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Iowa State University

Probability Methods Applied to Power System Resilience

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

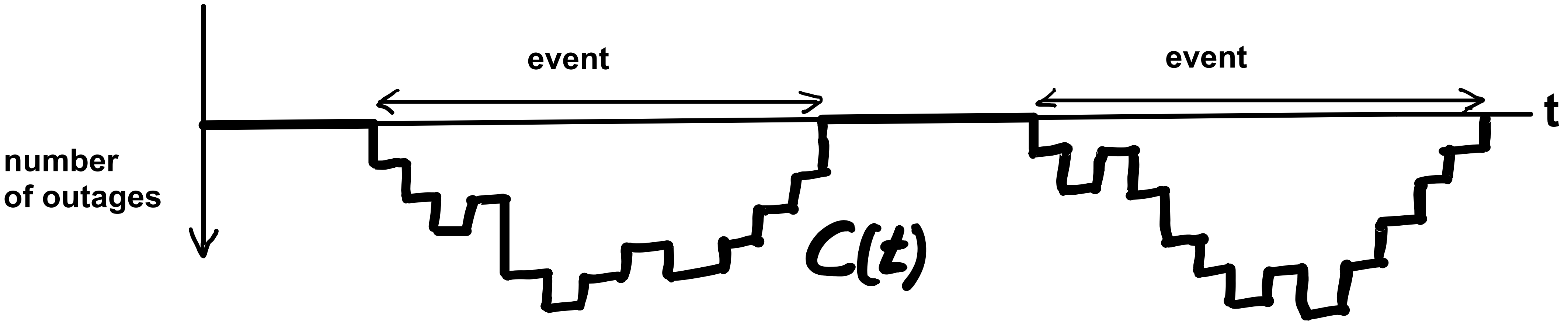
Utility distribution line outage data

- 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

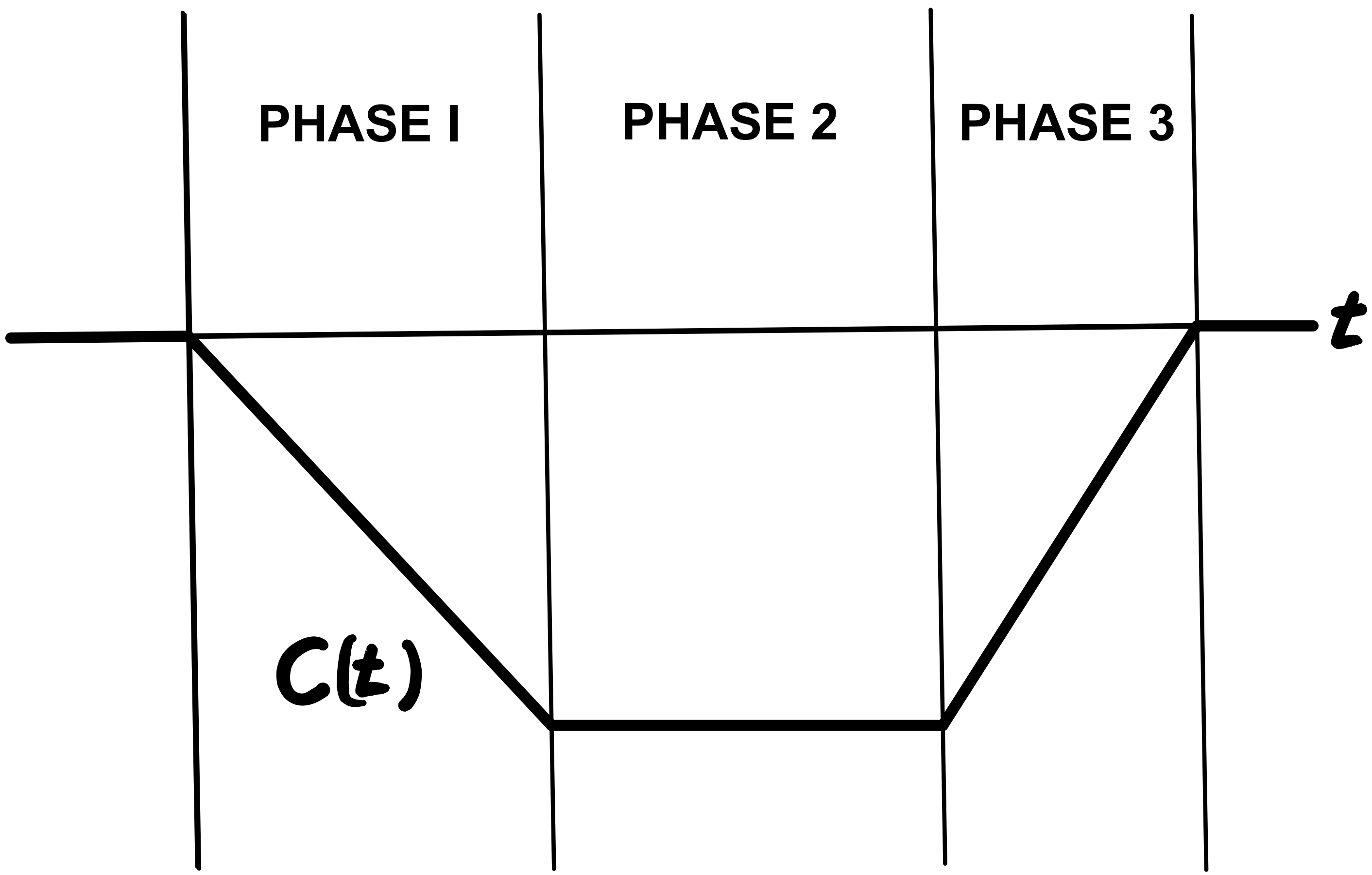
Extracting resilience events from utility data

