Extracting resilience metrics from utility data

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Transmission system resilience: data-driven CRISP simulation

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Distribution system: metrics of resilience processes from data

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Transmission Availability Data System TADS

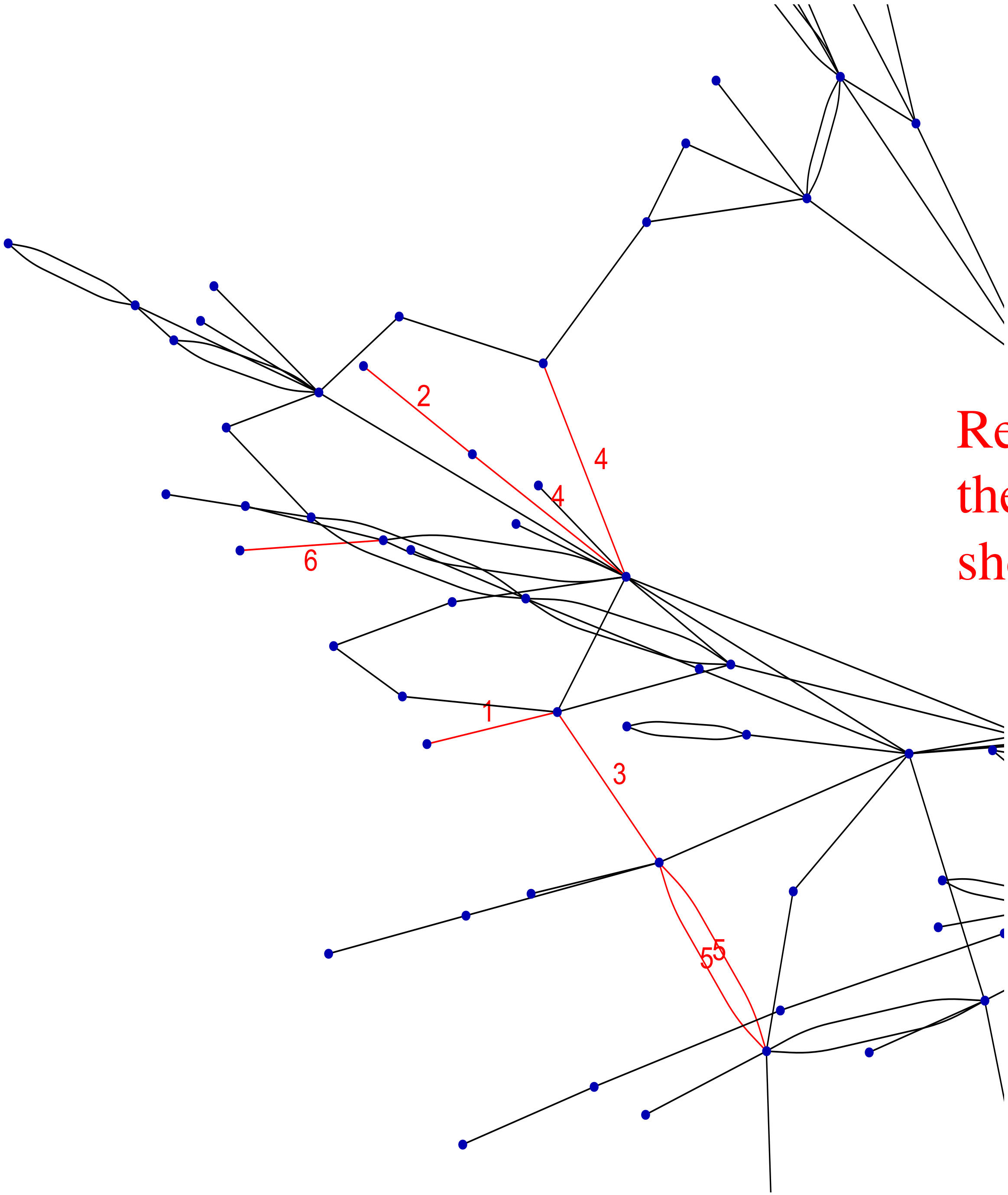
Automatic (Unplanned) Transmission Line Outages: 2009 Complete

CHRONOLOGICAL ORDER

Outage#	Tred ID	Line Name	Gen Flag	kV	District	Own Code	Length (Mi)	Out Date/Time	In Date/Time	Out Mins	Disp Cause
157560	339	xxxx-xxxxxx (230 kV)		230	xxxx	2	0.5	6/18/07 23:48	2/23/09 14:38	886550	81
164651	140	xxxx-xxxxxx (230 kV)	G	230	xxxx	1	61.9	1/2/09 2:35	1/2/09 17:43	908	31
164652	497	xxxx-xxxxxx (115 kV)	G	115	xxxx	1	24.8	1/2/09 3:55	1/2/09 6:59	184	90

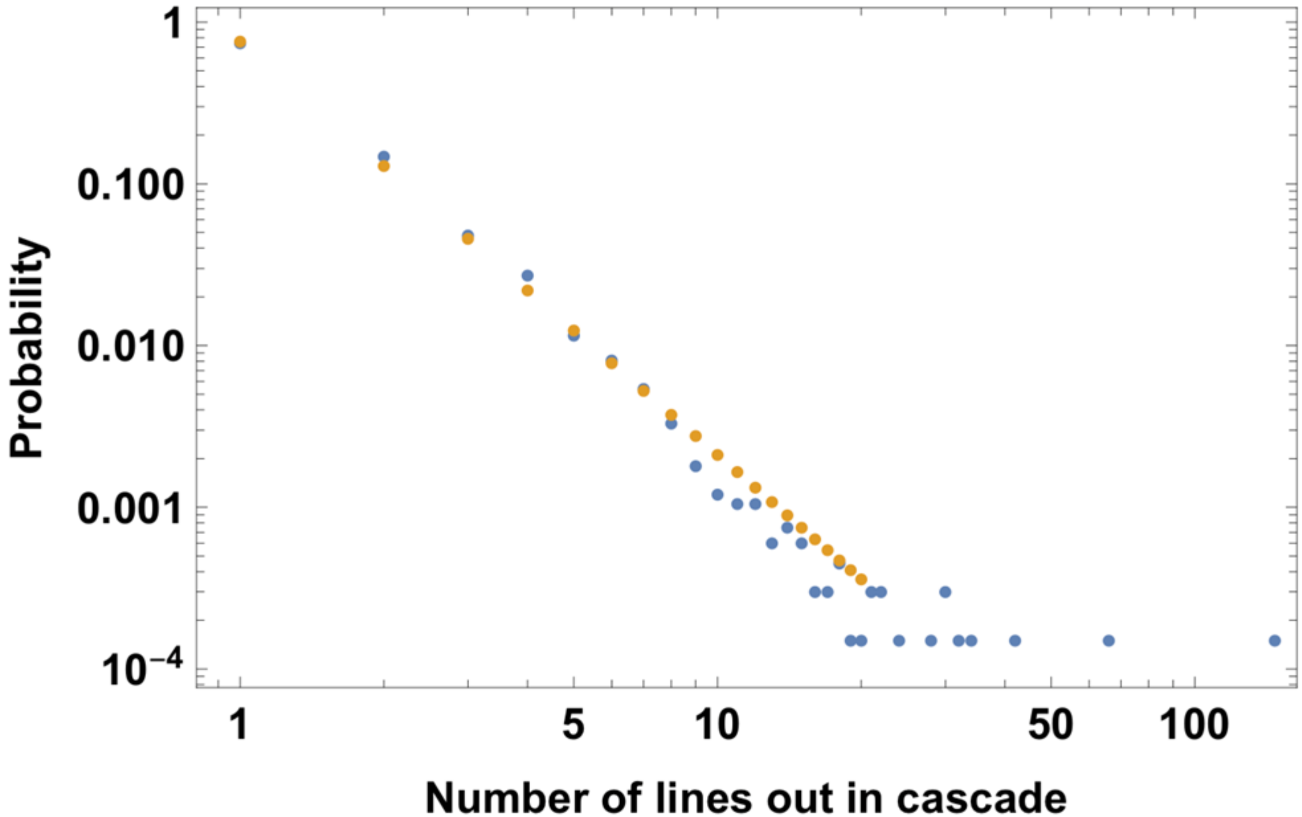
- Includes 10942 automatic line trip times to nearest minute
- All utilities in USA gather and report TADS data to NERC; similar data also gathered internationally
- We use 14 years of public TADS-like data public on the web

