.9112 75.98%

Incoming Model Border Points:

ID	State From	Pipeline	Predisruption Flow(MMcf/D)	% Reduction	Postdisruption Flow(MMcf/D)	Flow Lost(MMcf/D)
363	PA	Texas Eastern Trans Corp	6.3	75.98%	1.5132	4.7868
579	PA	Texas Eastern Trans Corp	1199.49	75.98%	288.1095	911.3805

Outgoing Model Border Points:

ID	State To	Pipeline	Predisruption Flow(MMcf/D)	% Reduction	Postdisruption Flow(MMcf/D)	Flow Lost(MMcf/D)
540	NY	Texas Eastern Trans Corp	243.82	75.98%	58.5639	185.2561

LDCs:

		Predisruption					Postdisruption						
ID	Name	Res(MMcf/D)	Com(MMcf/D)	Ind(MMcf/D)	Elec(MMcf/D)	Total(MMcf/D)	Res(MMcf/D)	Com(MMcf/D)	Ind(MMcf/D)	Elec(MMcf/D)	Total(MMcf/D)	% Reduction	Load Shed(MMcf/D)
176721739NJ	PIVOTAL UTILITY HOLDINGS INC DBA ELI	60.1513	33.9069	60.1835	1.1761	155.4178	60.1513	23.2709	0	0	83.4222	46.32%	71.9956
	Pipelines Serving:	Texas Eastern Trans Corp											
176162798NJ	TRANSCONTINENTAL GAS PIPELINE	0	0	0	0	0	0	0	0	0	0	%	0
	Pipelines Serving:	Texas Eastern Trans Corp											
176114569NJ	PUBLIC SERVICE ELECTRIC GAS CO	381.5341	348.2023	68.292	128.5831	926.6115	381.5341	115.8346	0	0	497.3687	46.32%	429.2428
	Pipelines Serving:	Texas Eastern Trans Corp											
176100879NJ	NEW JERSEY NATURAL GAS	118.3446	43.8354	7.4547	11.1638	180.7985	97.0455	0	0	0	97.0455	46.32%	83.7529
	Pipelines Serving:	Texas Eastern Trans Corp											
176001719NJ	ALGONQUIN GAS TRANSMISSION COMPANY	0	0	0	0	0	0	0	0	0	0	%	0
	Pipelines Serving:	Texas Eastern Trans Corp											
	TOTALS:	560.03	425.9446	135.9302	140.923	1262.8278	538.7309	139.1055	0	0	677.8364		
	Total Load Shed:						21.2991	286.8391	135.9302	140.923	584.9914		
	Total Customers Shed:						86395	138184	7474	307	232361		
	Total MW Shed:									1467.9478 MW			

Interconnects:

			Pre-Disruption Flow(MMcf/d)			Post-Disruption Flow(MMcf/d)		
Pipeline	Interconnect Pipeline	Capacity	Receipt	Delivery	Net Delivery	Net Delivery	Load Shed	Reduction
Texas Eastern Trans Corp	Algonquin Gas Trans Co	1511.2501	0.3590	294.5970	294.2380	157.9354	136.3026	46.32%
Texas Eastern Trans Corp	Transcontinental Gas P L Co	367.1687	0.0000	20.7608	20.7608	11.1436	9.6172	46.32%
Totals:		1878.4188	0.3590	315.3578	314.9988	169.0790	145.9198	

