Intro to Reliability Analysis Quality Digest

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Poll question

What is Reliability?

"Probability that a system, vehicle, machine, device, and so on, will perform its intended function under encountered operating conditions, for a specified period of time".

"Quality over time".

Statistical Methods for Reliability Data, William Q. Meeker, Louis A. Escobar, 1998

Products that Have Performed Beyond Life Expectations for Family and Friends

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Why is Reliability Important?

High Reliability Advantages:

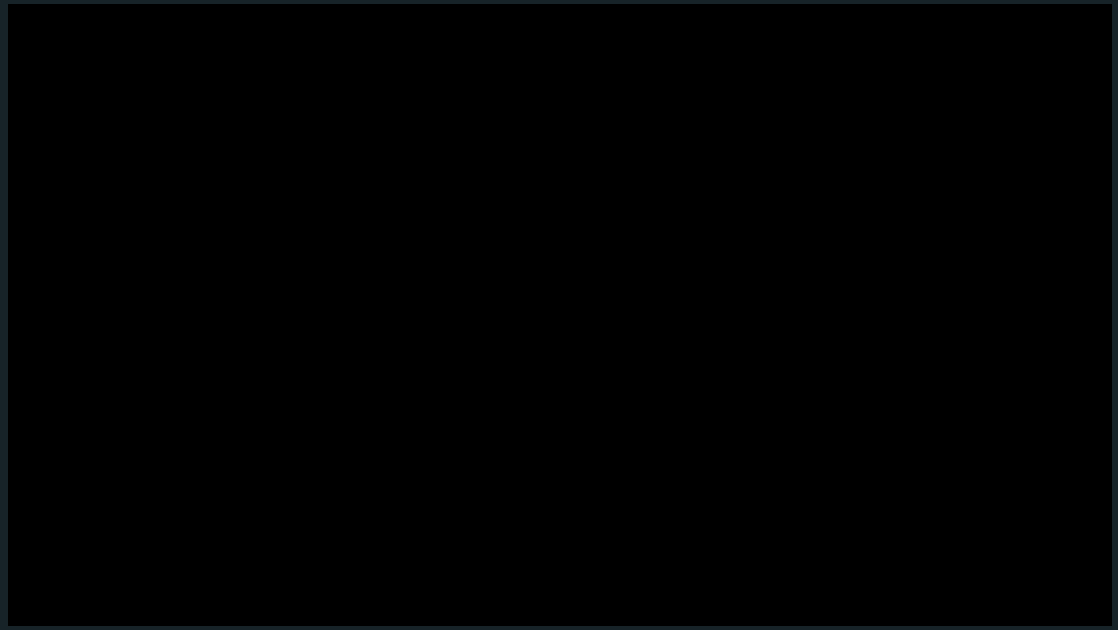
- Improved safety
- Products fail predictably
- Products fail at the end of or later than useful lifespan
- Happy customers = +$$.

Low reliability risks:

- Compromised safety
- Products fail unpredictably
- Products fail earlier than expected
- Low consumer confidence = -$$.

Common Reliability Questions

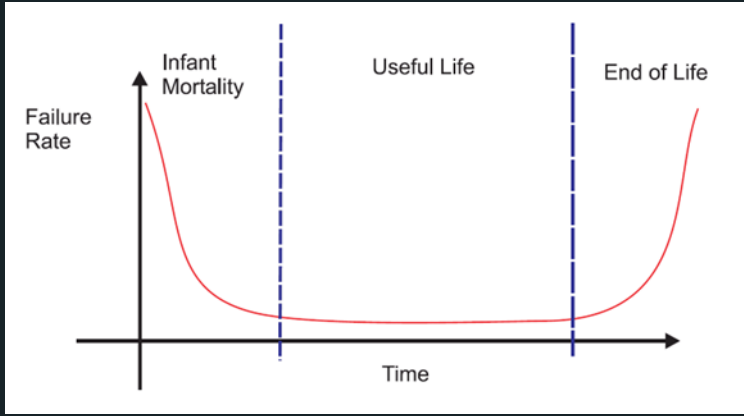
- When will my component fail?
- How long of a warranty should I offer?
- What expiration date should I use?
- How does something degrade over time?
- What can the distribution of failures say about underlying failure mechanisms?



Purpose of Reliability Analysis

Analysis of time-to-event data to determine the lifespan of a product.

– "Time" could also be mileage, cycles, load at failure, etc.

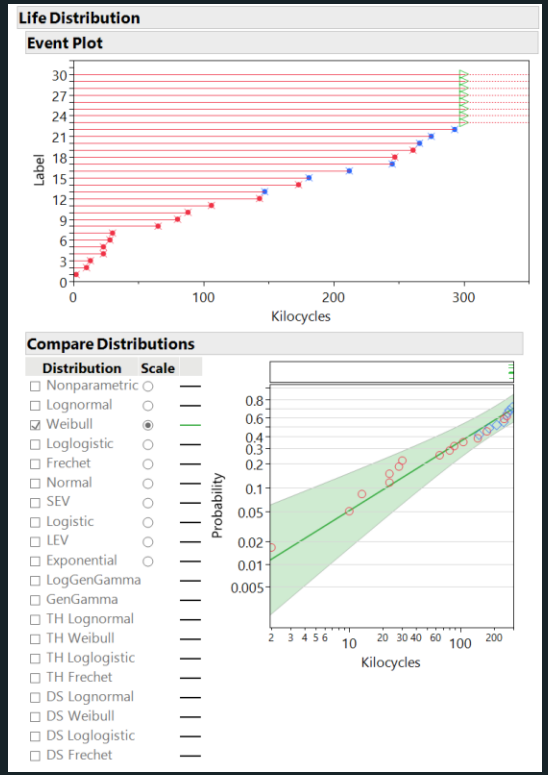


What are time-to-event data?

Properties of Time-to-Event Data

(Failure Terminology)

- Failure times are always positive (bounded).
- Failure time distributions are often skewed (non-normal).
- True failure time may not be known (censored).
- Extrapolation is expected.



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Guidelines for Choosing a Failure Time Distribution For Component Reliability Estimation

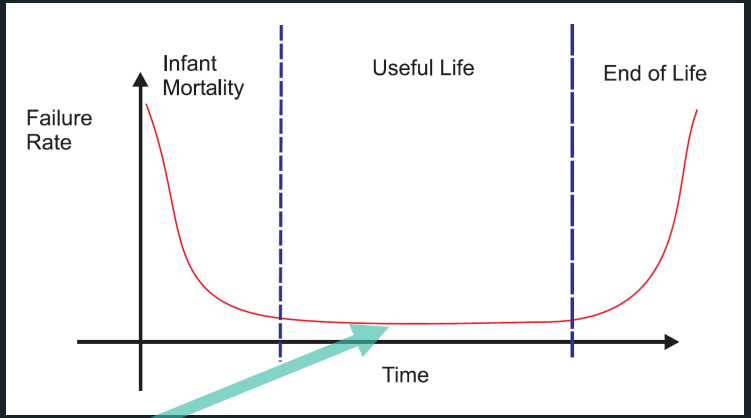
1. There is a theory that matches a failure mechanism to a distribution.

