A new way to analyze and monitor cascading failure

Ian Dobson, University of Wisconsin-Madison

Benjamin Carreras, BACV solutions

Carnegie Mellon Electricity Industry Conference
March 2011

Present and Past Funding from
California Energy Commission, DOE, PSerc
is gratefully acknowledged

UNIVERSITY OF WISCONSIN MADISON

LARGE BLACKOUTS

Blackouts typically become widespread by cascading failure

Cascading failure is a sequence of dependent outages of individual components that successively weakens the system

cascading = initial outages + propagation

Cascading mechanisms varied and complicated,
but in any case …

Transmission line outages are a blackout diagnostic

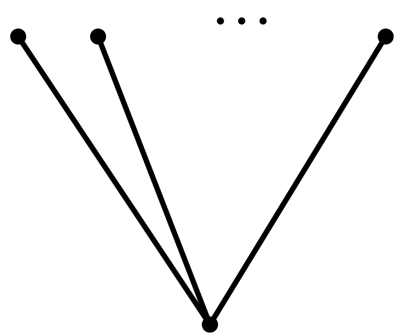
We seek probability distribution of the
total number of lines outaged

Galton-Watson branching process model for cascading failure

- New in risk analysis but applied to many other cascading processes
- Given the initial outages and propagation, can evaluate elegant formulas to compute distribution of the total number of outages

cascading = initial outages + propagation

Branching from one outage



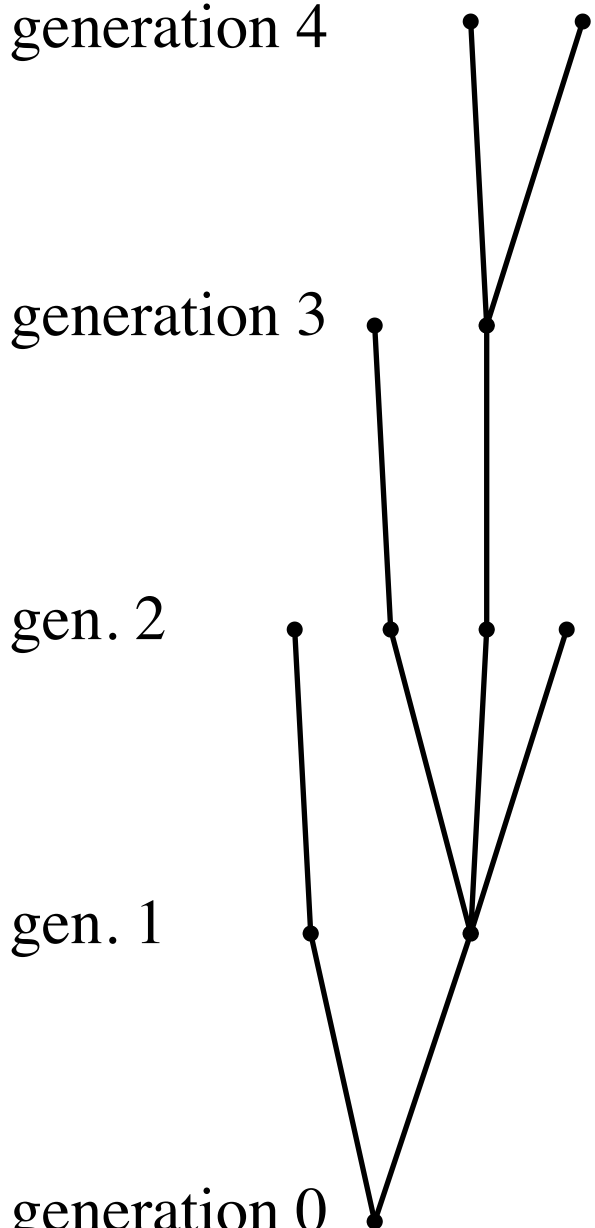
child outages

a parent outage

Random number of child outages according to Poisson offspring distribution.