Process automatic outages into cascades by their timing; outages starting close in time are in the same cascade

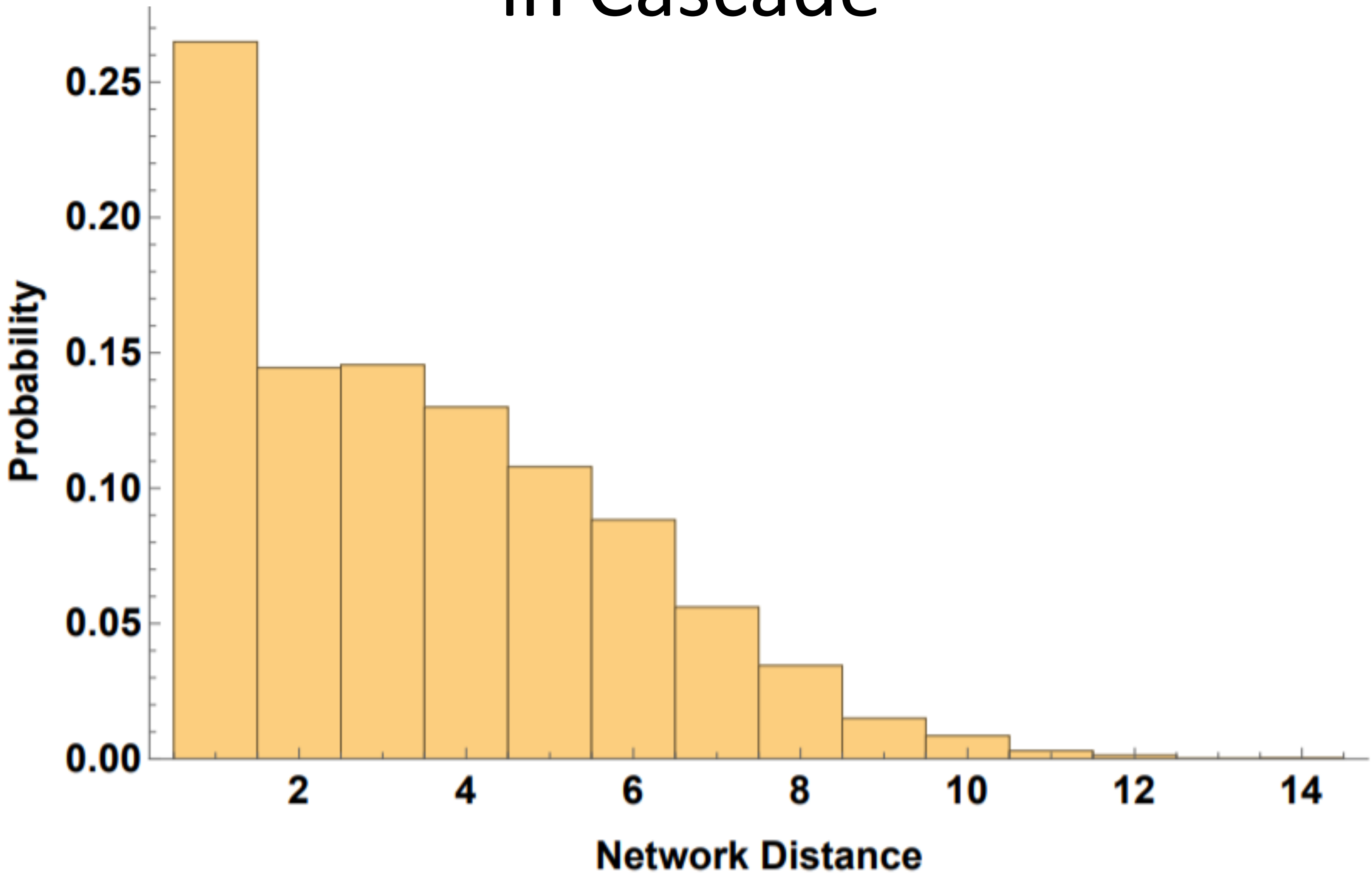


Red lines show one cascade; they outage in generations shown by the numbers

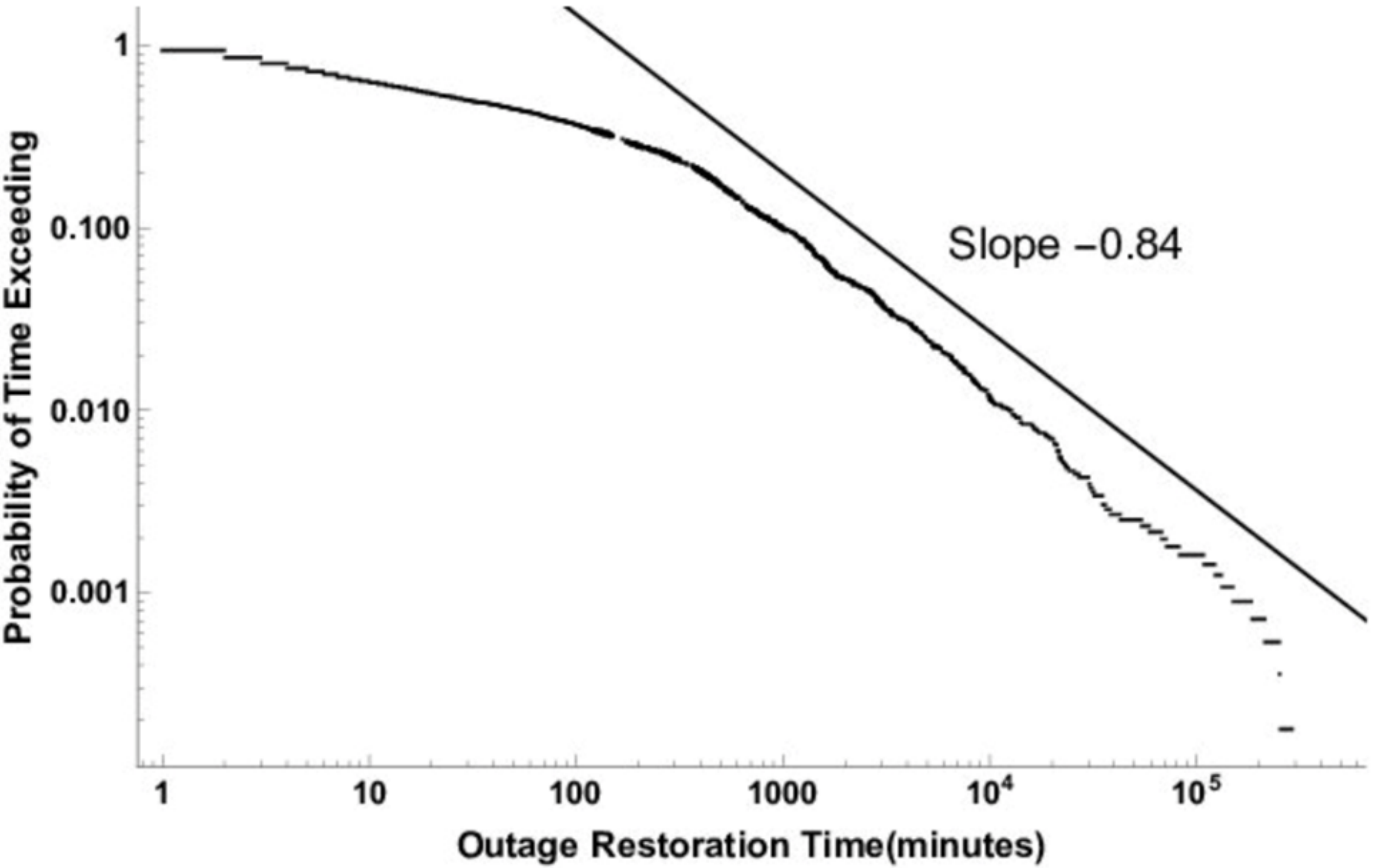
Cascade Size Distribution



Network Distance Between Lines in Cascade



Component Restoration Time Distribution



These statistics summarize **outcomes** of complicated cascading and restoration processes

Key idea: sample from these statistics to get a high-level probabilistic models of the cascading and restoration.

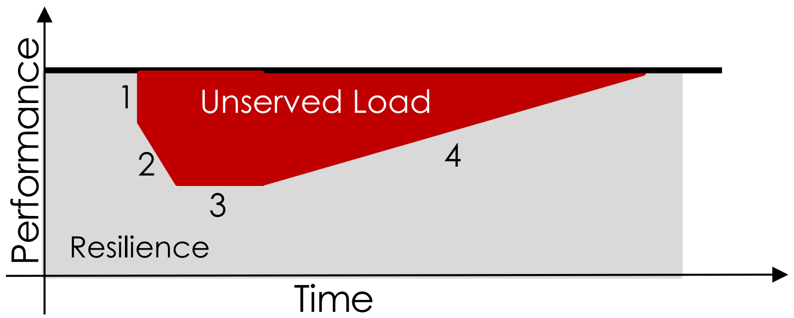
Coordinate these processes with an OPF to track system over time and compute resilience metrics to get CRISP resilience simulation platform