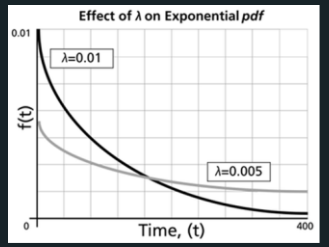
2. A distribution has been used successfully in the past for the same phenomena.

3. Distribution provides good fit to ALL the data.

Exponential

- When will a component fail given a constant failure rate?
- Common phenomena
  - Failures from random shocks or stresses in use.
  - Any time a unit/system does not fail early or wear out over time .
  - Often used to model the bottom of the bathtub curve.





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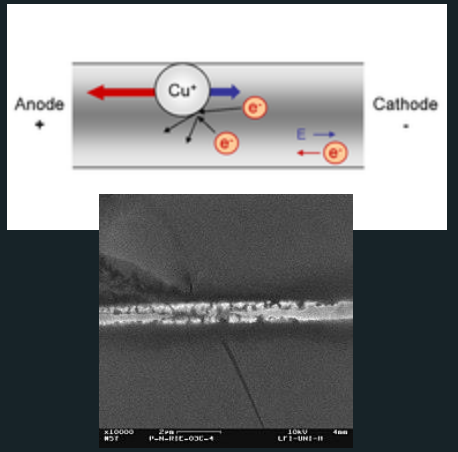
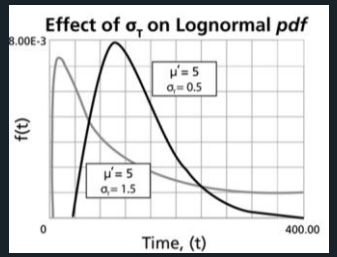
Lognormal Distribution

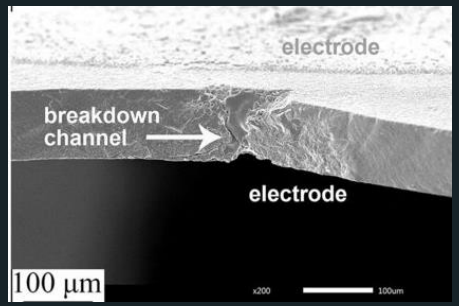
- When will a component fail due to **degradation** over time?
- Common phenomena
  - Wear, electromigration, corrosion...

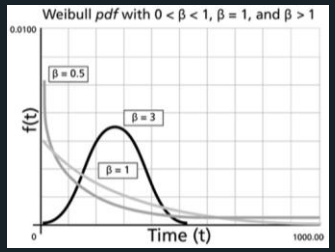




Weibull

- When will a component/system fail given competing SIMILAR failure processes (weakest link)?
- Common phenomena
  - Capacitor time-dependent dielectric breakdown (TDDB), Brittle Fracture (ceramics), systems…

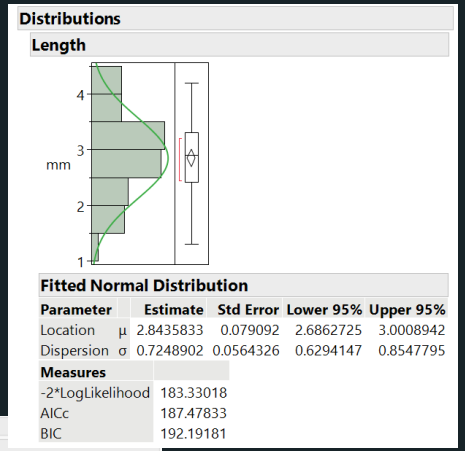


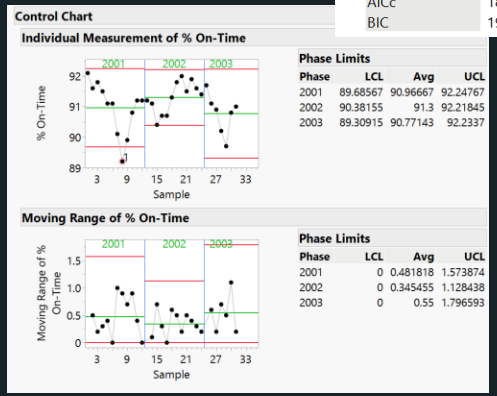


What are non-time-to-event data?

Properties of Non-Time-To Event Data

- Measurement values can be negative (unbounded).
- Measurement values must be known (no censoring).
- Measurement values of this kind are often used in quality methods
  - Control charts, capability, variability charts…





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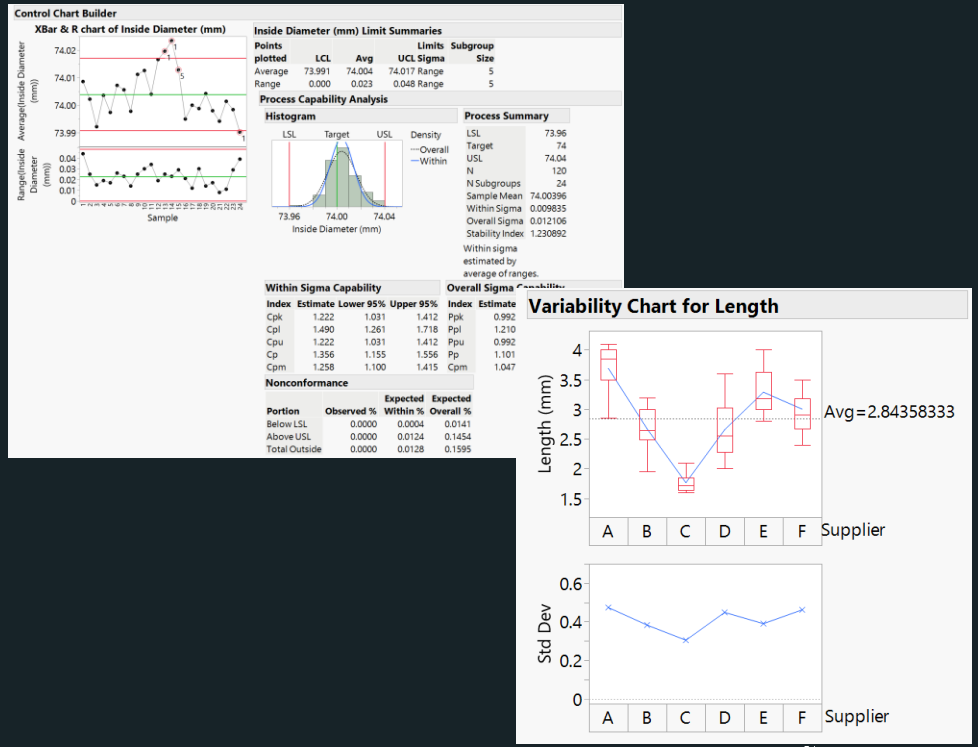
Common Questions

- Is there evidence of special cause variation in the measurement data?
- Is a process capable of making components within measurement specification limits?
- Given measurements taken across different groups e.g. suppliers of same component
  - Is there evidence of differences?
  - Is there evidence of equivalences?