Average number of children = λ

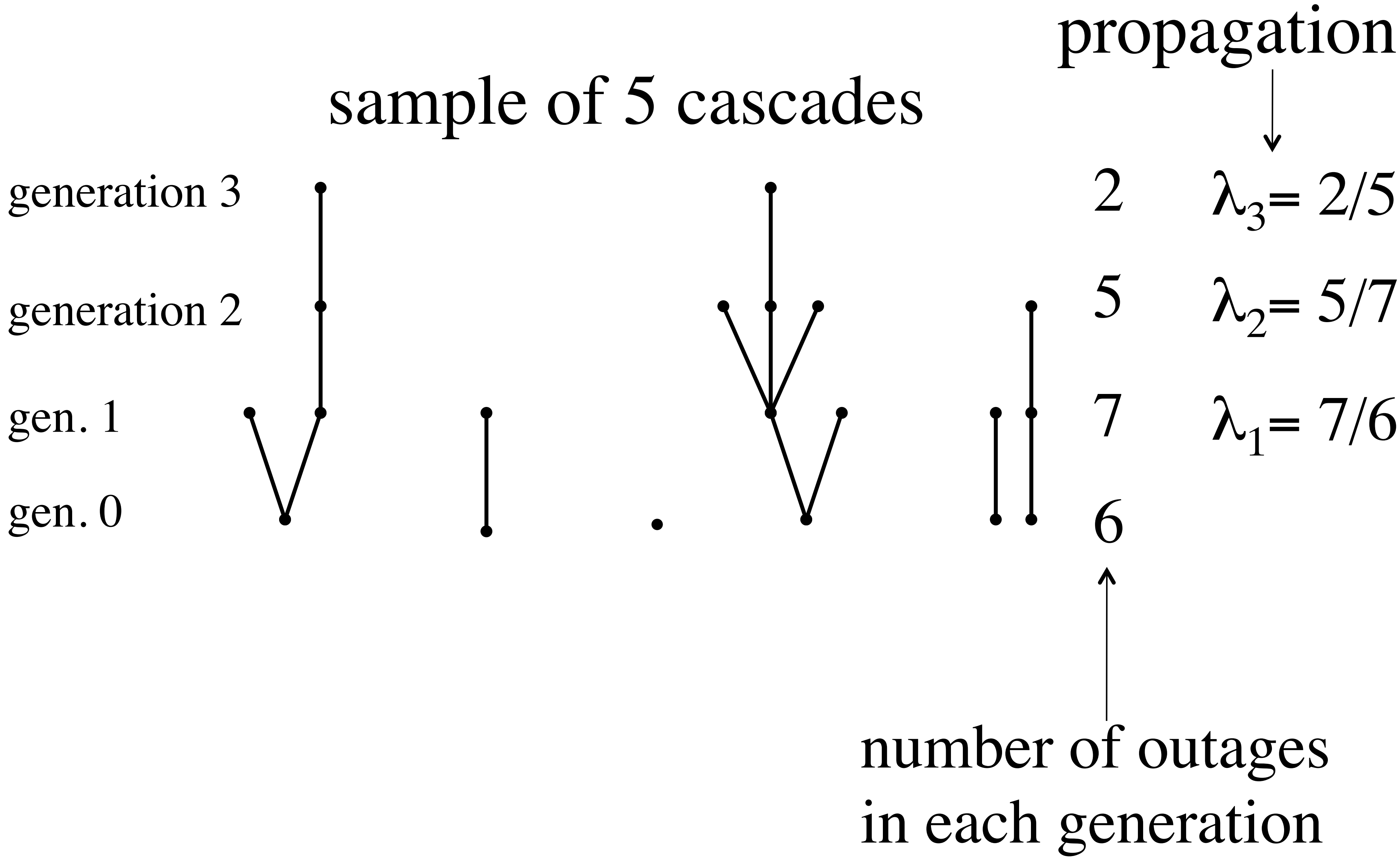
Branching Process



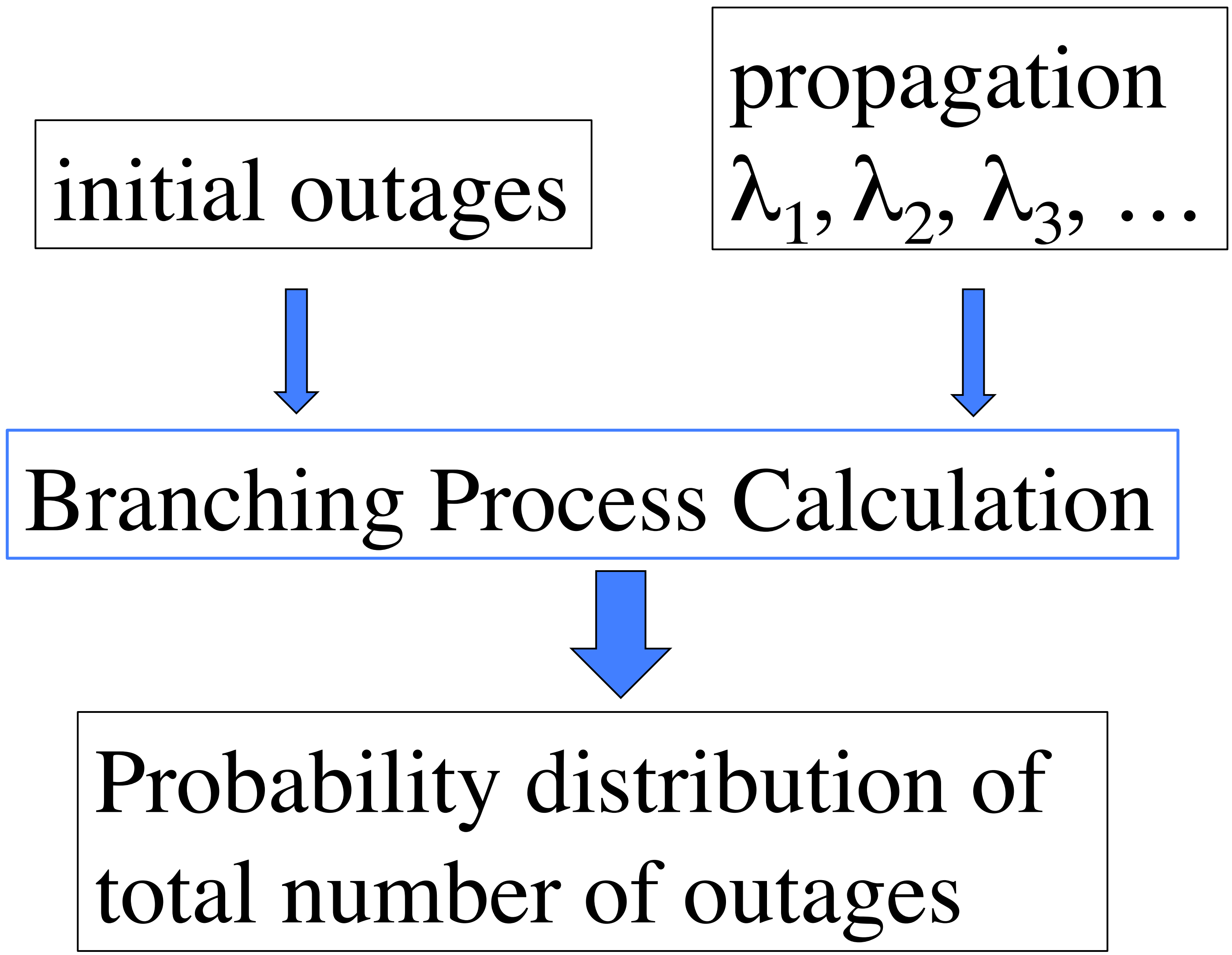
– each outage independently has random number of child outages in next generation

– λ_k = average number of generation k children per parent outage

ESTIMATING PROPAGATION λ



Branching process can compute extent of cascading



Part of formula for computing the generating function of total number of outages; recursive structure mirrors cascading generations

