



THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
Santa Clara Valley Section

Reliability

Reliability Performance & Measurement of Repairable Systems

Wendai Wang, Applied Materials

Wendai_wang@amat.com

March 30, 2008

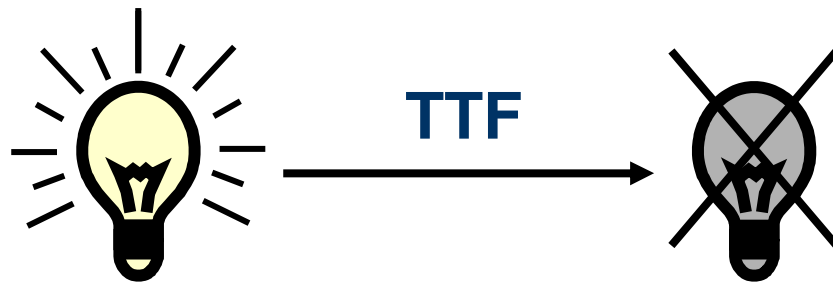
Let's Start with Non-repairable



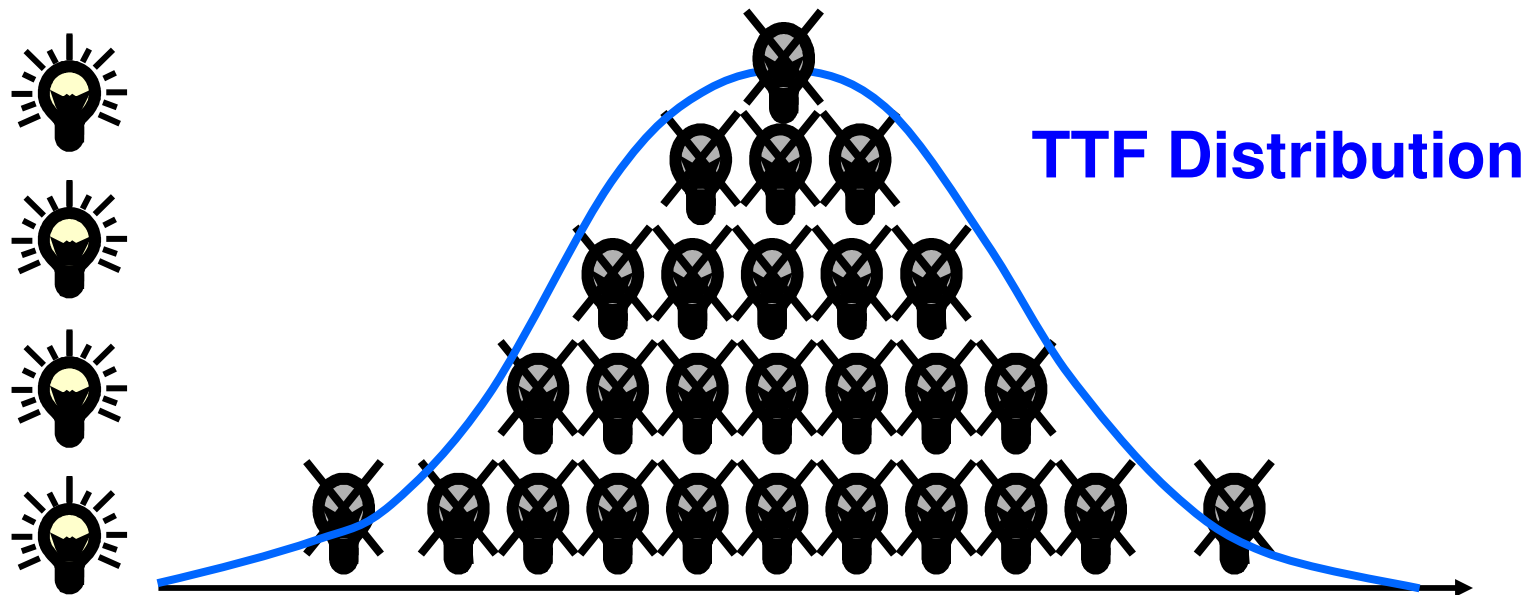
?

How to measure reliability performance of a new bulb ?