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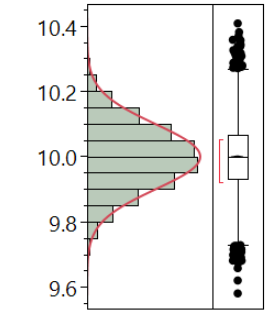
Normal Distribution

- Do independent measurements of an attribute fall under a bell-shaped curve?
- Common phenomena
  - Part geometry, lead times, average student test scores…

Distributions

Normal



Normal(9.99927,0.09944)

Fitted Normal

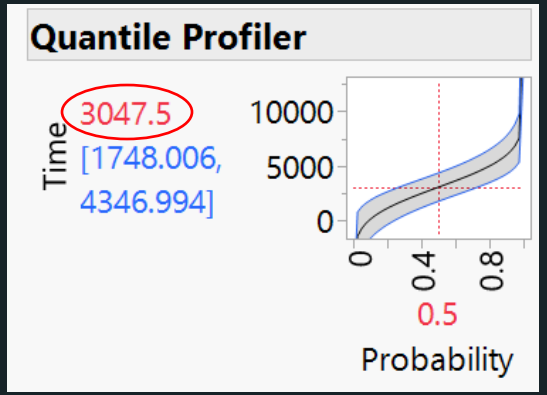
Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	9.9992716	9.9974923	10.001051
Dispersion	σ	0.0994365	0.0981943	0.1007108

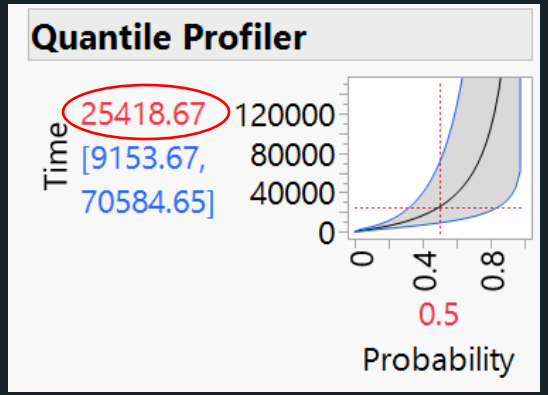
Measure	
-2*LogLikelihood	-21344.14
AICc	-21340.14
BIC	-21325.36

What happens if we treat time-to-event data like we do non-time-to-event data?

Estimate of failure time assuming normally distributed failures and only considering failed components.



Estimate of failure time assuming lognormally distributed failures and considering all components under test.



Poll Question

Introduction to Analysis of Reliability Data

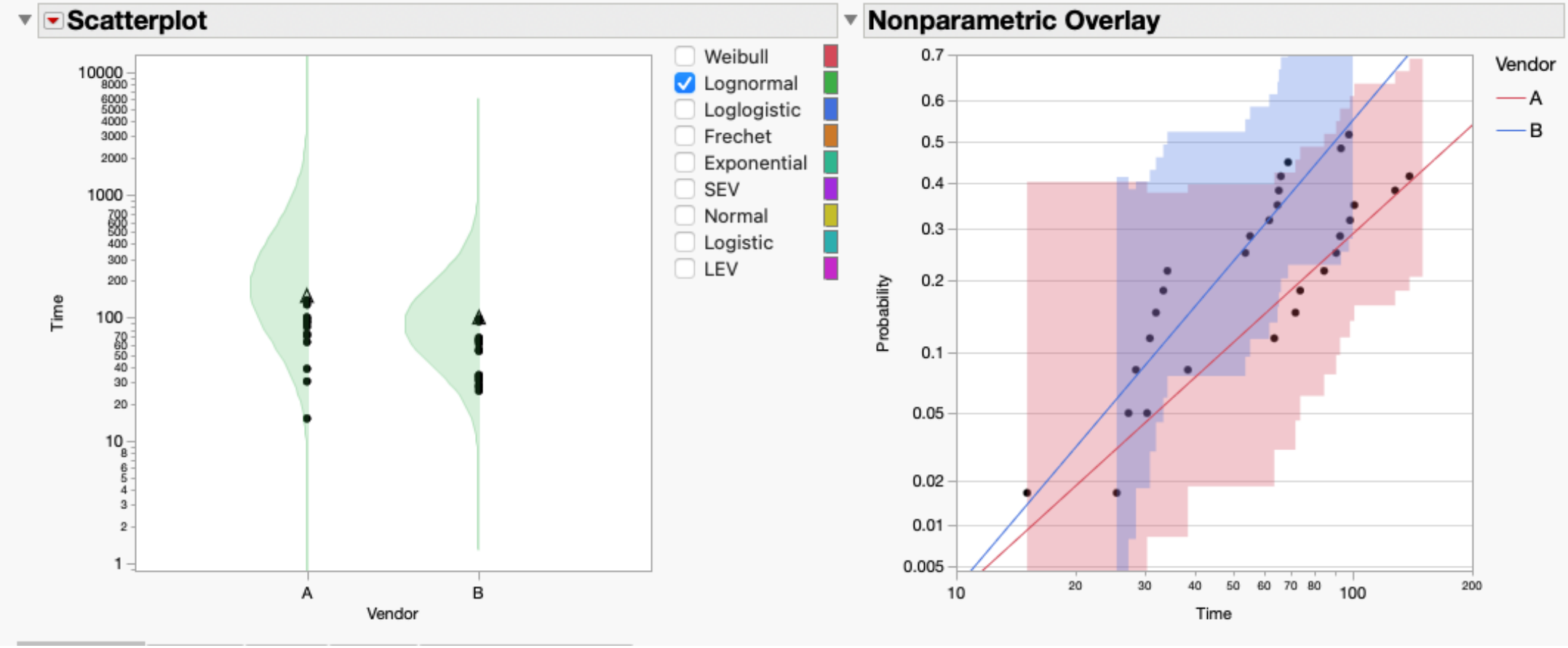
Reliability concepts extended

- Other inputs affect reliability
- Soft failure
- System reliability
- Repairable system reliability