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

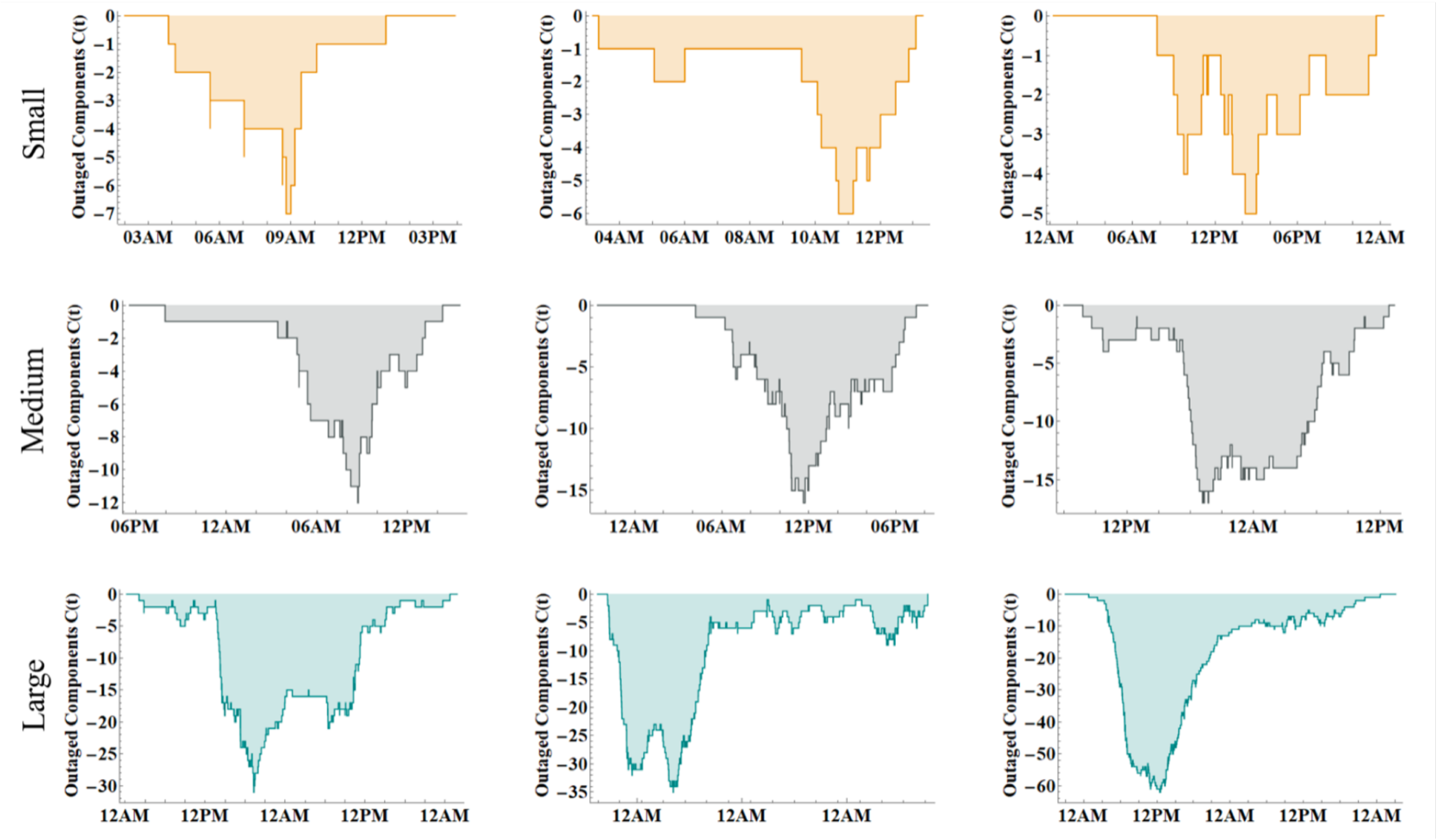
An **event** is the resilience curve dropping below zero and then returning to zero as outages occur and are restored.