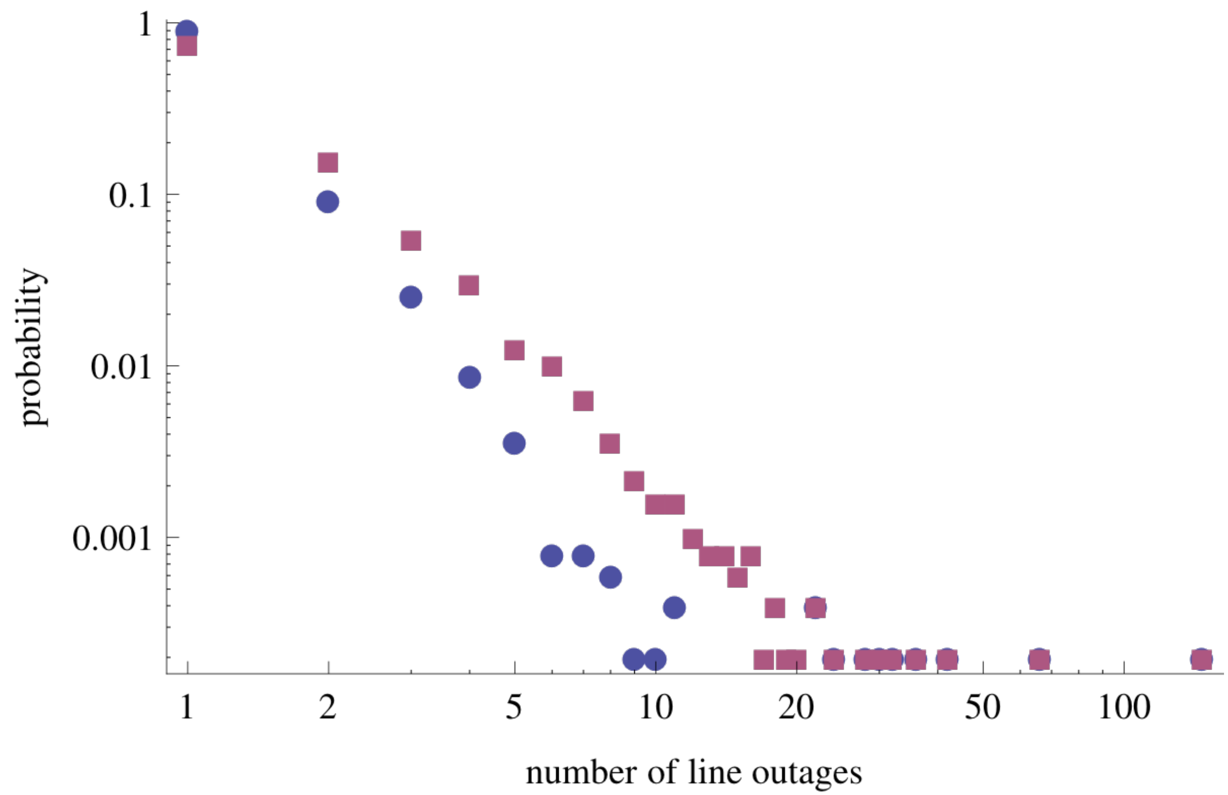
$$e^{-\lambda_1+\lambda_1 s e^{-\lambda_2+\lambda_2 s e^{-\lambda_3+\lambda_3 s e^{-\lambda_4+\lambda_4 f_B(s)}}}}$$

PROCESSING OBSERVED TRANSMISSION LINE OUTAGES

- 8600 automatic line outages over 10 years in utility data
- This is data that must be reported to NERC
- Only look at time of outages
- Group outages into 5227 cascades and then into generations by their timing
- This gives
  6254 outages in generation 0,
  1143 outages in generation 1,
  434 outages in generation 2, etcetera…