Introduction to Analysis of Reliability Data

Other inputs affect reliability

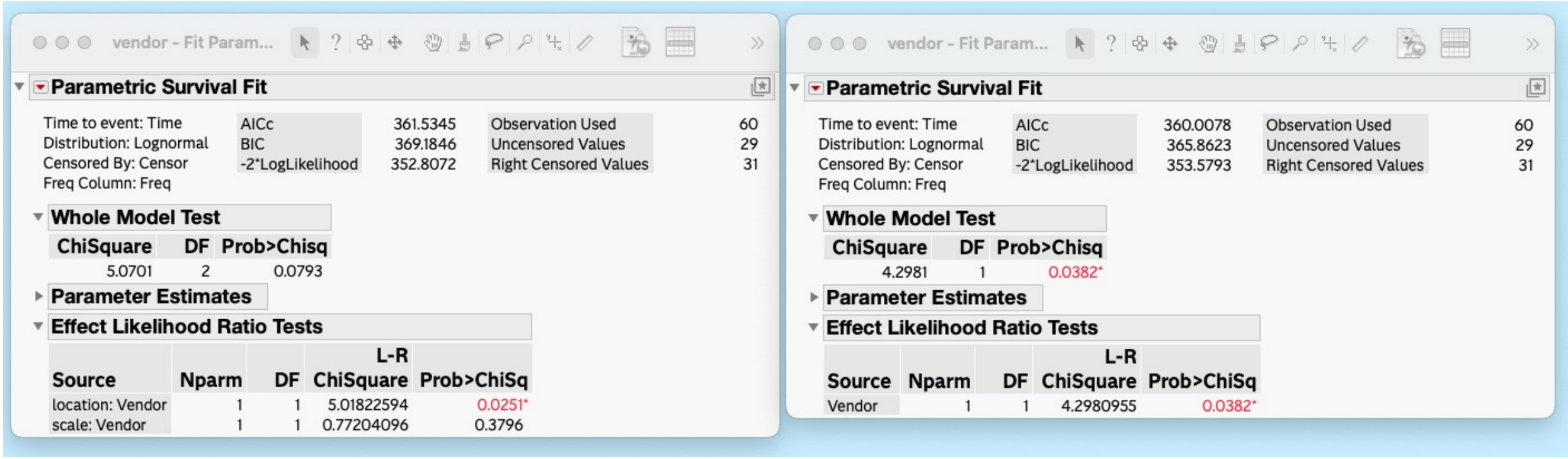
- Example – Compare reliability of two suppliers (Tobias & Trindade)



Introduction to Analysis of Reliability Data

Other inputs affect reliability

- Example – Compare reliability of two suppliers



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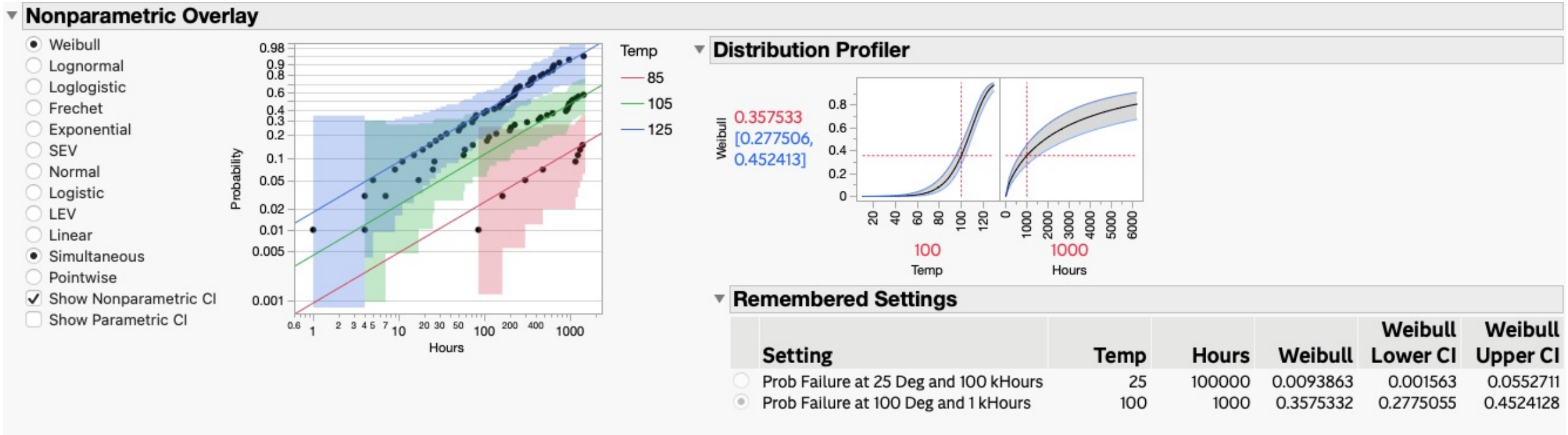
Other inputs affect reliability

- Example – Accelerated Life Test on Capacitors



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Other inputs affect reliability

- Example – Early Product Failures: Plant or Process? (Tobias & Trindade)

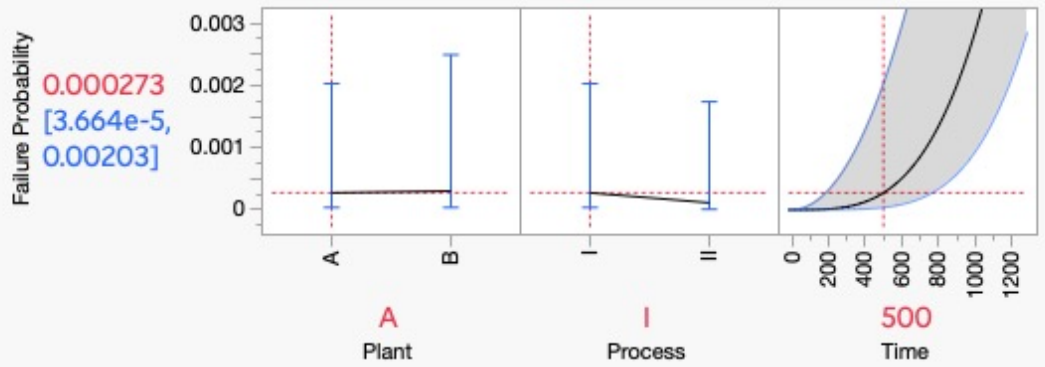
Whole Model Test

ChiSquare	DF	Prob>Chisq
9.1971	3	0.0268*

Effect Likelihood Ratio Tests

Source	Nparm	DF	L-R ChiSquare	Prob>ChiSq
Plant	1	1	0.63866152	0.4242
Process	1	1	5.58335383	0.0181*
Process*Plant	1	1	0.84223009	0.3588