Simply Say: the Lifetime of Light Bulb

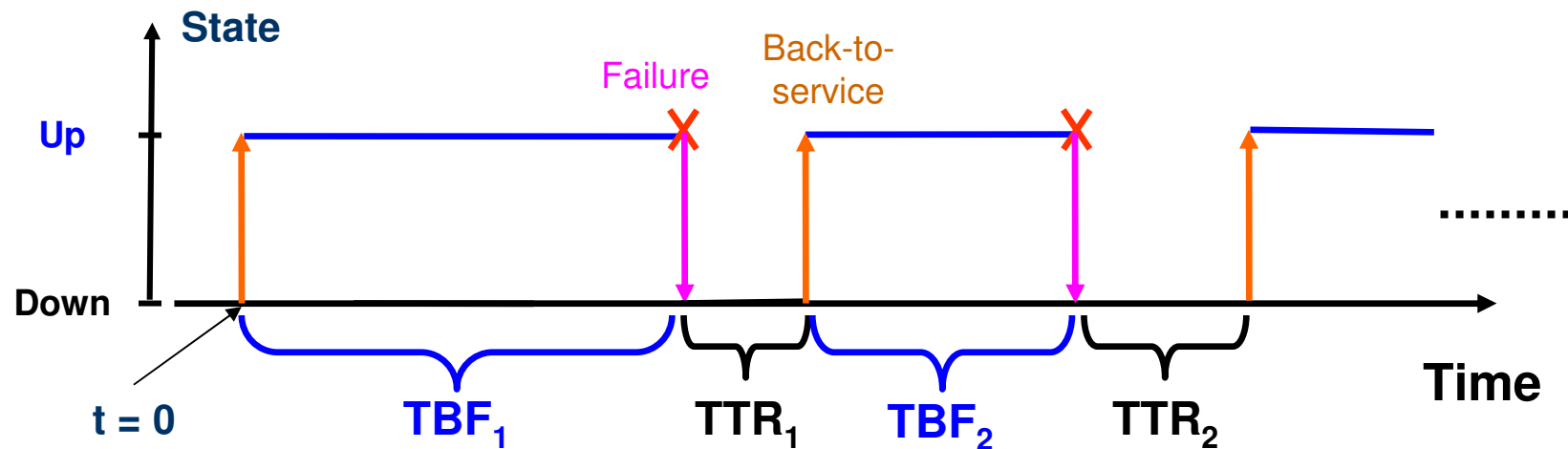


Reliability of Non-repairable



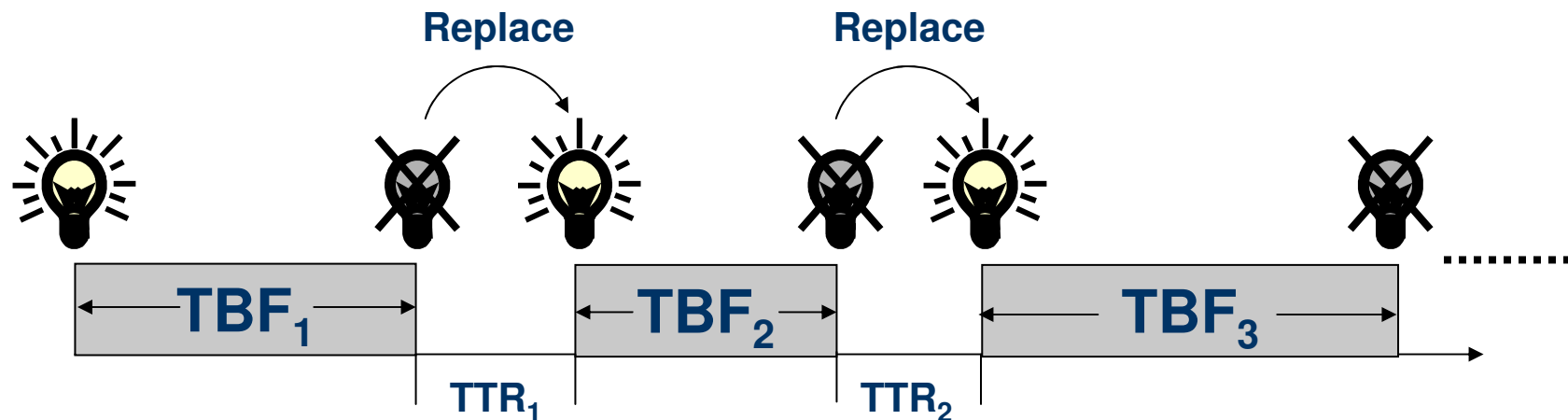
Reliability, Failure Rate, MTTF, Bx Life, etc.

Reliability Performance of Repairable



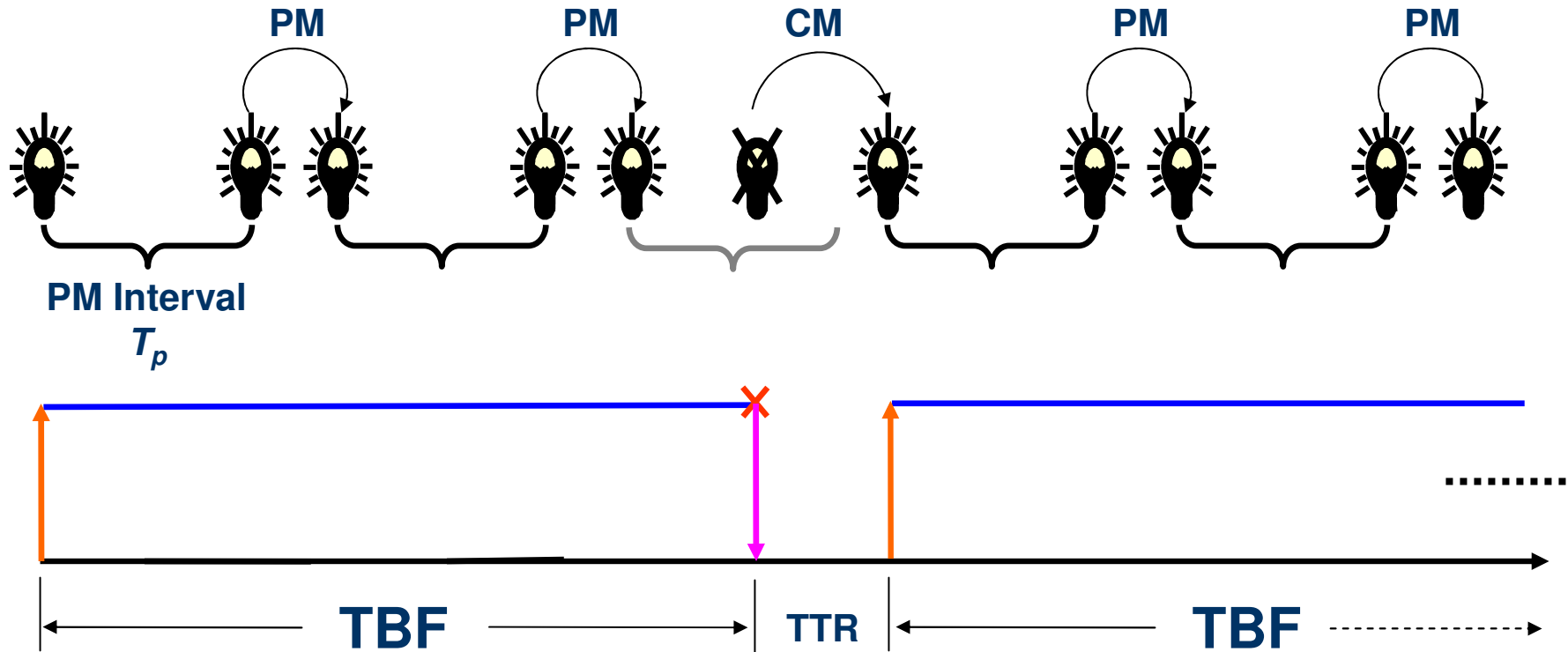
- An alternating process:
 - Up state – TBF (reliability)
 - Down state – TTR (maintainability)
- Availability

Part with CM (Replacement)



- Renewal Process
 - Poisson Process (e.g., HPP & NHPP)
- $TBF_i \cong TTF$ statistically
- $TTR_i \cong TTR_{i+1}$ statistically
- Reliability performance can be summarized by TBF and TTR (mathematically their distributions)

Part with CM plus PM (Replacement)