CRISP: Computing Resilience Interactions Simulation Platform

- CRISP is a new high-level statistical approach to quantify resilience of transmission networks
- Instead of detailed modeling, CRISP samples from utility statistical data to quantify all resilience phases.
- For example, we can use CRISP to quantify the effect of distributed PV and storage on overall resilience
- Resilience includes low probability and high impact events

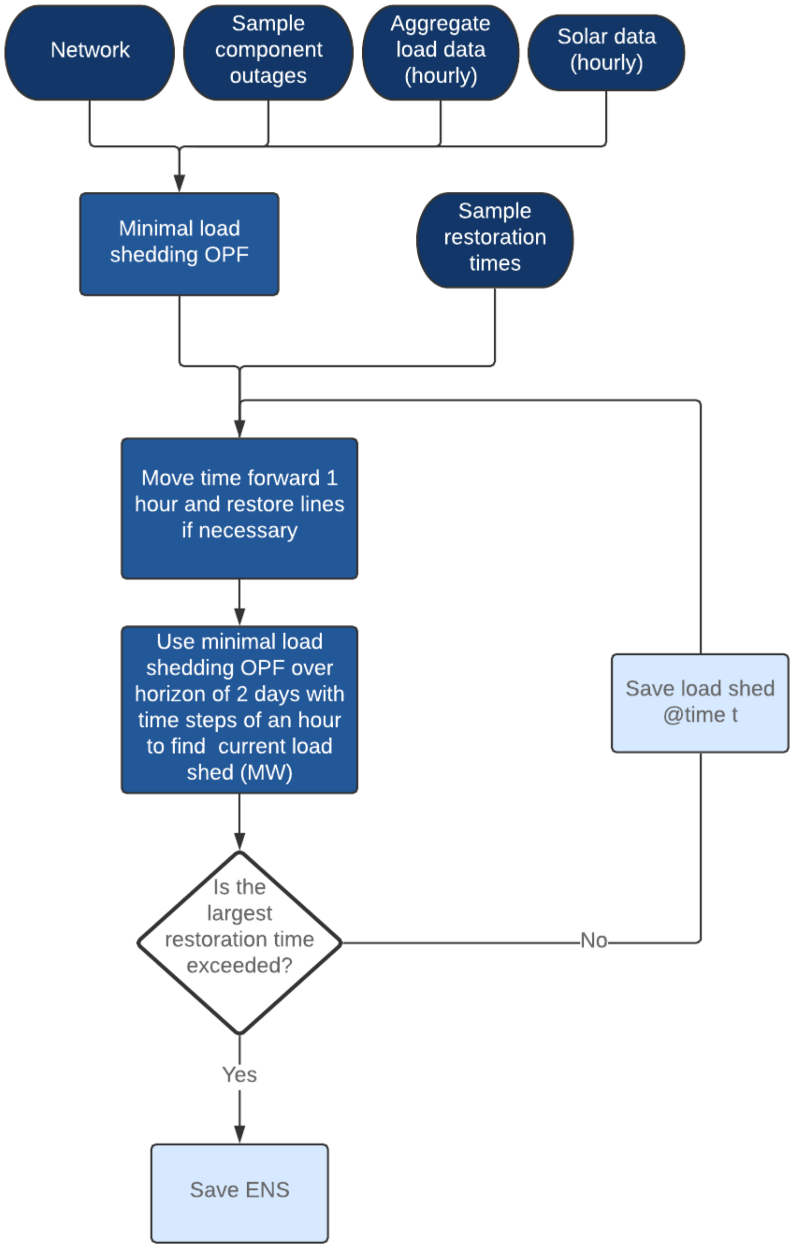
Processes in Resilience Events

1. Stress causes component failures
2. Cascading outages
3. Service interruptions and degraded performance
4. Restoration
5. Quantification of Resilience Impacts