Distribution Profiler



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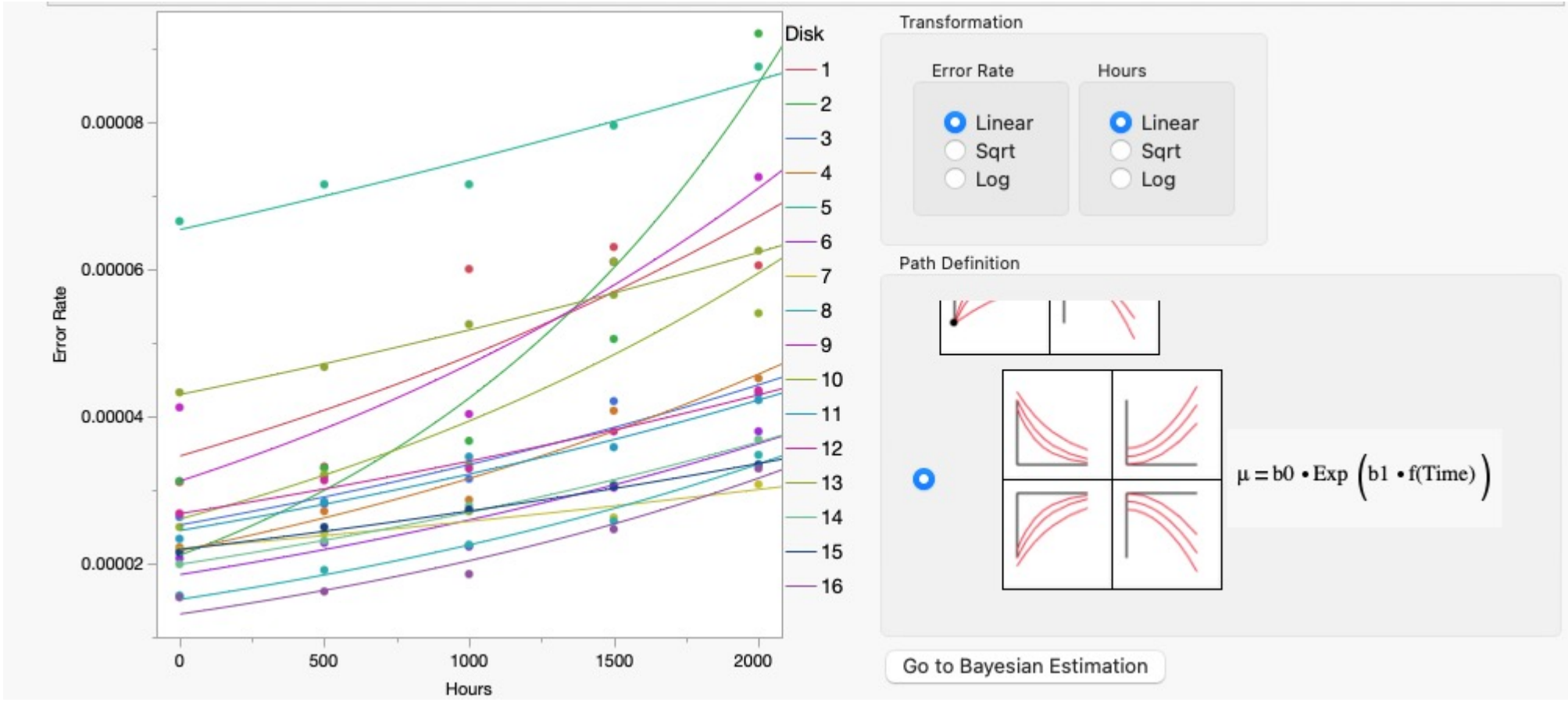
Soft failures

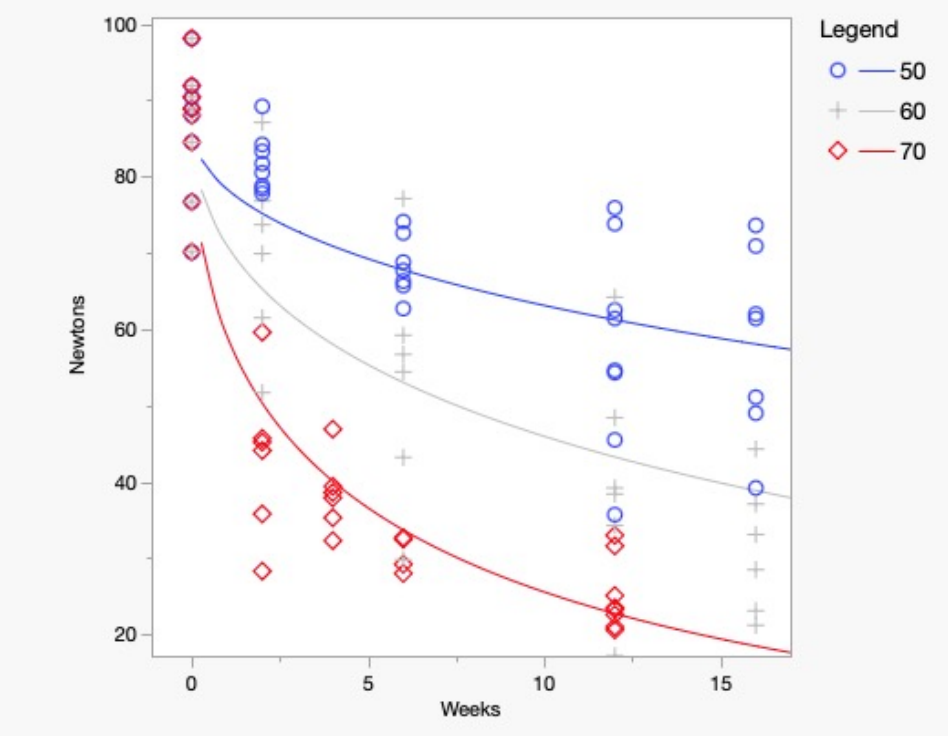
- Example – Hard Disk Byte Error Rate (Meeker, Escobar & Pascual)