- TBF \gg TTR
- TBF is approximated to the exponential distribution

CM plus PM by Age Replacement

$$MTBF = \frac{\int_0^{T_p} R(t) dt}{1 - R(T_p)}$$

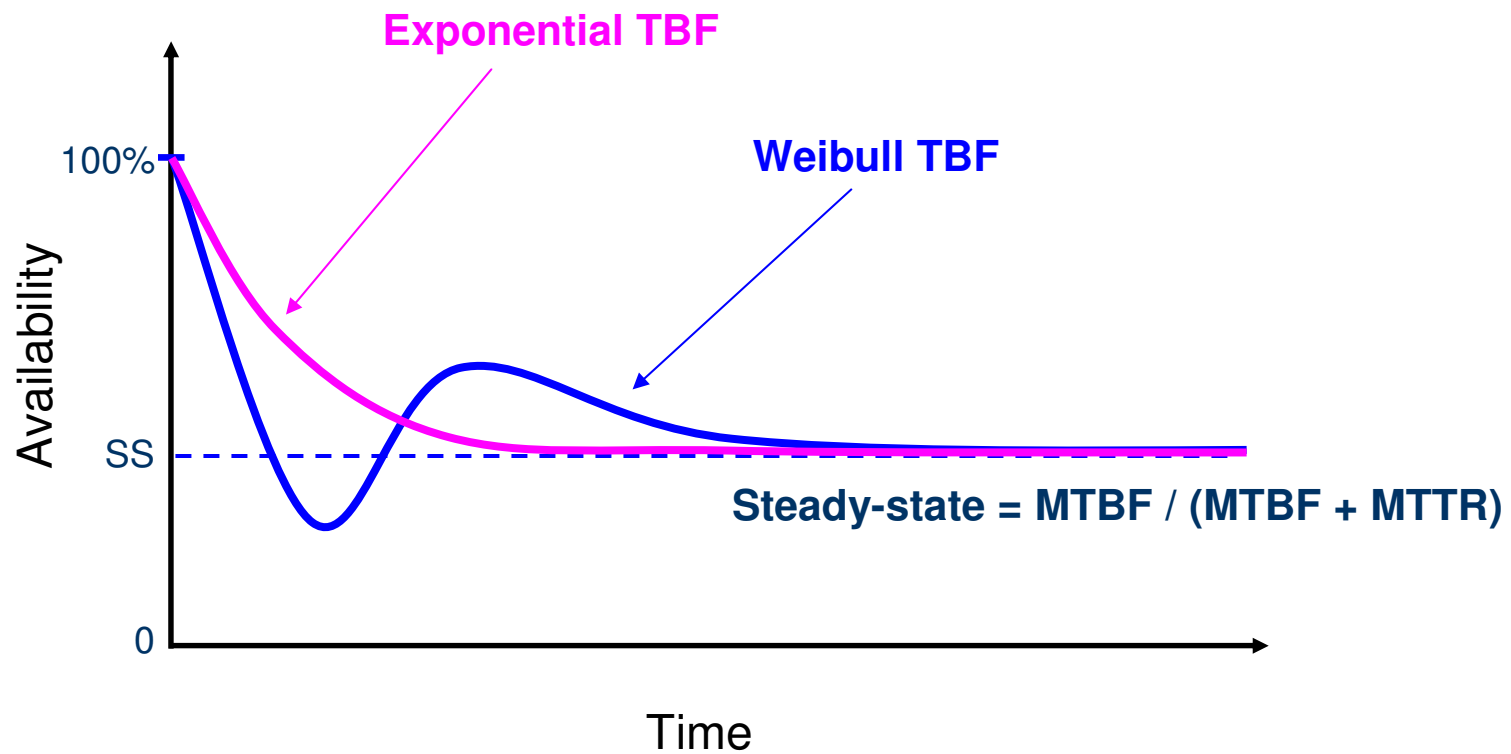


$$MTBF = \frac{\int_0^{T_p} \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] dt}{1 - \exp\left[-\left(\frac{T_p}{\eta}\right)^\beta\right]}$$



$$MTBF_A = T_p \times \left(\frac{\eta}{T_p}\right)^\beta$$

Availability Curve



Availability

- Point Availability – instantaneous availability at a given time.
- Average (Mean) Availability – the average of instantaneous availability over a time interval, or the average fraction of uptime.

$$\text{Mean Availability} = \frac{\text{Total Uptime}}{\text{Time Period}} = \frac{\text{Time Period} - \text{Total Downtime}}{\text{Time Period}}$$

- Steady-state Availability – limiting value.

- Inherent Steady-state Availability

$$A_{I-ss} = \frac{MTBF}{MTBF + MTTR}$$

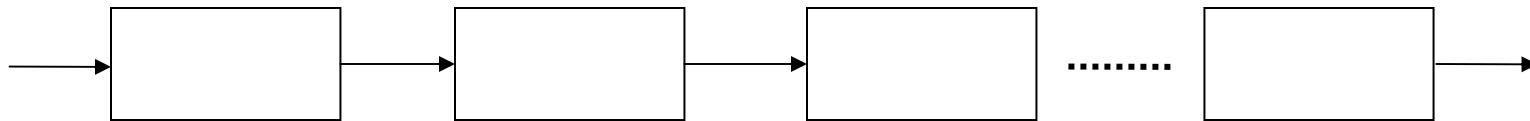
- Operational Steady-state Availability

$$A_{O-ss} = \frac{MUT}{MUT + MDT}$$

Multiple-part Repairable Systems

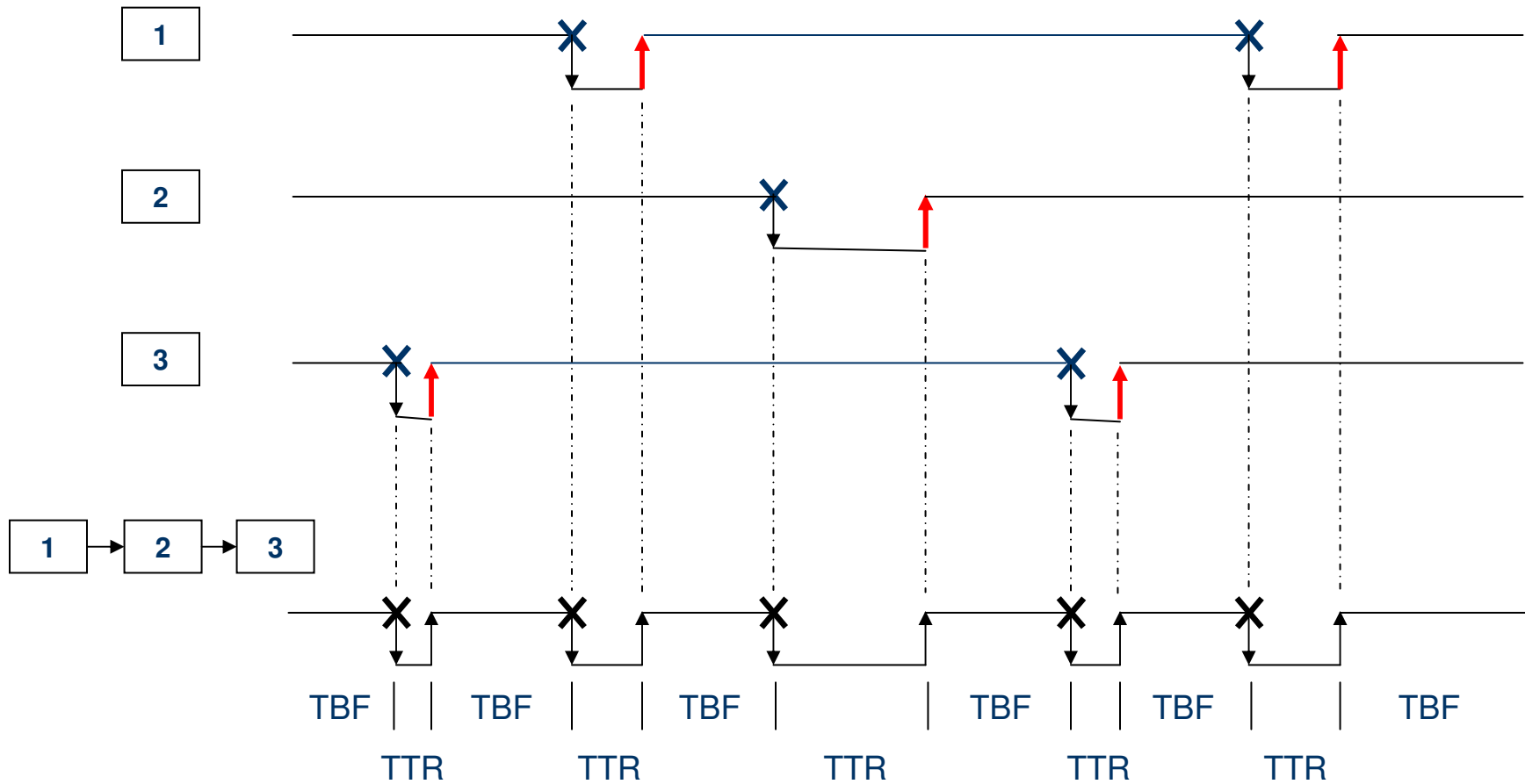
Let's first look at a **simple series system**:

- A series system
- Parts are independent (operate, fail & restore)
- A failed part will be replaced with a new one

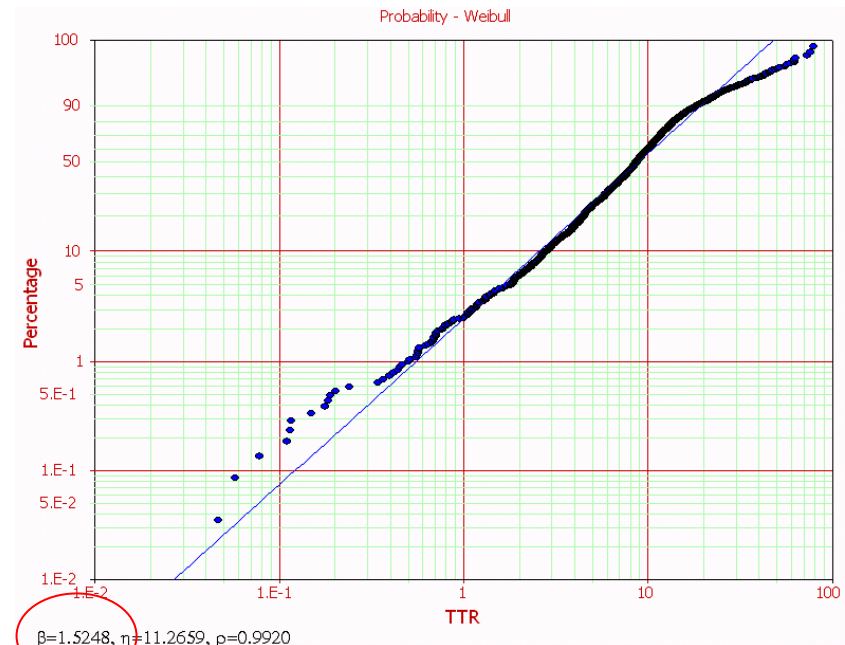
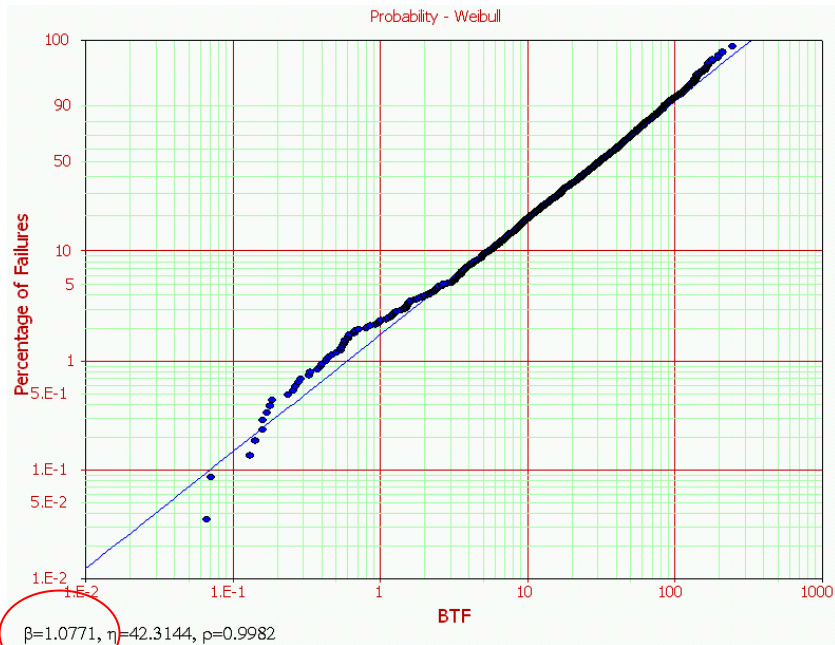
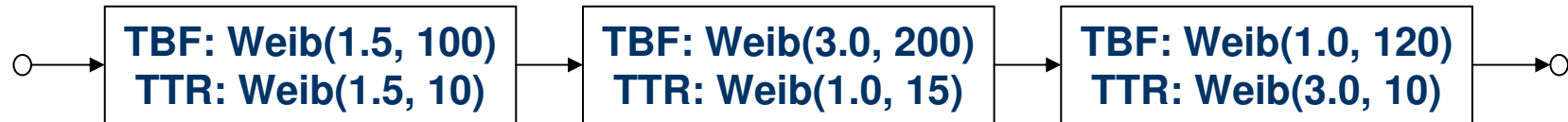


- Restorations take place at part level
- System is not renewed, but a superposition of the n renewal processes