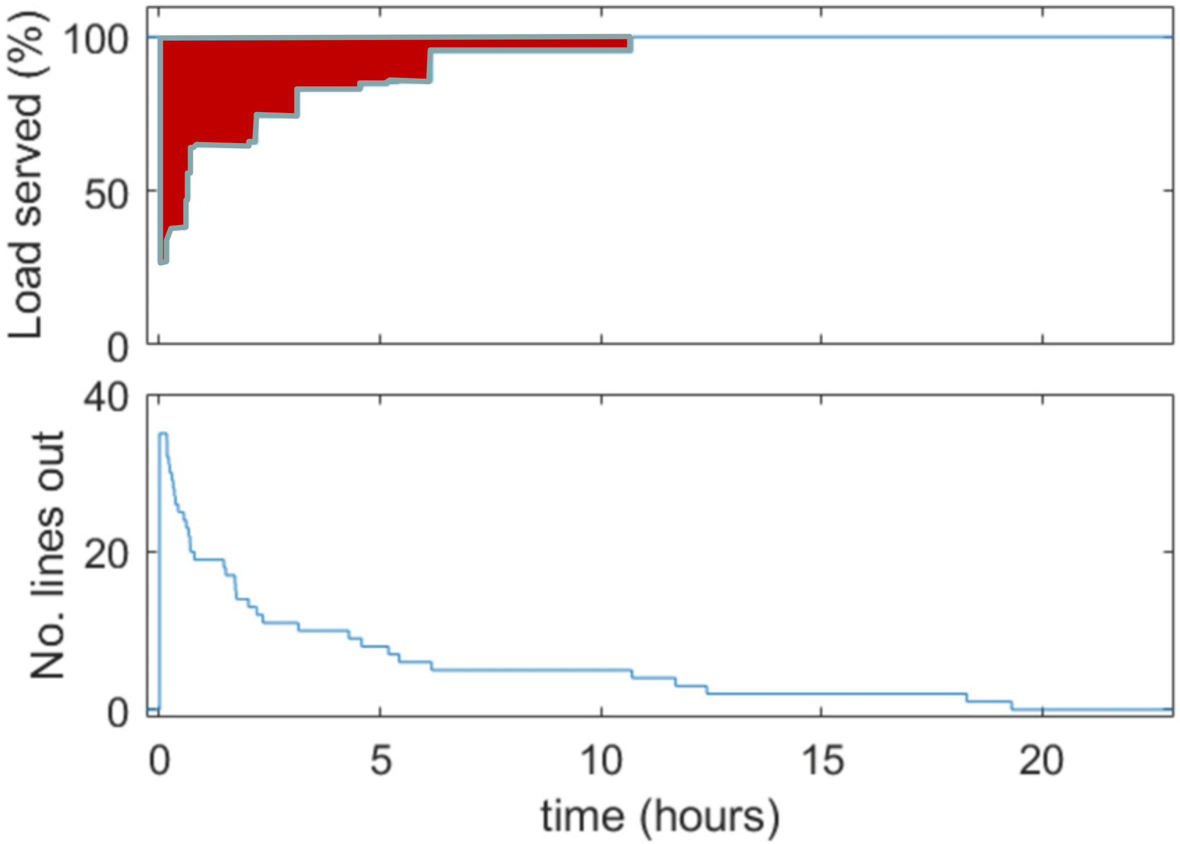


CRISP: Single Event

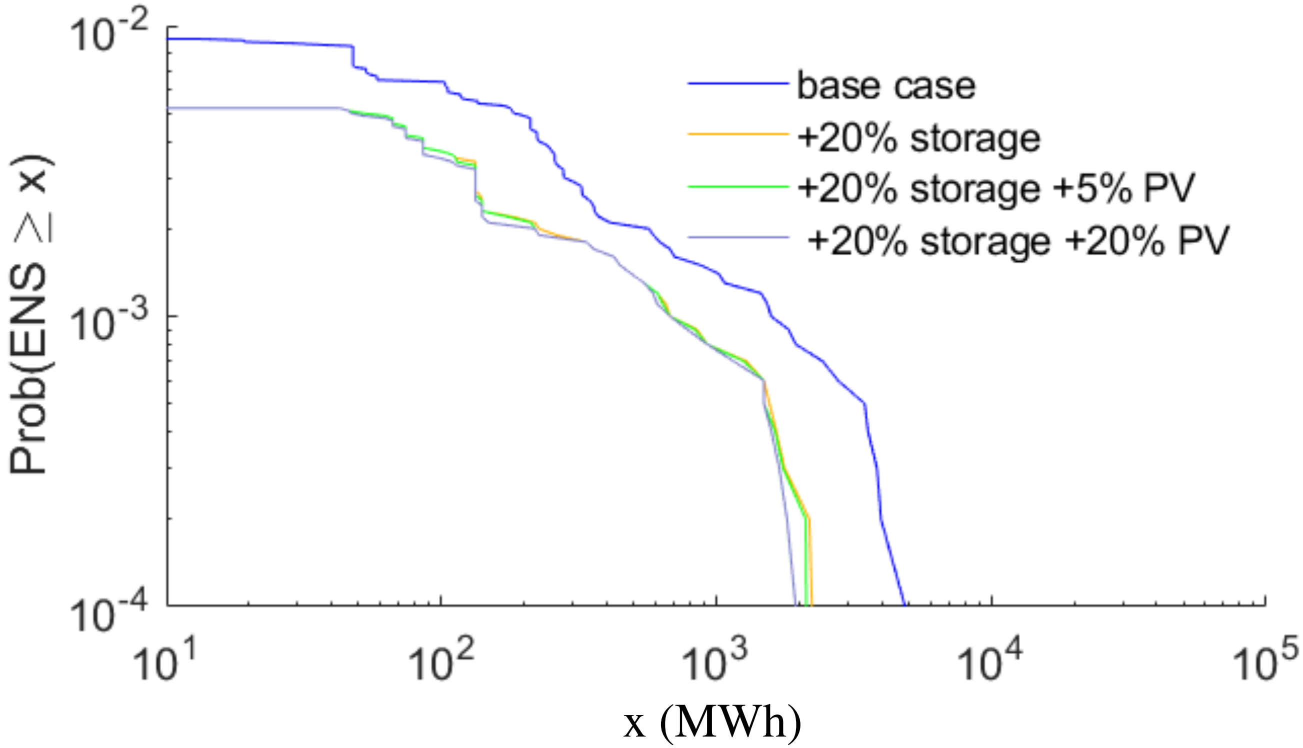
1. Outages After Cascade
   - Pick Initial Line Outage
   - Network Distance Distribution to Choose Other Line Outages
   - Sample Generator Outages
2. Blackout
   - Islanding
   - Minimal Load Shedding Optimization
3. Restoration
4. Blackout Impact
   - Energy Not Served (ENS) = Red Area