Introduction to Analysis of Reliability Data

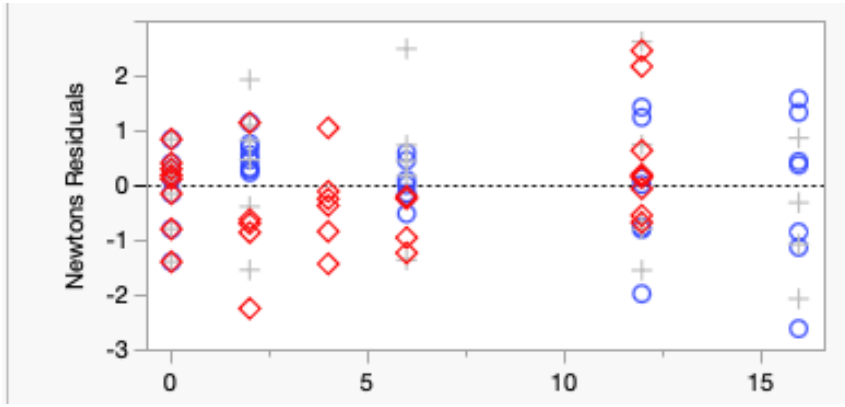
Soft failures

- Example – Adhesive Bonds (Meeker, Escobar & Pascual)



$$\text{Beta0} - \text{Exp}\left(\text{Beta1} + \text{Beta2} \bullet \left(\frac{-11605}{(\text{Degrees C} + 273.15)}\right) \bullet \sqrt{\text{Weeks}}\right)$$

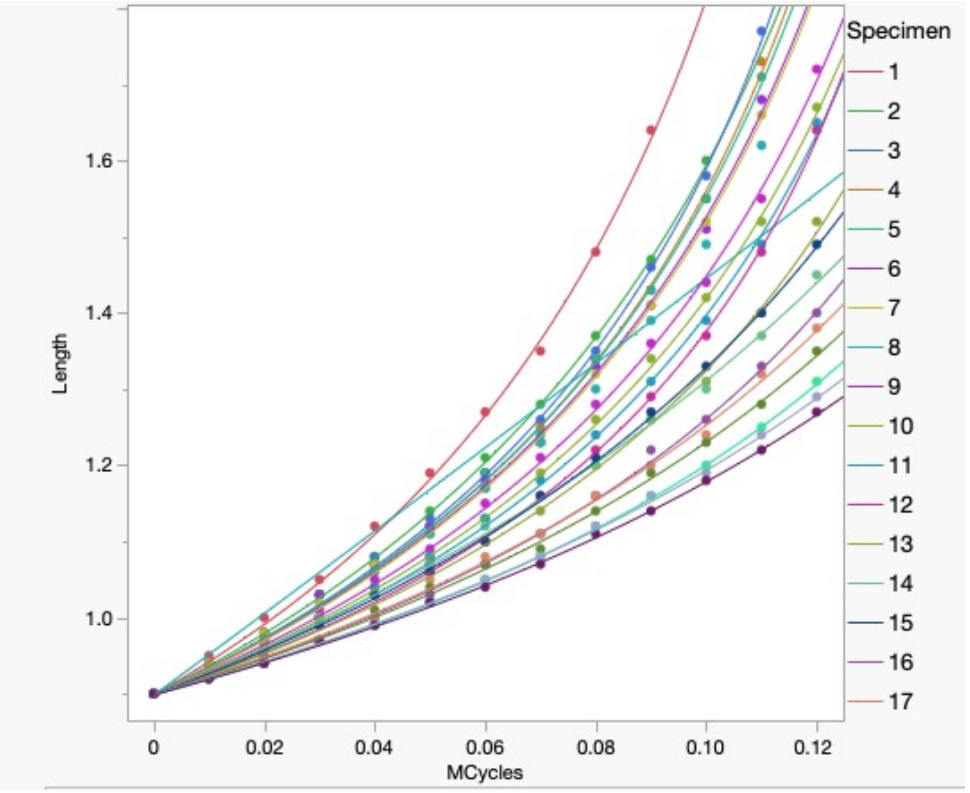
Parameter	Estimate		Low	High	Fixed
Beta0	4.46103		4.38228	4.53978	
Beta1	20.8933		16.058	25.7286	
Beta2	0.64604		0.50309	0.789	
Sigma	0.15023		0.11804	0.18242	



Introduction to Analysis of Reliability Data

Soft failures

- Example – Alloy Cracking (Meeker, Escobar & Pascual)



Paris-Erdogan Crack Growth with Time

$$\text{if } b2 \neq 2 \quad , \quad \left(\mu_0 \left(1 - \frac{b2}{2} \right) + \left(1 - \frac{b2}{2} \right) \cdot b1 \cdot f(\text{Time}) \right)^{\left(\frac{2}{(2 - b2)} \right)}$$

$$\text{if } b2 == 2 \quad , \quad \mu_0 \cdot \text{Exp}\left(b1 \cdot f(\text{Time}) \right)$$

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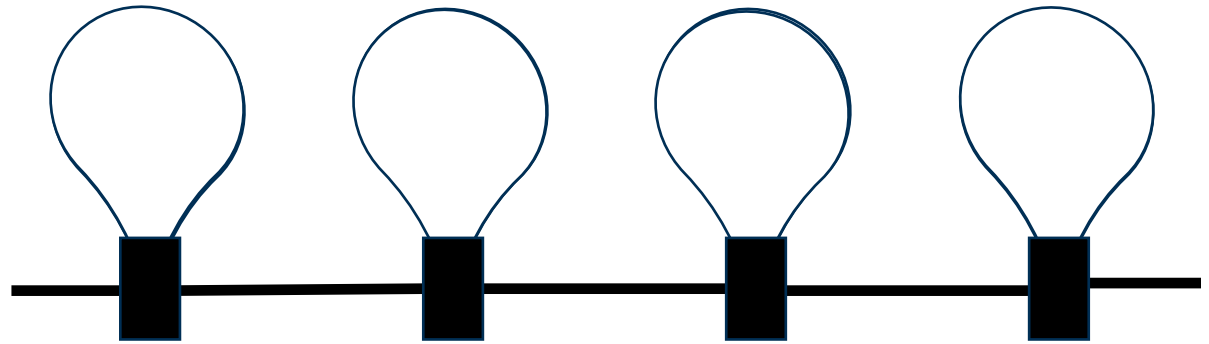
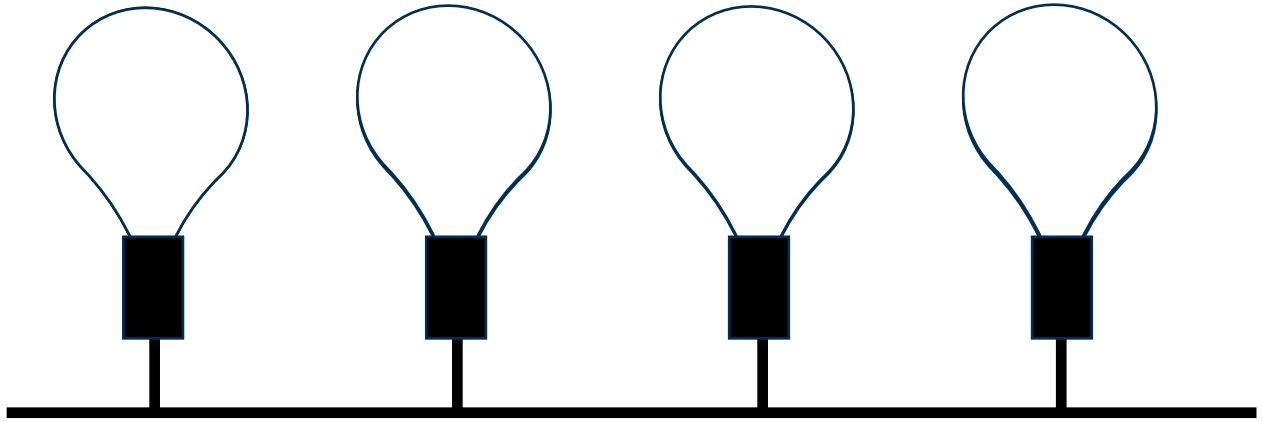
System Reliability