Power Plants: None

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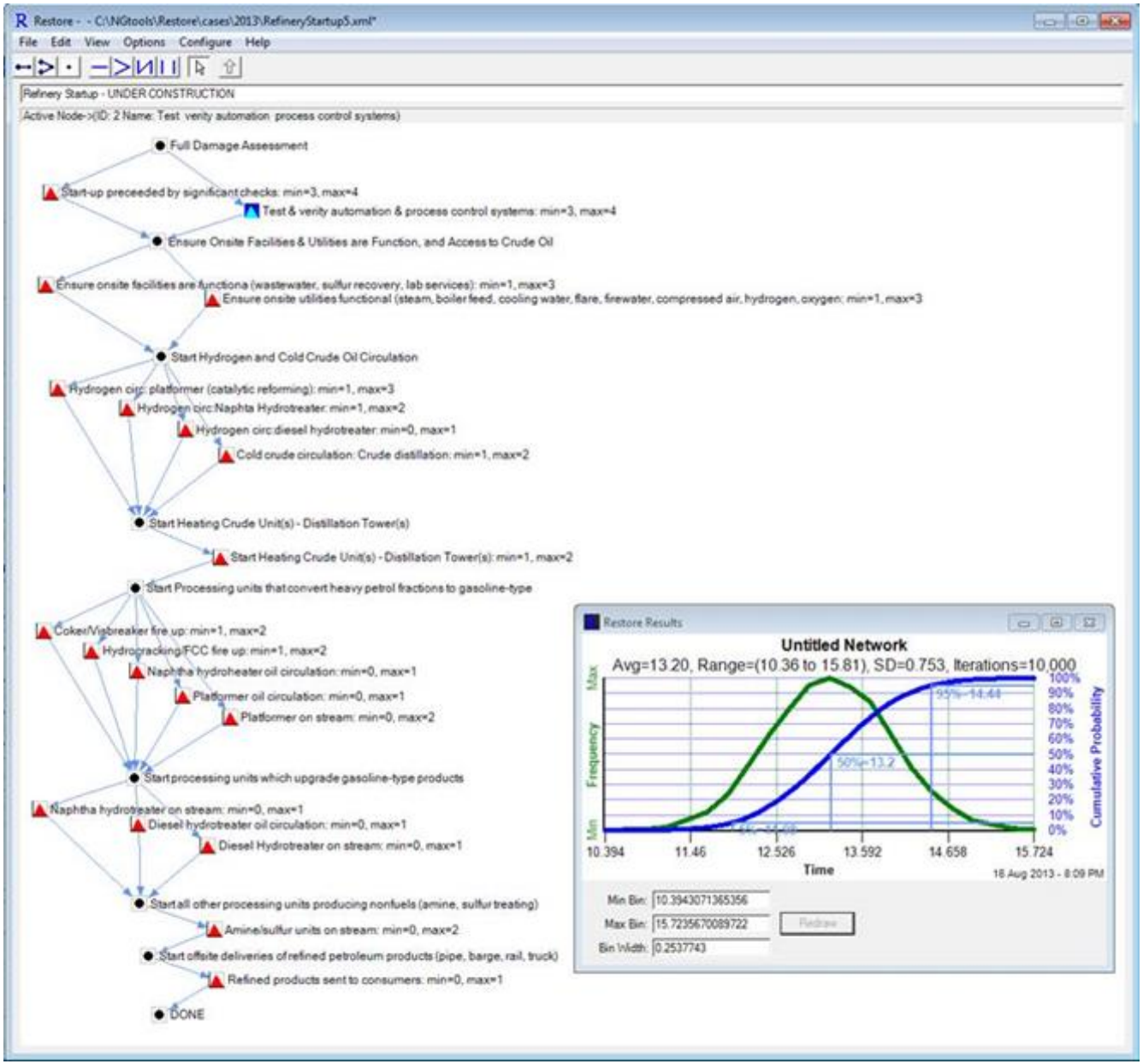
Restore©

- **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**

- Runs **Monte Carlo simulations** using **transition diagrams** to **define probability distribution** that captures the uncertainty in the time required to complete a step

Restore©


Restore - C:\NGtools\Restore\cases\2013\RefineryStartup5.xml*
File Edit View Options Configure Help
Refinery Startup - UNDER CONSTRUCTION
Active Node->(ID: 2 Name: Test verity automation process control systems)
Full Damage Assessment
Start-up preceeded by significant checks: min=3, max=4
Test & verity automation & process control systems: min=3, max=4
Ensure Onsite Facilities & Utilities are Function, and Access to Crude Oil
Ensure onsite facilities are functiona (wastewater, sulfur recovery, lab services): min=1, max=3
Ensure onsite utilities functional (steam, boiler feed, cooling water, flare, firewater, compressed air, hydrogen, oxygen: min=1, max=3
Start Hydrogen and Cold Crude Oil Circulation
Hydrogen circ: platformer (catalytic reforming): min=1, max=3
Hydrogen circ:Naphta Hydrotreater: min=1, max=2
Hydrogen circ:diesel hydrotreater: min=0, max=1
Cold crude circulation: Crude distillation: min=1, max=2
Start Heating Crude Unit(s) - Distillation Tower(s)
Start Heating Crude Unit(s) - Distillation Tower(s): min=1, max=2
Start Processing units that convert heavy petrol fractions to gasoline-type
Coker/Visbreaker fire up: min=1, max=2
Hydrocracking/FCC fire up: min=1, max=2
Naphtha hydroheater oil circulation: min=0, max=1
Platformer oil circulation: min=0, max=1
Platformer on stream: min=0, max=2
Start processing units which upgrade gasoline-type products
Naphtha hydrotreater on stream: min=0, max=1
Diesel hydrotreater oil circulation: min=0, max=1
Diesel Hydrotreater on stream: min=0, max=1
Start all other processing units producing nonfuels (amine, sulfur treating)
Amine/sulfur units on stream: min=0, max=2
Start offsite deliveries of refined petroleum products (pipe, barge, rail, truck)
Refined products sent to consumers: min=0, max=1
DONE
Restore Results
Untitled Network
Avg=13.20, Range=(10.36 to 15.81), SD=0.753, Iterations=10,000
Max
Frequency
Min
95%=14.44
50%=13.2
10.394
11.46
12.526
13.592
14.658
15.724
Time
Cumulative Probability
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
18 Aug 2013 - 8:09 PM
Min Bin: 10.3943071365356
Max Bin: 15.7235670089722
Bin Width: 0.2537743
Redraw

EPfast, NGfast, and Restore©

- Use in tandem to **provide a more holistic picture of infrastructure resilience**

- Provide insight on a small portion of regional resilience but constitute an **important step to understand impacts** of disruption of critical infrastructure systems

Summary

WHY

- Experience from **recent disasters**
- Consideration of **many interconnected elements**

WHAT

- Improve overall understanding of **Critical Infrastructure Systems**
- Lay the foundation **for enhanced resilience**

HOW

- Develop a **Regional Resilience Framework** combining tools and indices
- Use of mathematical tools – **EPfast, NGfast, and Restore©**