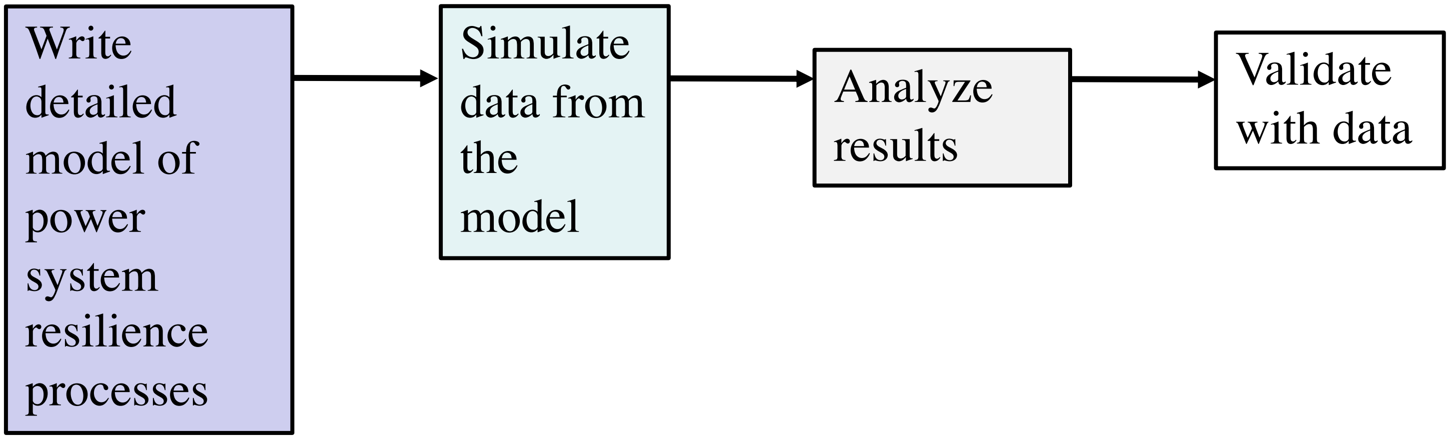
Example Event



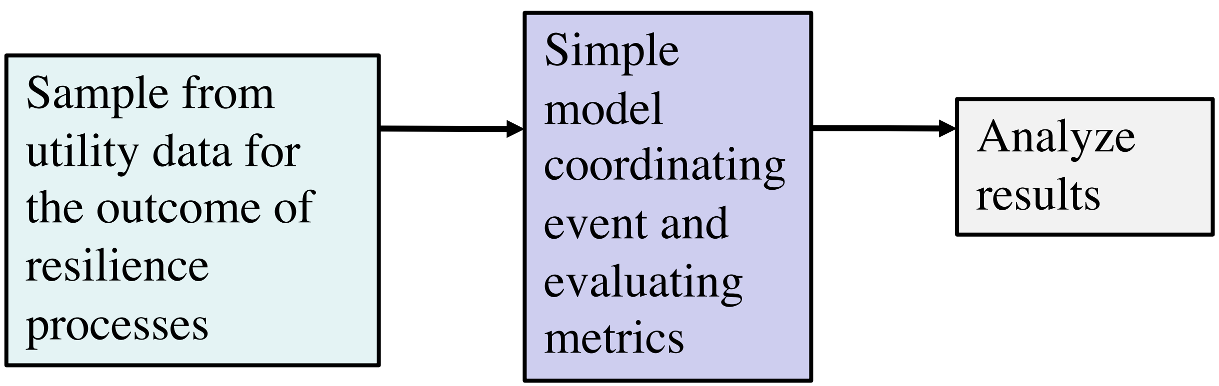
Distribution of Energy Not Served



Traditional detailed simulation model:



CRISP Data-driven high-level statistical simulation



Summary of data-driven simulation

- New CRISP simulation approach to quantify overall resilience
- We need to model 5 processes

  Stress → Cascading → Outage → Restoration → Analysis
- Sample from utility data for resilience process *outcomes*; avoid many modeling assumptions
- Take many samples to get statistics of metrics

MR Kelly-Gorham, PDH Hines, K Zhou, I Dobson, Using utility outage statistics to quantify improvements in bulk power system resilience, PSCC, July 2020, and Electric Power Systems Research, December 2020.

DISTRIBUTION SYSTEM RESILIENCE

Objective: Process standard distribution utility data to obtain statistics of resilience metrics

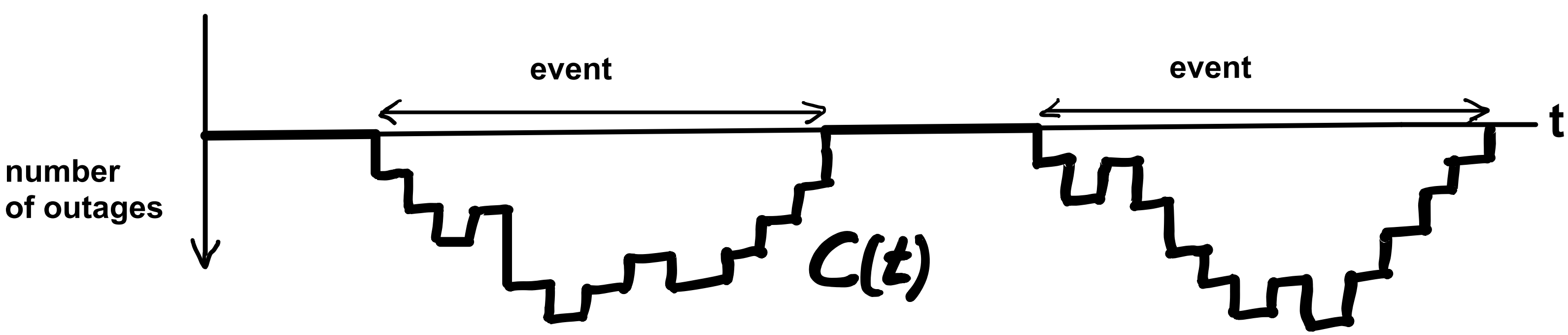
Utility distribution line outage data

- We work with standard data for automated utilities
- 32,000 outages over 5 years from one distribution utility
- Each outage records start and finish times to the nearest minute and number of customers out
- 1500 events

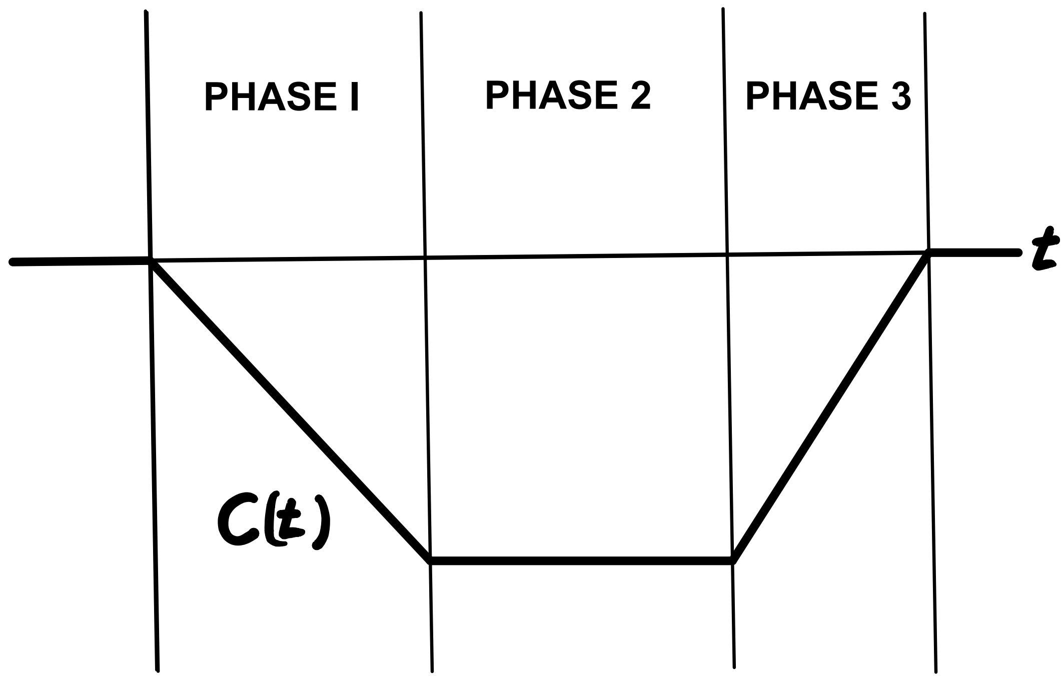
Extracting resilience events from utility data

Look at **resilience curve C(t)**: negative of cumulative number of outages as a function of time t.