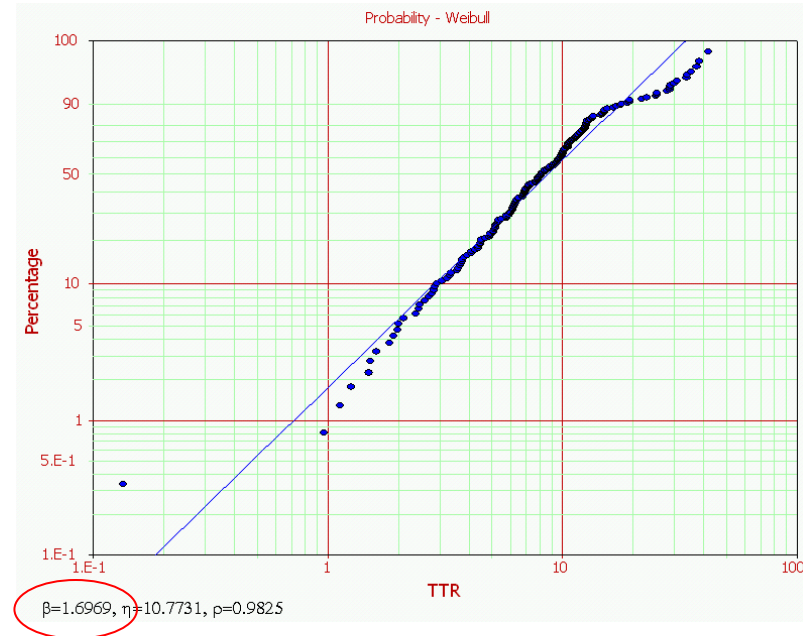
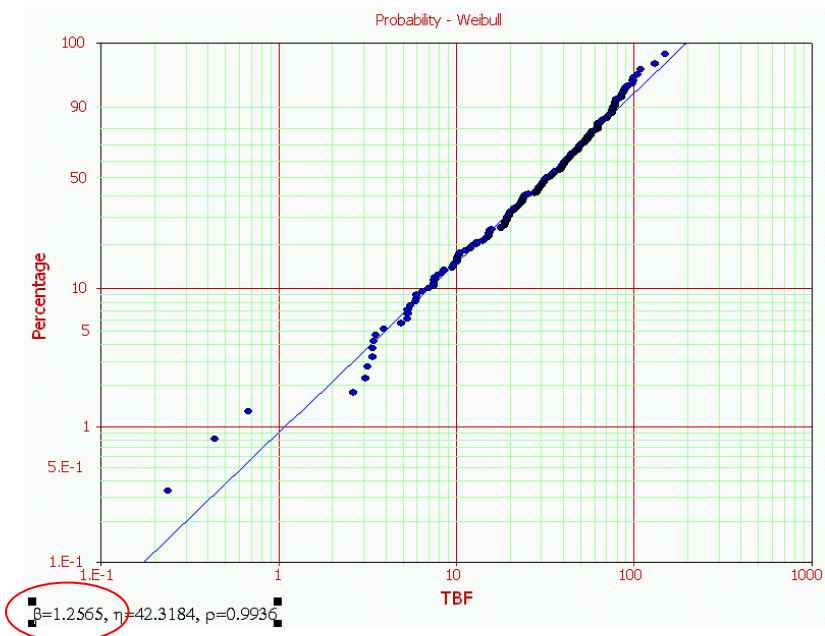
System Reliability Performance