- More than one component connected to create a system



Series



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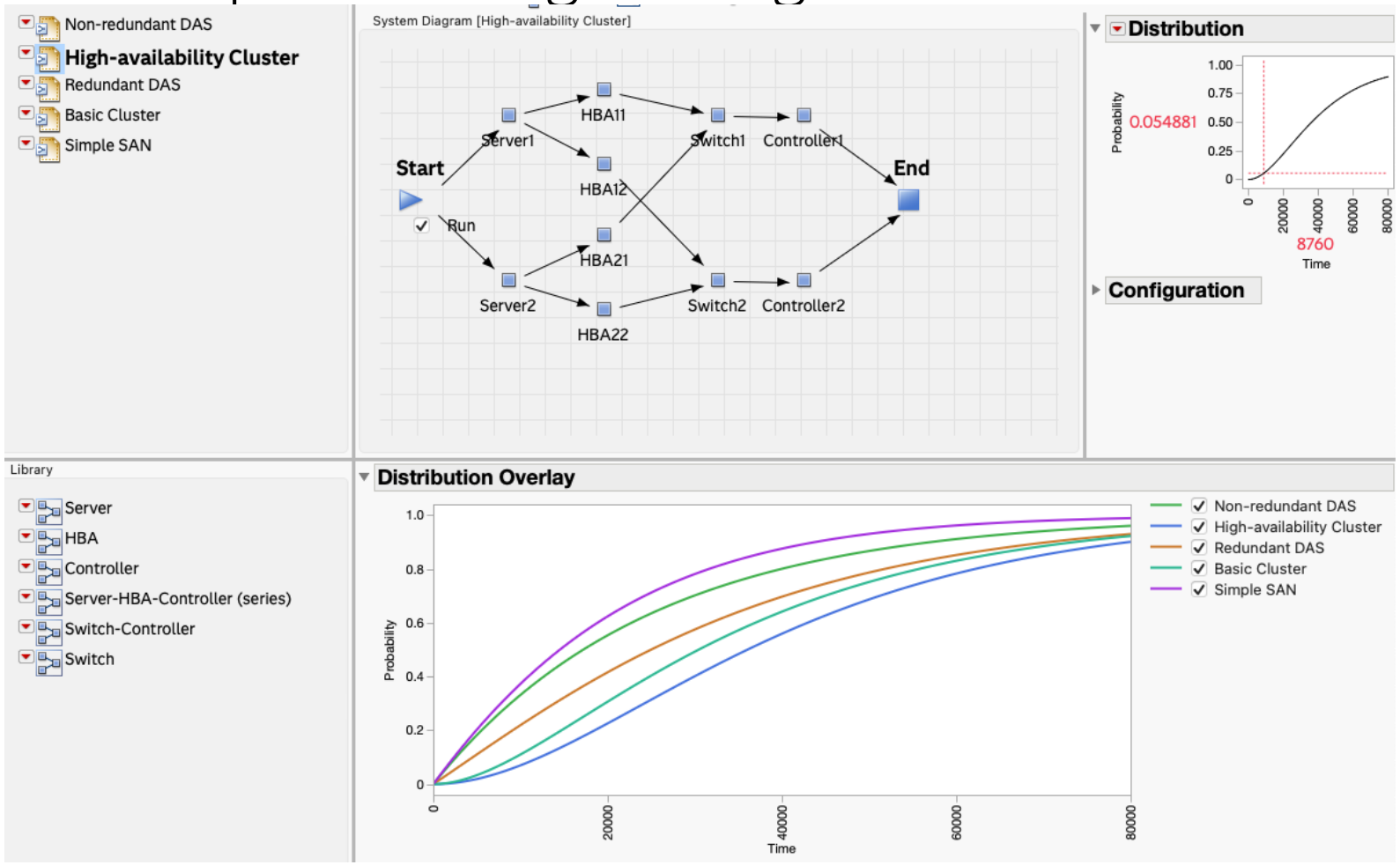
Introduction to Analysis of Reliability Data

System Reliability

- Example – Computer storage configurations



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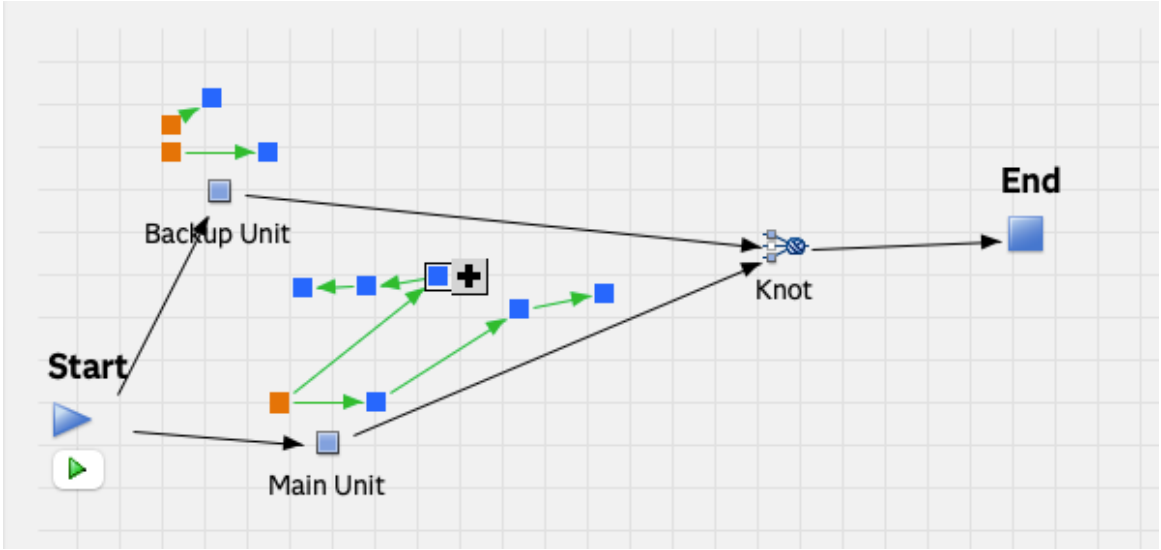
Repairable System Reliability