Distributions of line outages

Probability

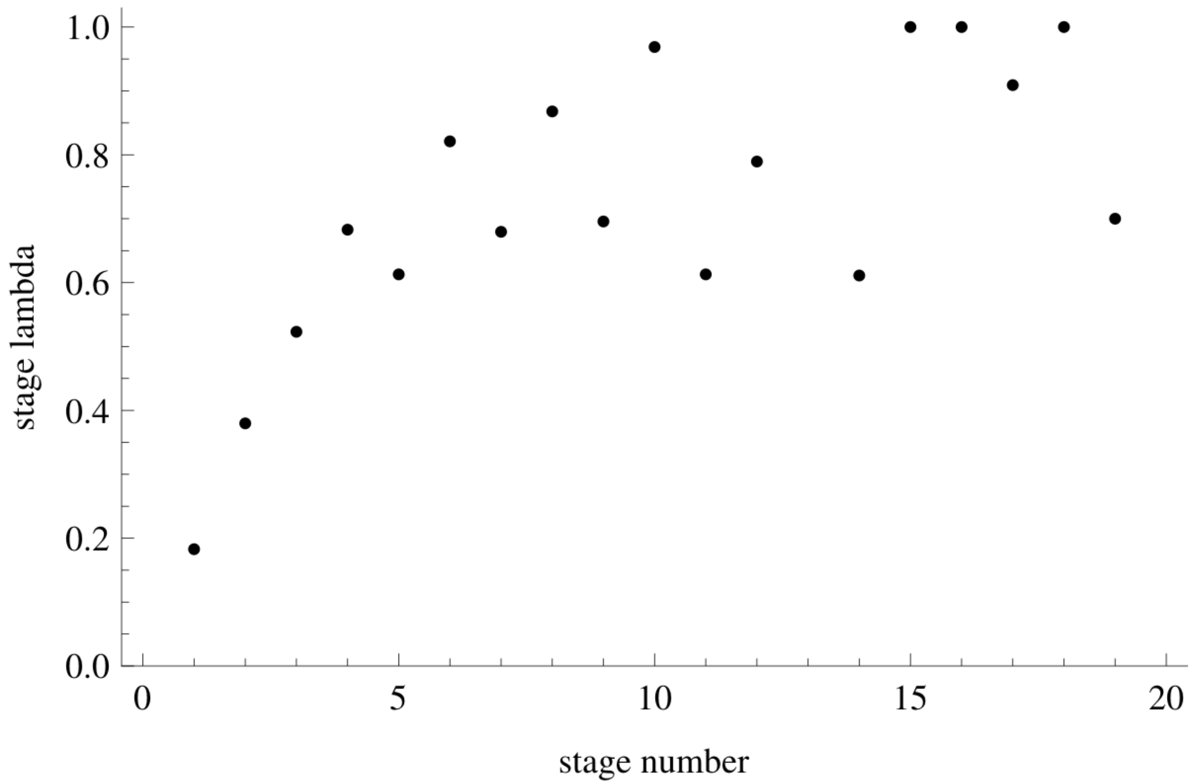


Number of line outages

Blue dots: initial line outages (generation 0) in each cascade
Red squares: total line outages in each cascade