Standard resilience curve trapezoid with phases separated by time



Resilience curves of events in real data

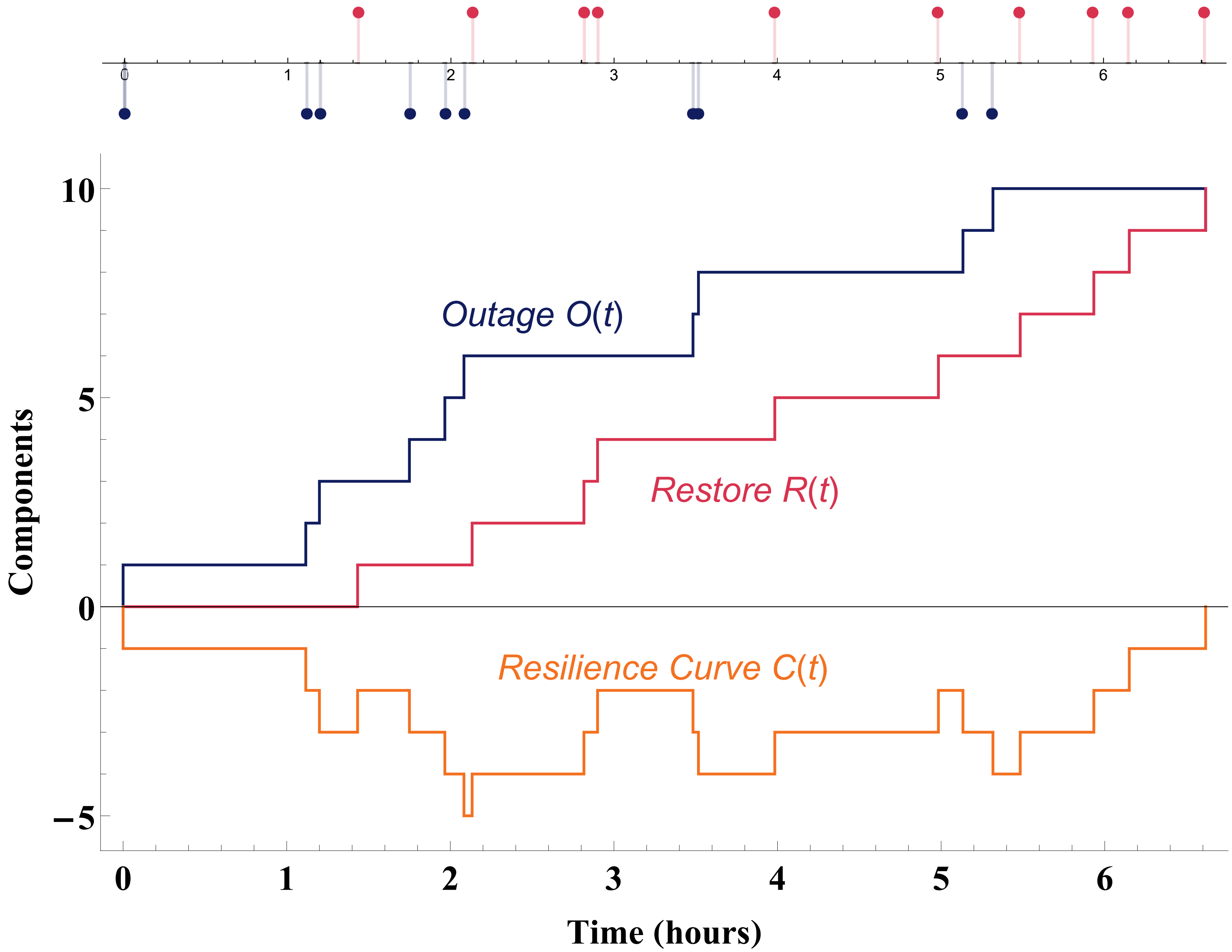


Processes not phases

Decompose resilience curves into overlapping outage and restoring processes

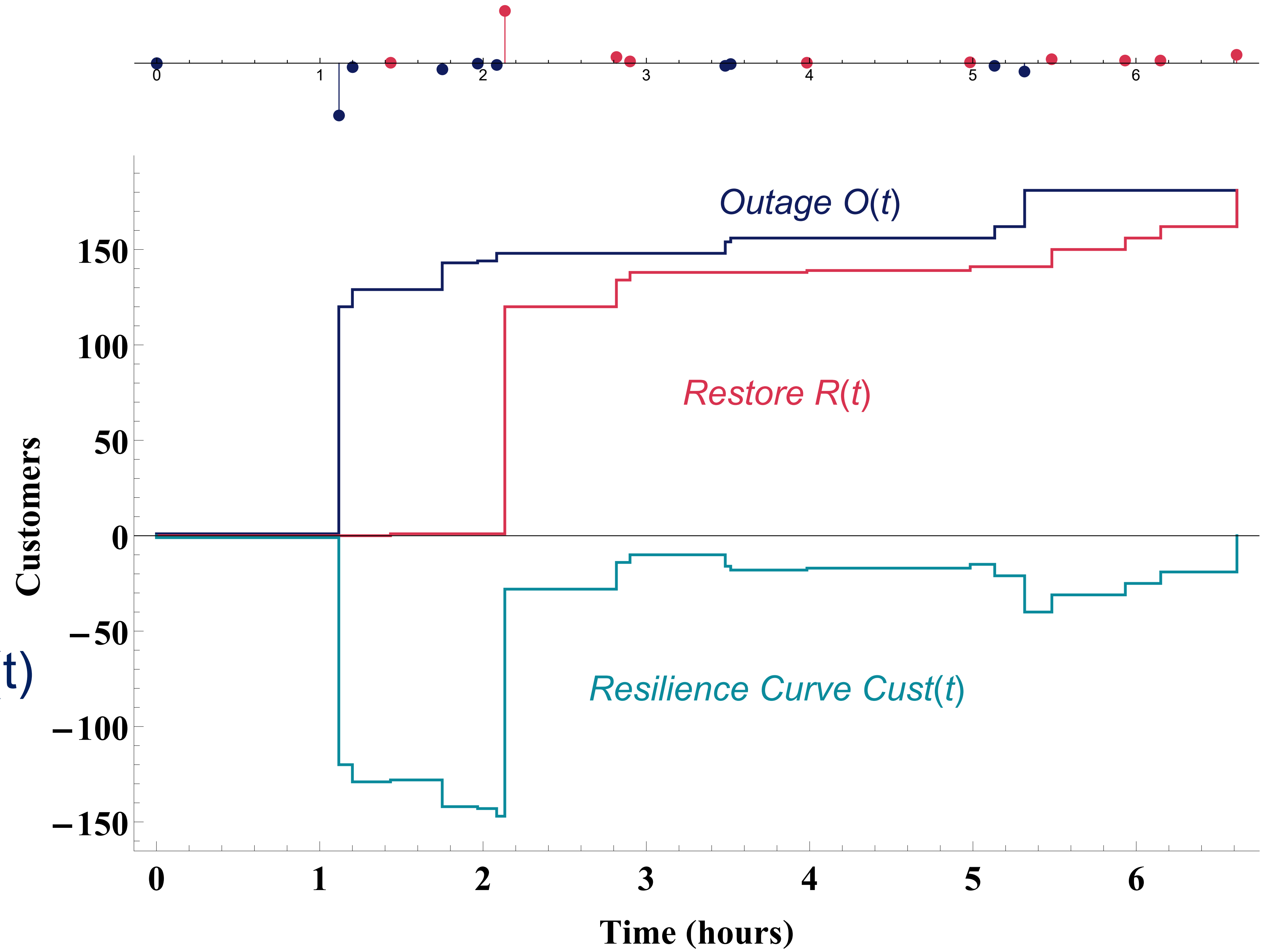
Decomposition into outage and restoring processes is always possible and unique. These processes also appear in queue models pioneered by Wei and Ji, Non-stationary random process for large-scale failure and recovery of power distributions, Applied Mathematics, 2016, and Zapata, Modeling the repair process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