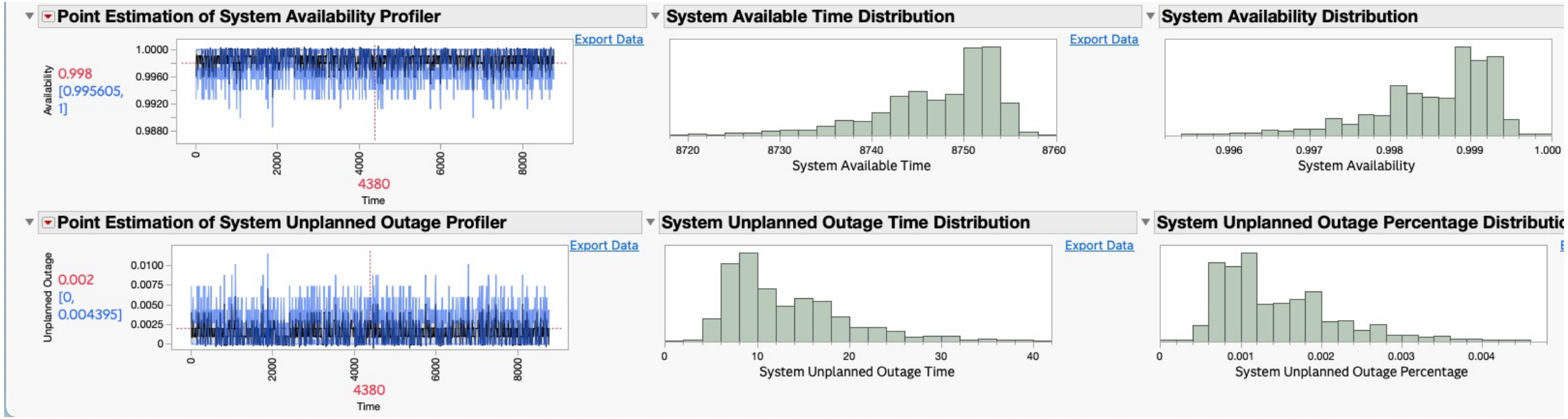
- Example – Main unit with a backup as a standby in case of failure. Backup has cold startup with 30 minute startup time. Eight hour maintenance on the backup is performed after control is passed back to the main unit. 99% switch reliability. Exponential(500) lifetime distribution for both. Failing blocks are replaced with new units. 1000 simulation conducted for 1 year time span.



Introduction to Analysis of Reliability Data

Repairable vs. non-repairable

- Examples Results



Introduction to Analysis of Reliability Data

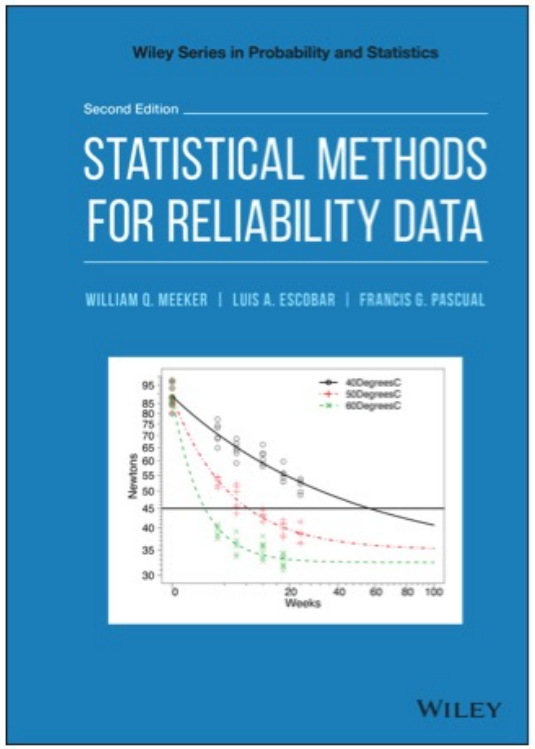
Summary

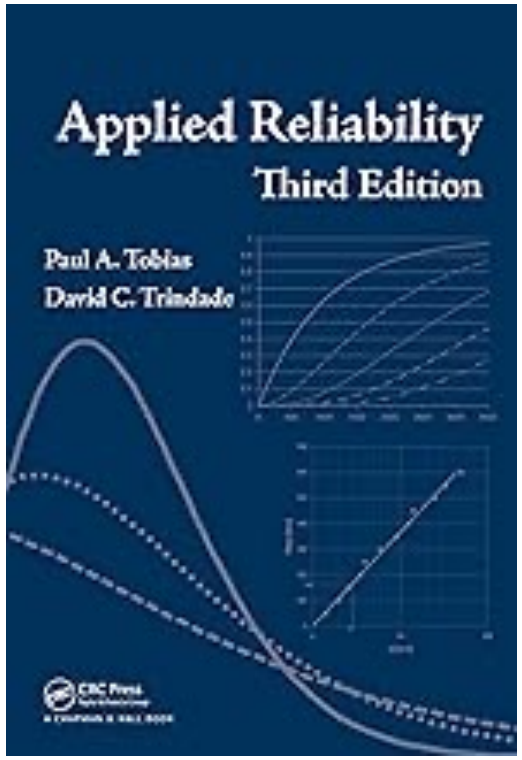
- In its most basic form, reliability analysis is about modeling the life distribution of components or processes.
- Conditions such as temperature and environment may affect the shape of the distribution.
- It is common to model life using soft failure data when true hard failure data are not available.
- Reliability can be calculated for a combined system of non-repairable components.
- Simulation is a common approach to modeling reliability when repair and maintenance are performed on a system of components.

Introduction to Analysis of Reliability Data

References

- Meeker, William Q., Luis Escobar, Francis Pascual. Statistical Methods for Reliability Data, 2nd Edition. Wiley-Blackwell, 2022-01-24. VitalBook file.





- Tobias, Paul A. & David Trindade. Applied Reliability, 3rd Edition. CRC Press, 2012.