The increasing propagation λ from data

Propagation
λ
in each
generation

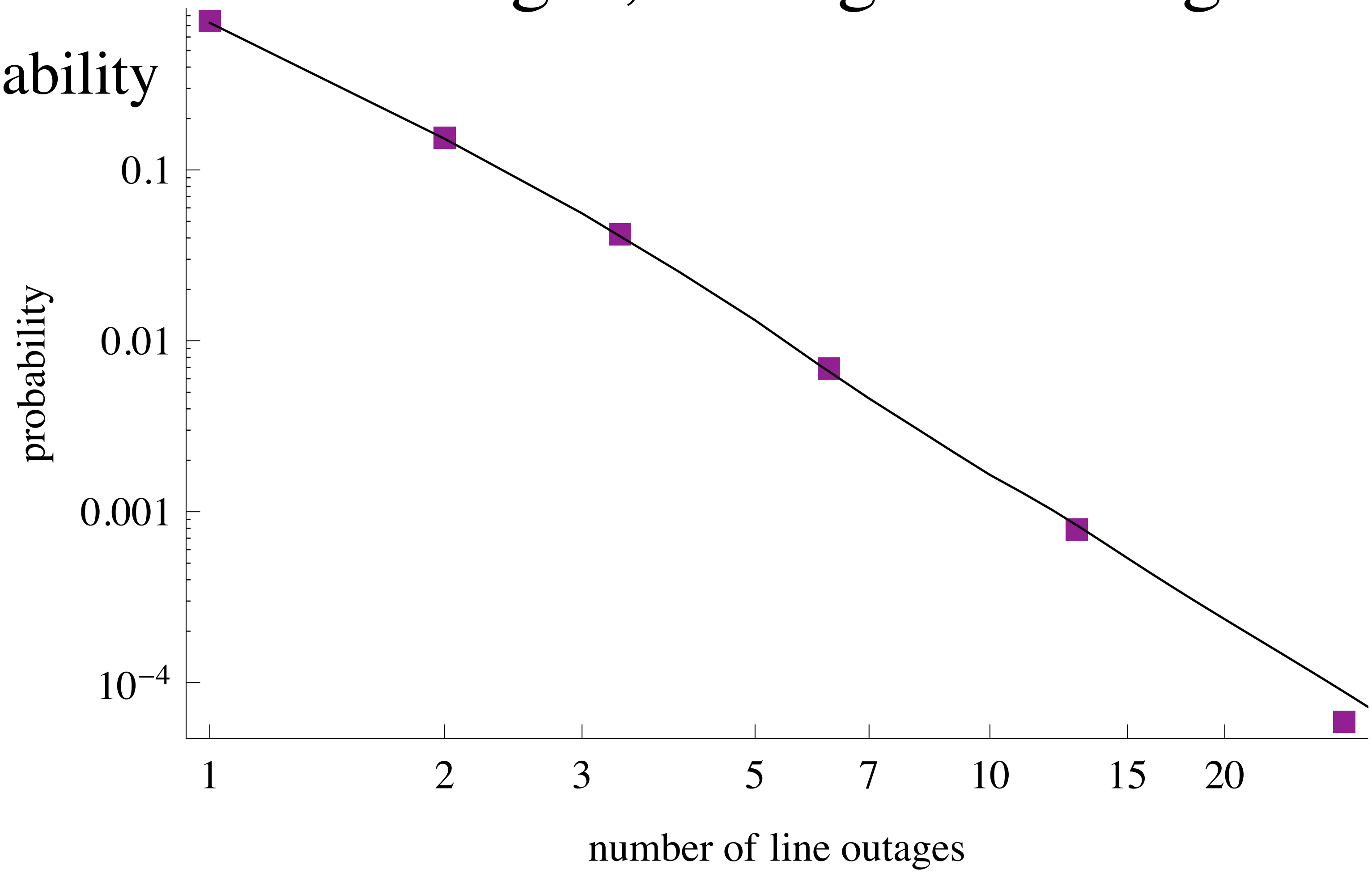


Generation number

$\lambda 1 = 0.18,\ \lambda 2 = 0.38,\ \lambda 3 = 0.52,\ \lambda 4 = 0.68, \lambda 5{+} = 0.75$