Decomposing Component Resilience curve into Outage and Restoring processes



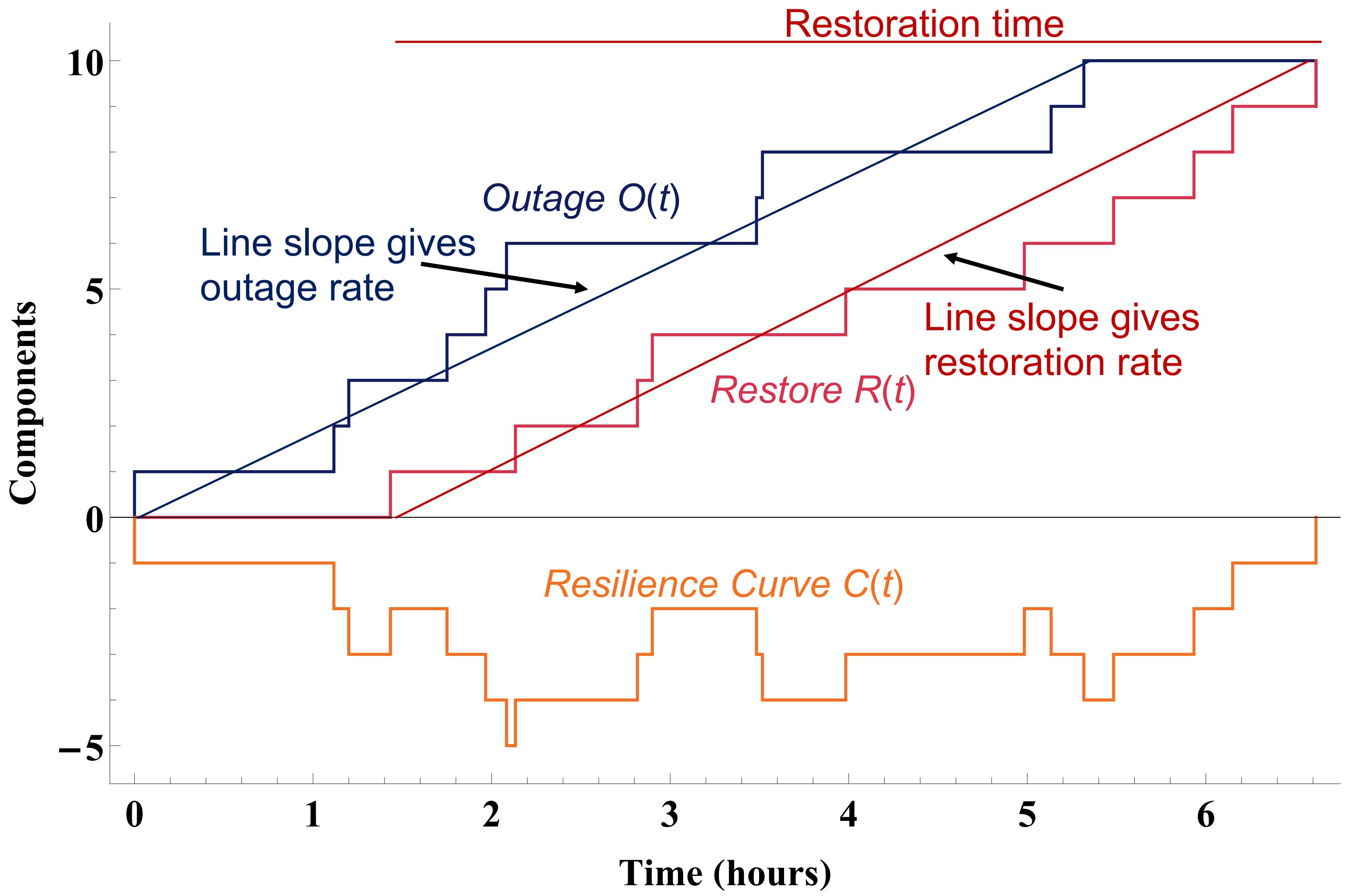
C(t)=R(t)-O(t)