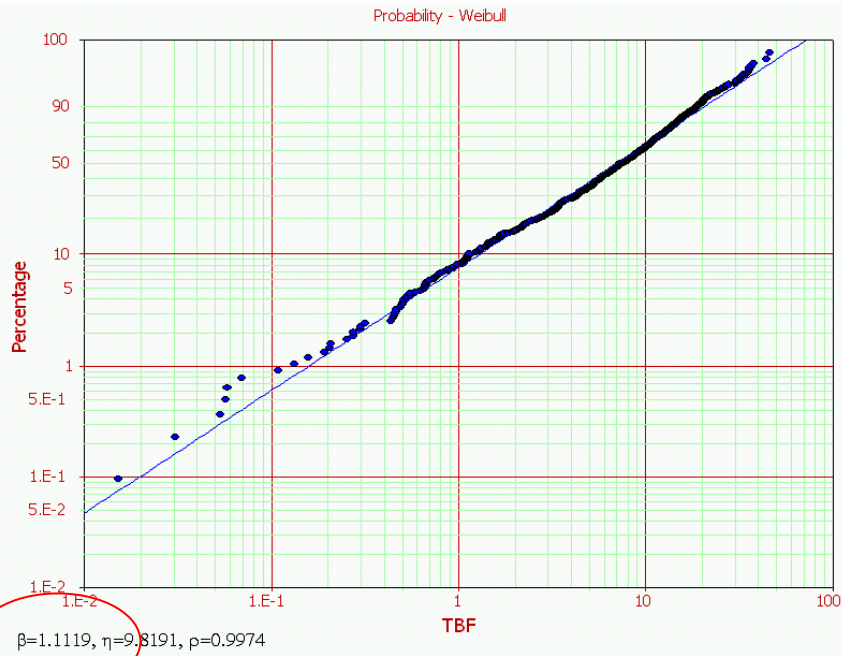
Simulation Studies



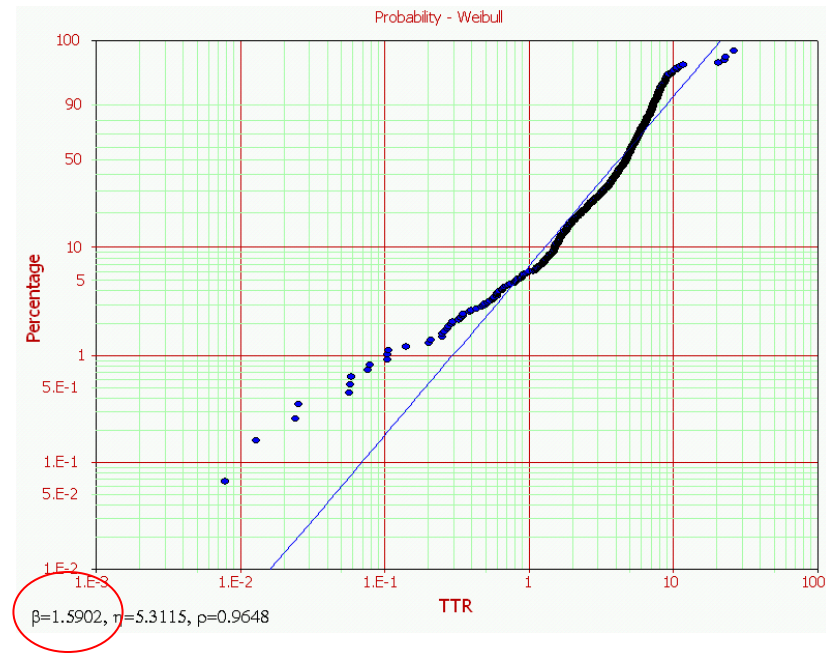
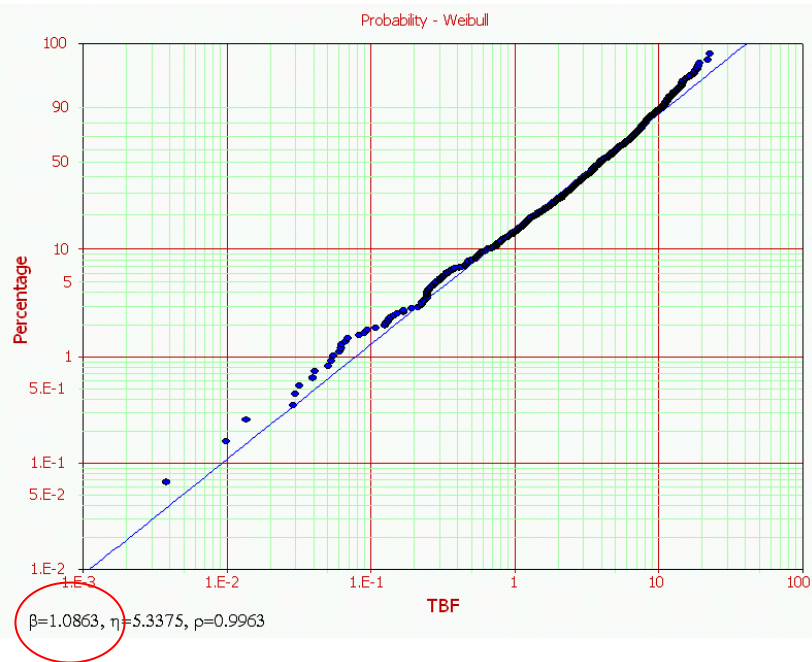
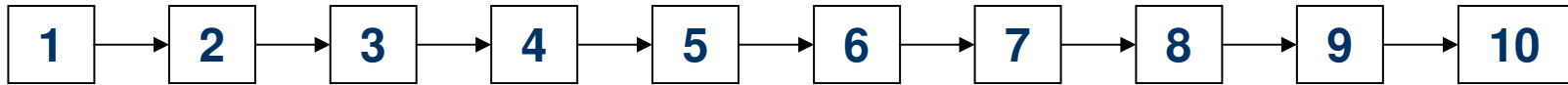
Simulations (con't)

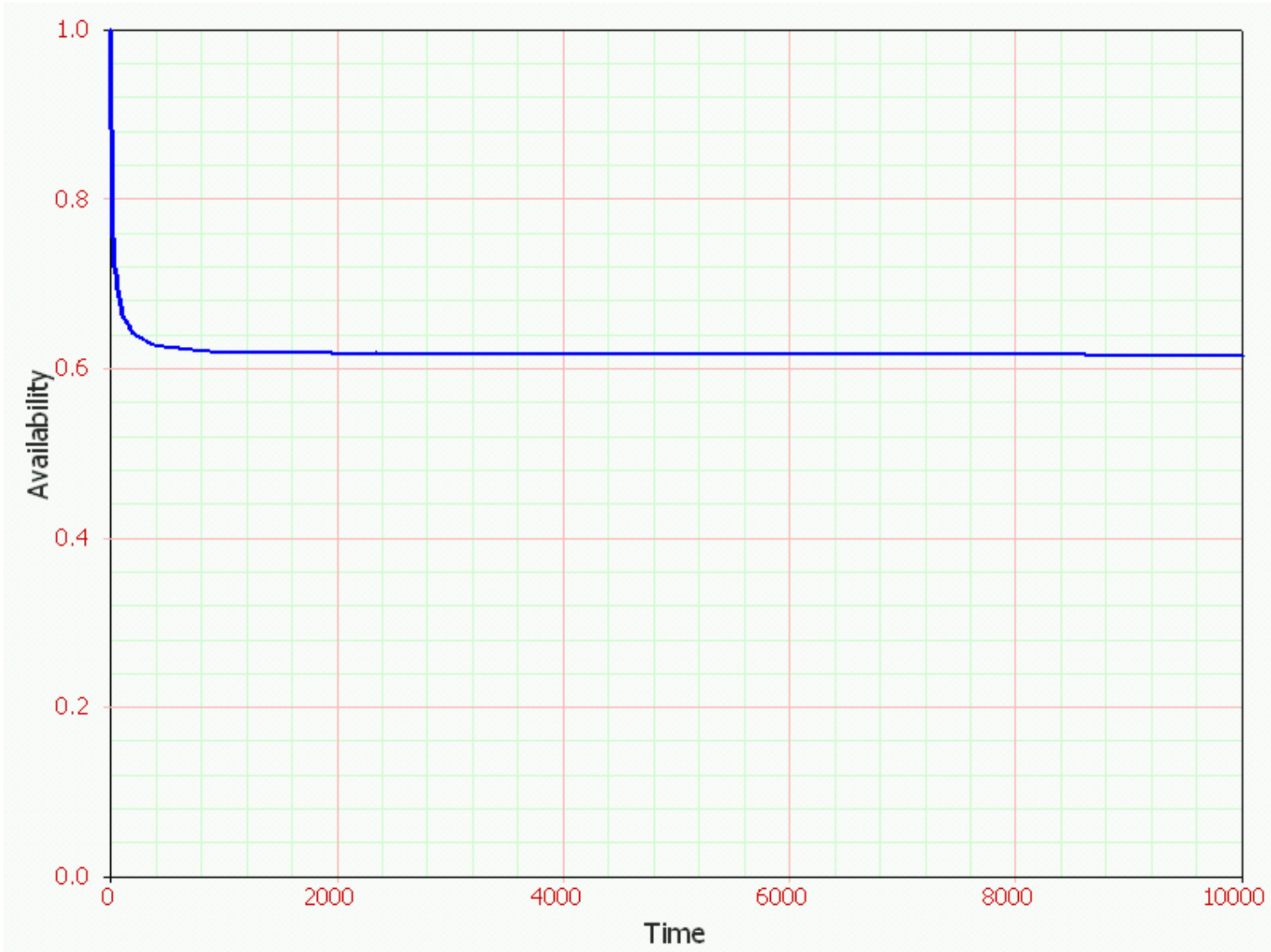


Simulations (con't)