Distributions of outages; testing branching model

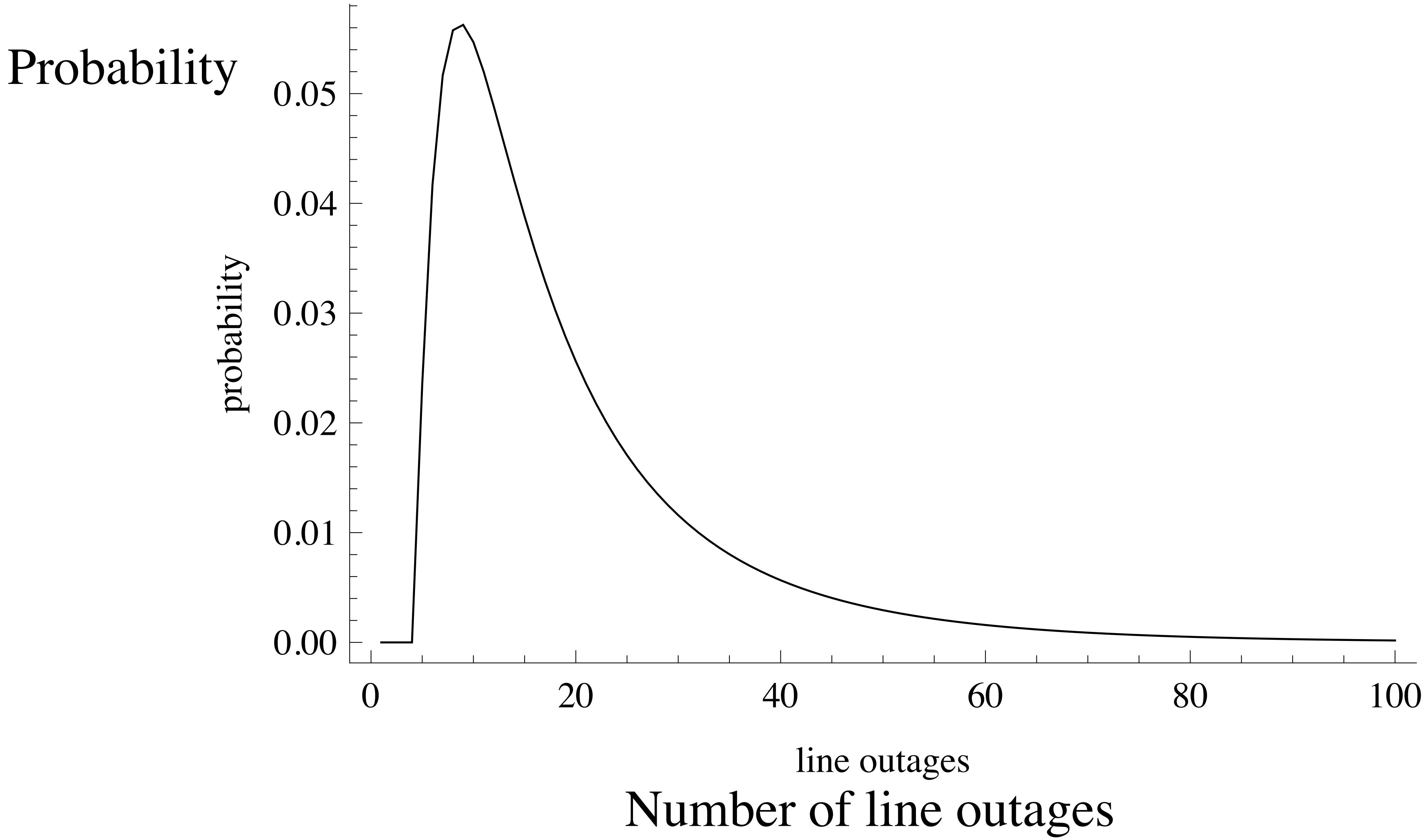
Probability



Number of line outages

Purple squares: Observed data

Line: Predicted by branching process with the varying λ



Probability distribution of total number of line outages assuming 5 initial line outages

Conclusions

- Branching process model of propagating line outages consistent with the utility data
- Can estimate cascading blackout extent from given initial outages based on observed data (conventional risk analysis can estimate initial outages) (also works for simulated data)
- Data used is in required utility reports to NERC
- λ is a metric of propagation and resilience
- New capability and practical method to quantify effect of cascading based on data (needs about one year of data in a large utility)

for more details, google Ian Dobson papers

Next steps for monitoring cascading

- More testing; get more observed data
- Further application to simulated cascade data
- Mitigate propagation as well as initial outages?
- challenge: Extend to load shed (blackout size)

for more details, google Ian Dobson papers

Validating and applying branching processes to simulated cascading data

Objective: efficiently estimate pdf of total number of failures

- Run simulation to produce large amount of data (number of lines outaged in each generation)
- Estimate propagation and initial failures and use branching process to predict pdf
- Compare pdf with empirical pdf to validate branching process
- If validated, can use smaller amount of data to estimate pdf, especially the tail (estimate propagation and initial failures and then calculate pdf with branching process)