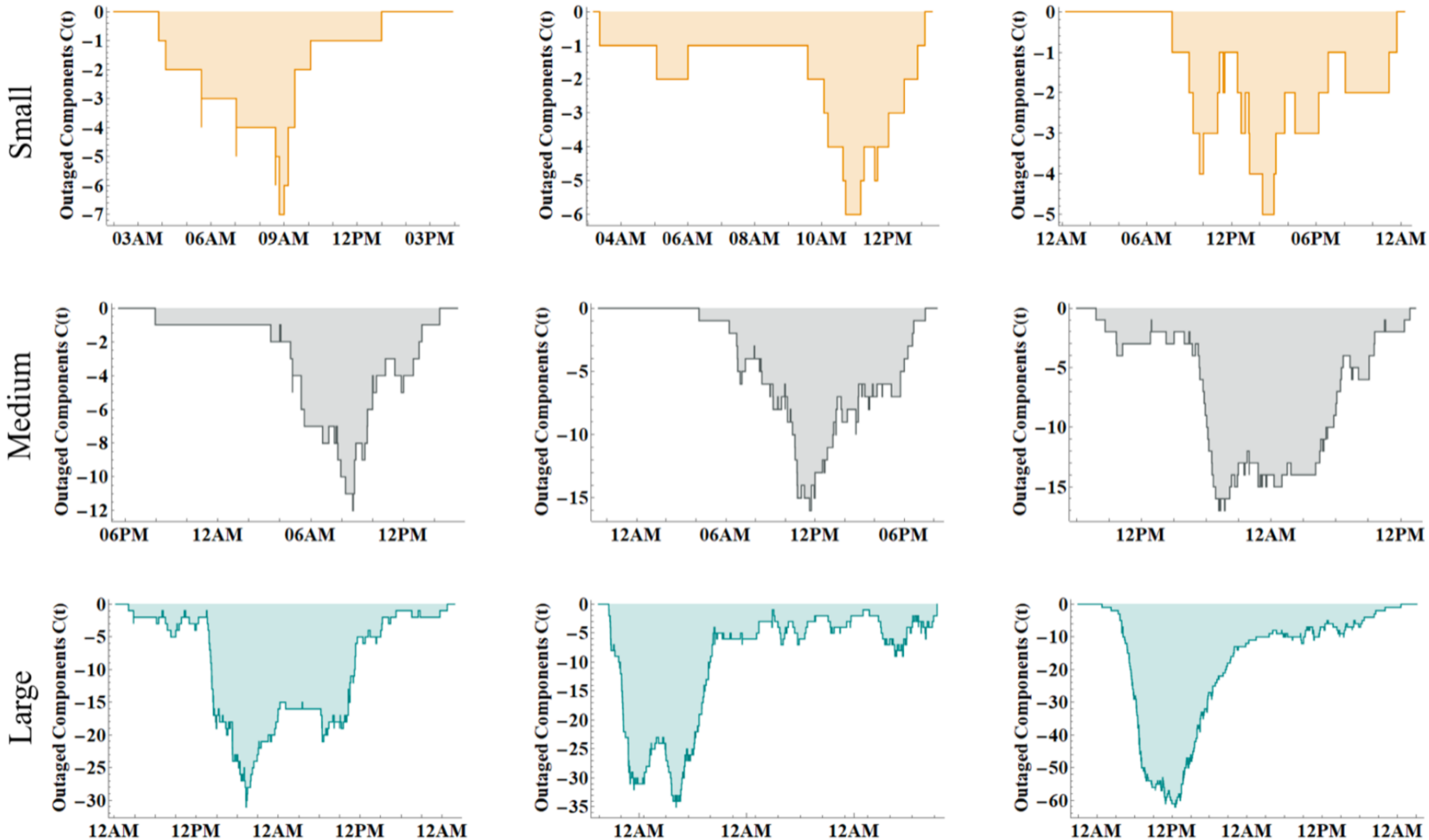
An **event** is the resilience curve dropping below zero and then returning to zero as outages occur and are restored.