Decomposing Customer Resilience curve into Outage and Restoring processes



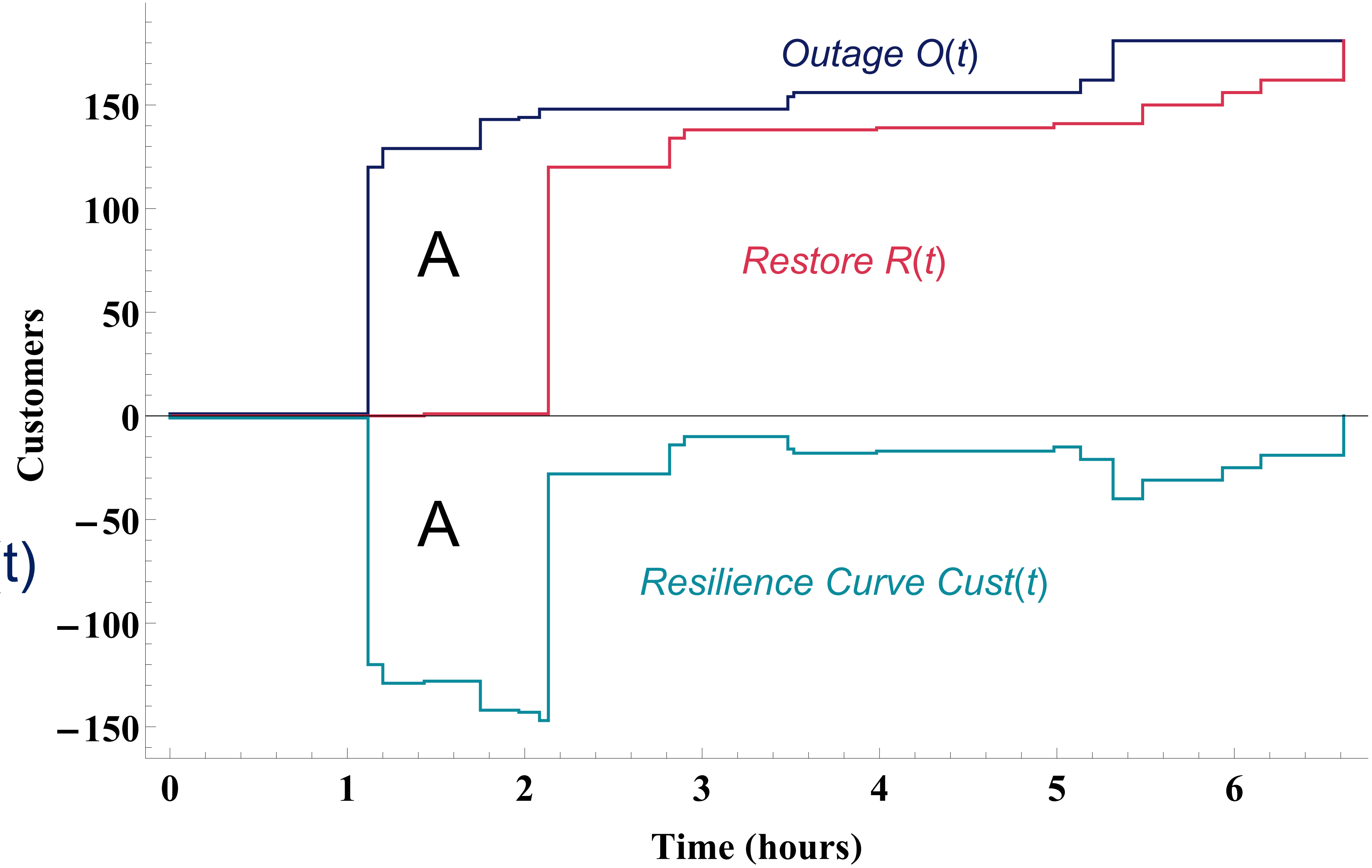
Cust(t)=R(t)-O(t)

Resilience Metrics



Area A = customer hours metric

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



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.

Themes

- 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

- If you would like to try processing some of your utility data, please contact Ian at dobson@iastate.edu