…see paper Dobson, Kim, Wierzbicki in Risk Analysis 2010

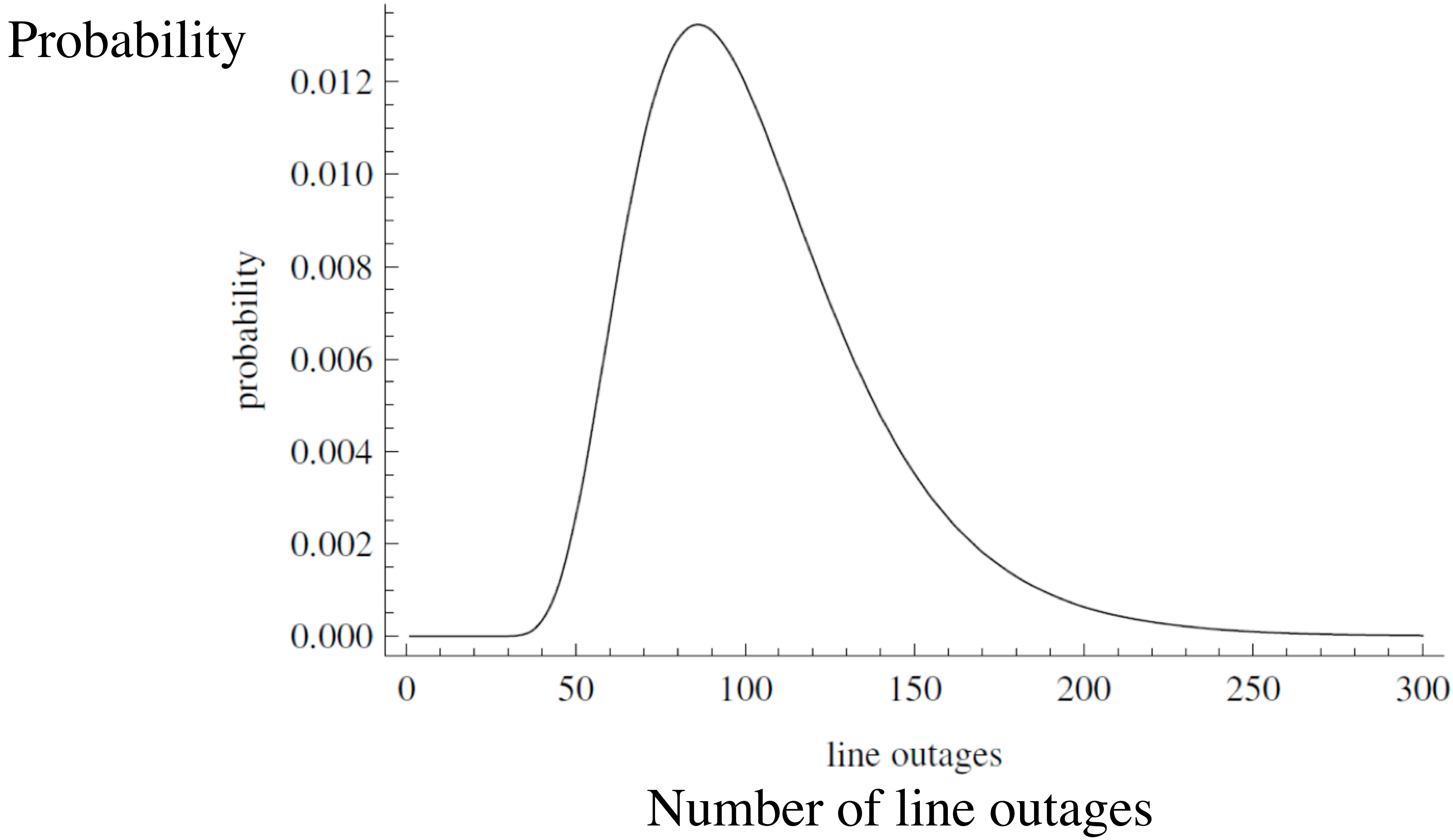
Illustrative application: Large blackout sensitivity to propagation

$\lambda 1 = 0.18,\ \lambda 2 = 0.38,\ \lambda 3 = 0.52,\ \lambda 4 = 0.68, \lambda 5+ = 0.70$

Probability at least 20 lines out = 0.0024

- decrease $\lambda 1$ by 0.1 reduces Probability by 0.0014
- decrease $\lambda 2$ by 0.1 reduces Probability by 0.0007
- decrease $\lambda 3$ by 0.1 reduces Probability by 0.0005
- decrease $\lambda 4$ by 0.1 reduces Probability by 0.0004

More effective to reduce propagation at early generations



Probability distribution of total number of line outages assuming 26 initial line outages