Standard resilience curve trapezoid with phases separated by time



Resilience curves of events in real data



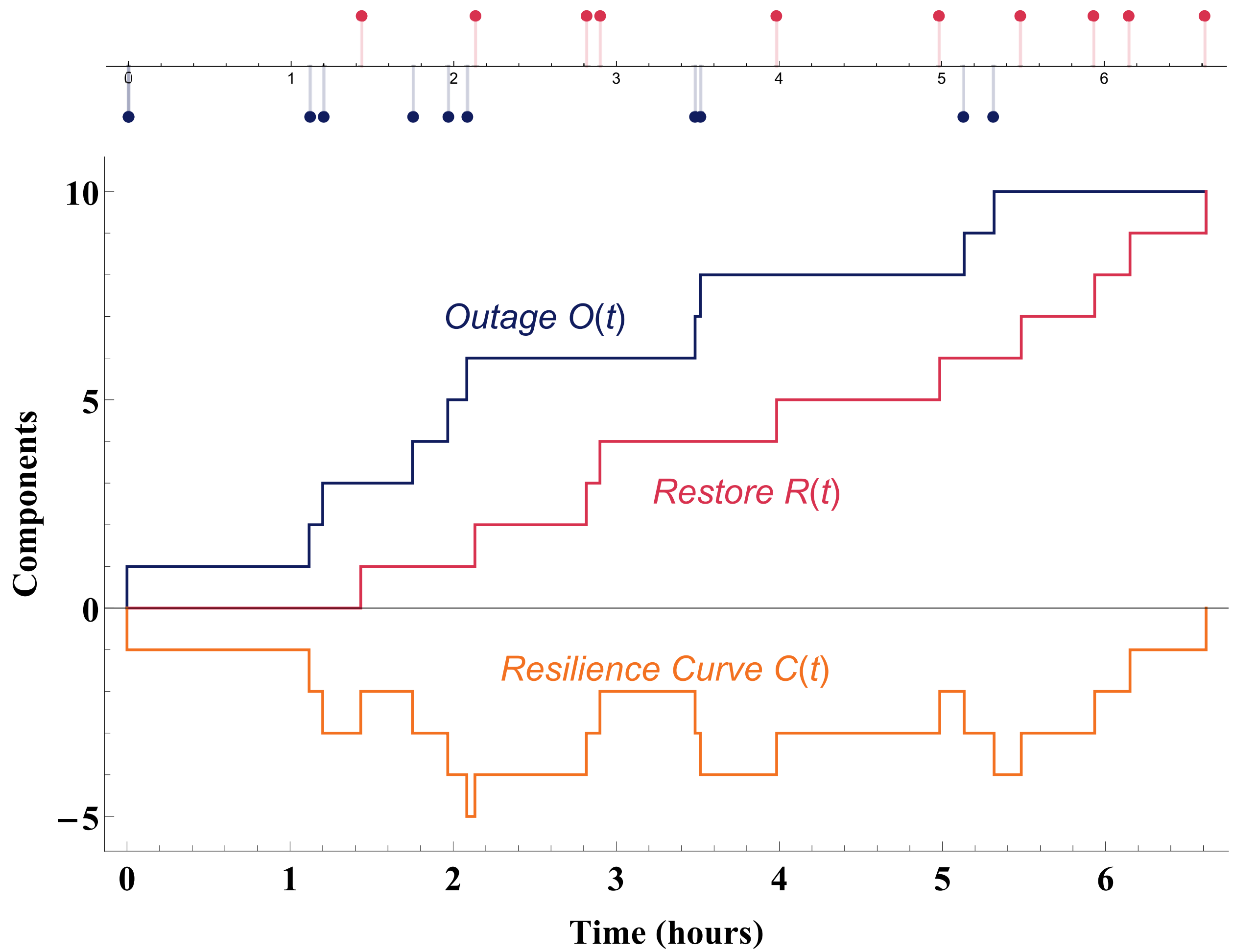
Processes not phases

Decompose resilience curves into overlapping outage and restoring processes

Decomposition into outage and restoring processes is always possible and unique. These processes also appear in queue models pioneered by Wei and Ji, Non-stationary random process for large-scale failure and recovery of power distributions, Applied Mathematics, 2016, and Zapata, Modeling the repair process of a power distribution system, IEEE/PES T&D Latin America, 2008.

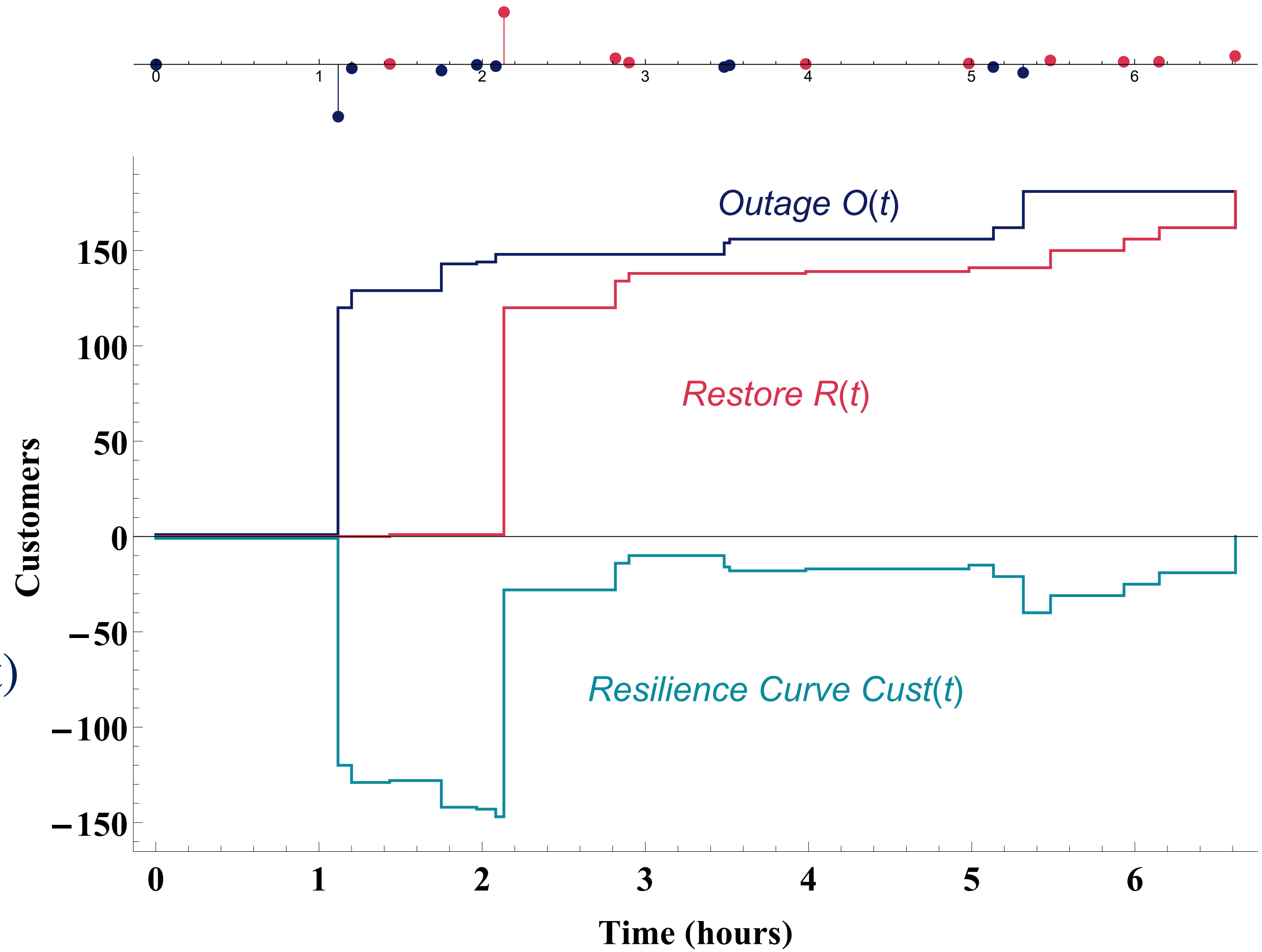
Decomposing Component Resilience curve into Outage and Restoring processes