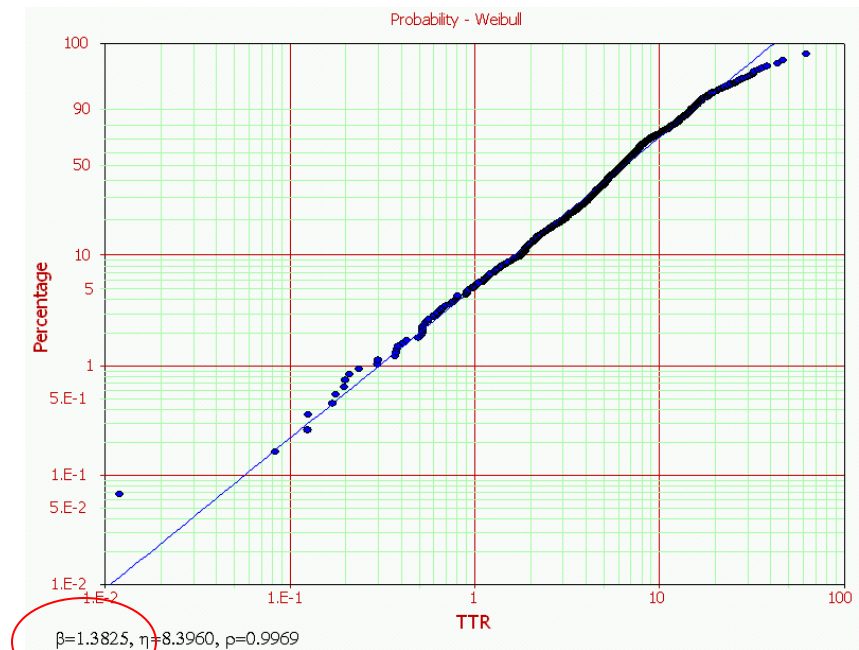
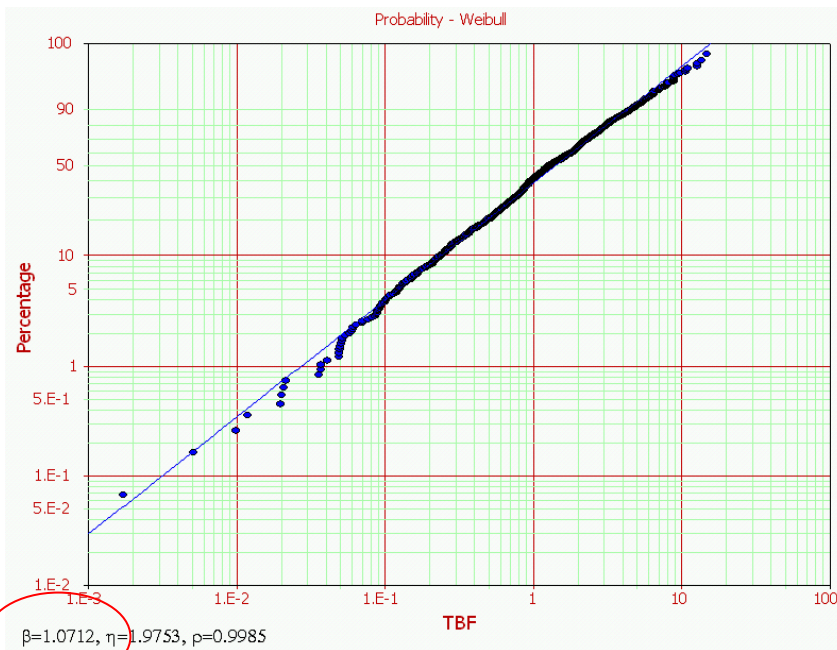
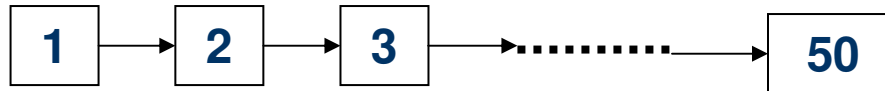


Simulations (con't)

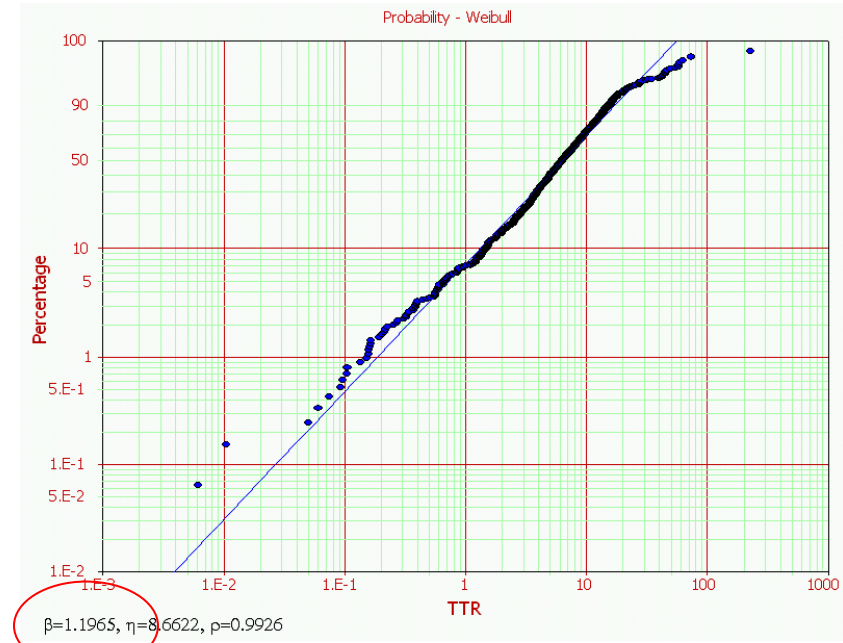
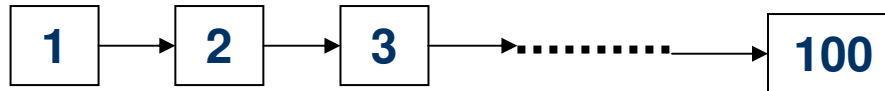




Simulations (con't)



Simulations (con't)



Simple Series Systems

Drenick's
theorem

- System TBF tends to be exponentially distributed

$$MTBF_{system} = \frac{1}{\frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \dots + \frac{1}{MTBF_n}}$$