$C(t)=R(t)-O(t)$

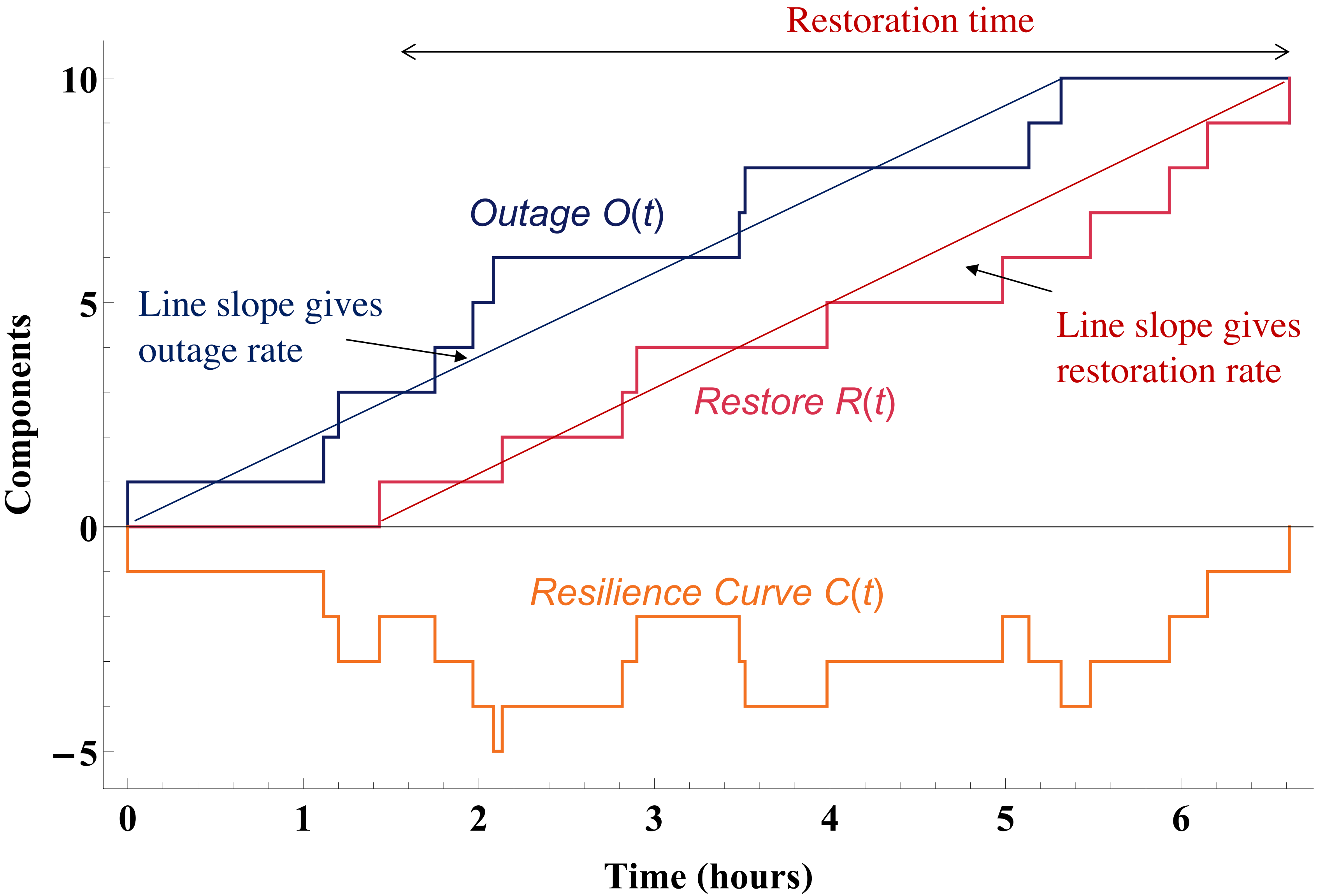


Decomposing Customer Resilience curve into Outage and Restoring processes

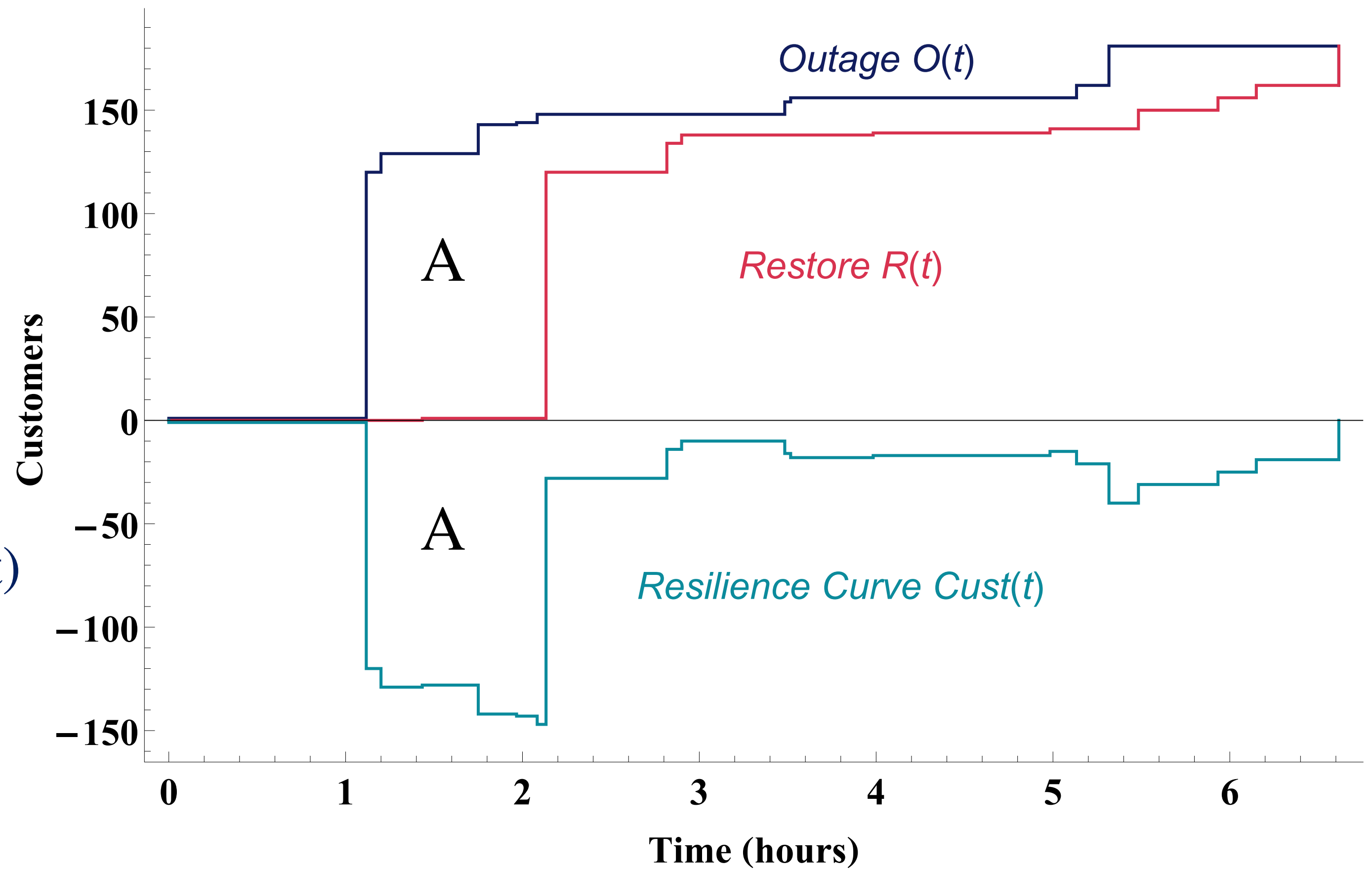
Cust(t)=R(t)-O(t)



Resilience Metrics



Area A = customer hours metric



$$\mathrm{Cust}(t)=R(t)-O(t)$$

Example of statistics of restoring process

Δr = time between successive restores
Mean(Δr)
Standard Deviation(Δr) = SD(Δr)
n = number of outages

Mean restoration time = (n-1) Mean(Δr)
SD restoration time = $\sqrt{n-1}$ SD(Δr)
Find Gamma distribution with that mean and SD.
Then find 95th percentile of restoration time:
Gives useful upper bound on restoration time.

Summary of resilience metrics from distribution system utility data

- Decompose real data into overlapping
  outage and restoring processes, not phases.

- Systematically extract many events to get statistics

- Can get mean and variability of standard resilience metrics from standard utility data

- Overall, an expanded perspective by working with real data

N.K. Carrington, I. Dobson, Z. Wang, Extracting resilience statistics from utility data in distribution grids, preprint in preparation for arXiv