- System TTR has an ??? distribution

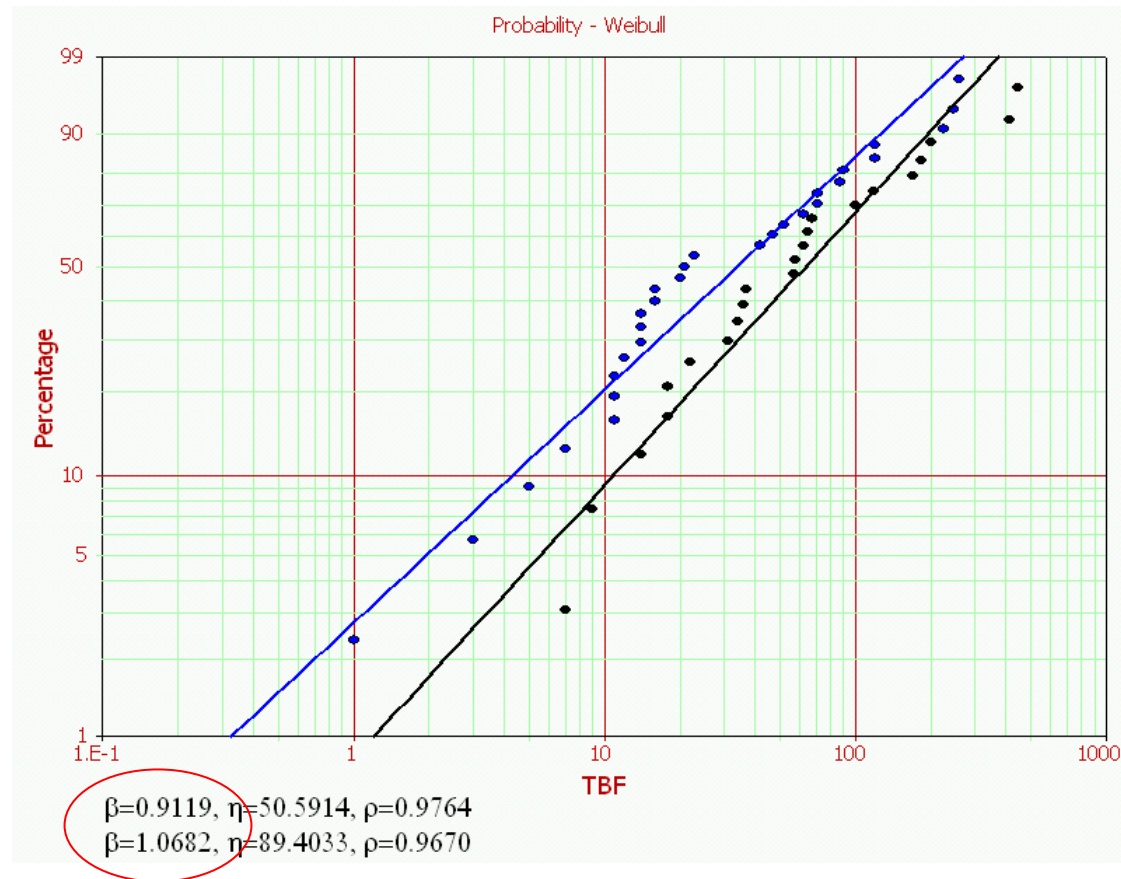
$$MTTR_{system} = \frac{\frac{MTTR_1}{MTBF_1} + \frac{MTTR_2}{MTBF_2} + \dots + \frac{MTTR_n}{MTBF_n}}{\frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \dots + \frac{1}{MTBF_n}}$$

- System steady-state availability exists

$$System\ Availability_{ss} = \frac{MTBF_{system}}{MTBF_{system} + MTTR_{system}}$$

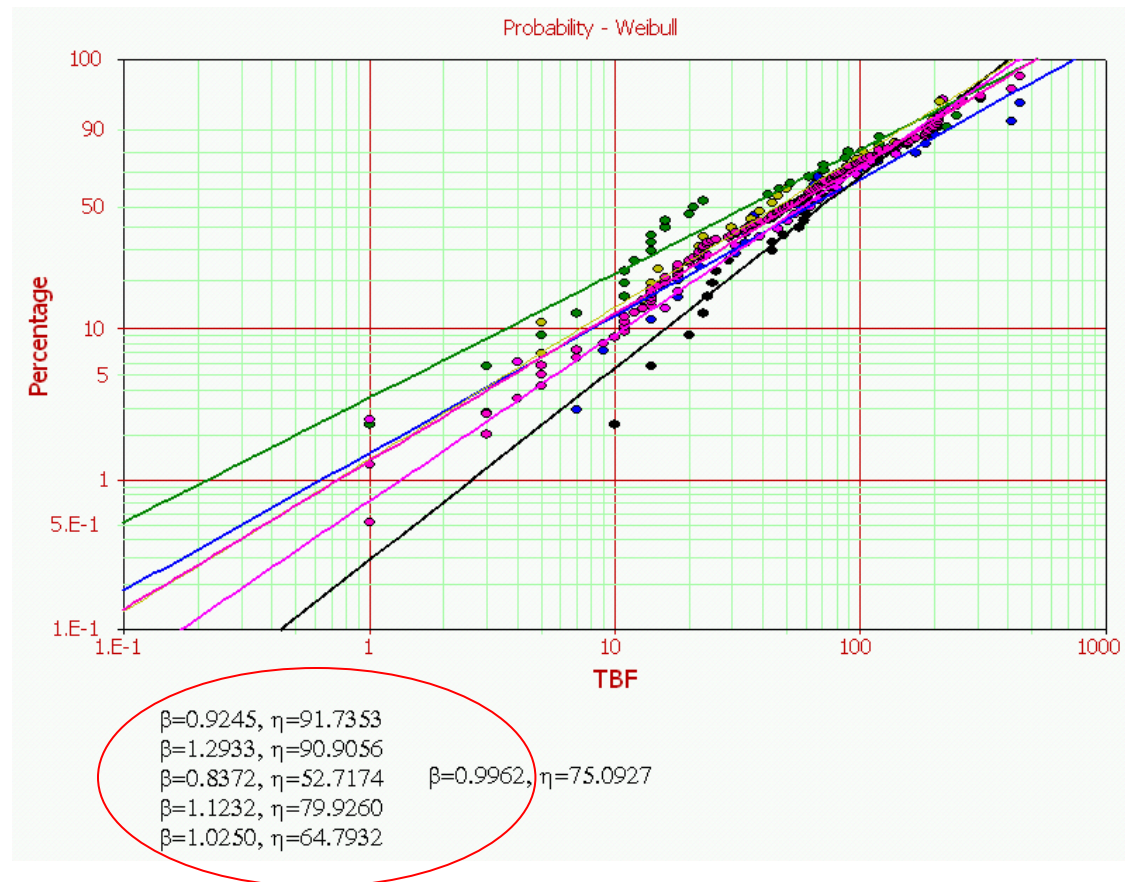
Boeing 720 AC Equipment TBF Data

“Some Test for Comparing Reliability Growth/Deterioration Rates of Repairable Systems”, *IEEE Trans on Reliability*, Vol. 38, No. 4, 1989.



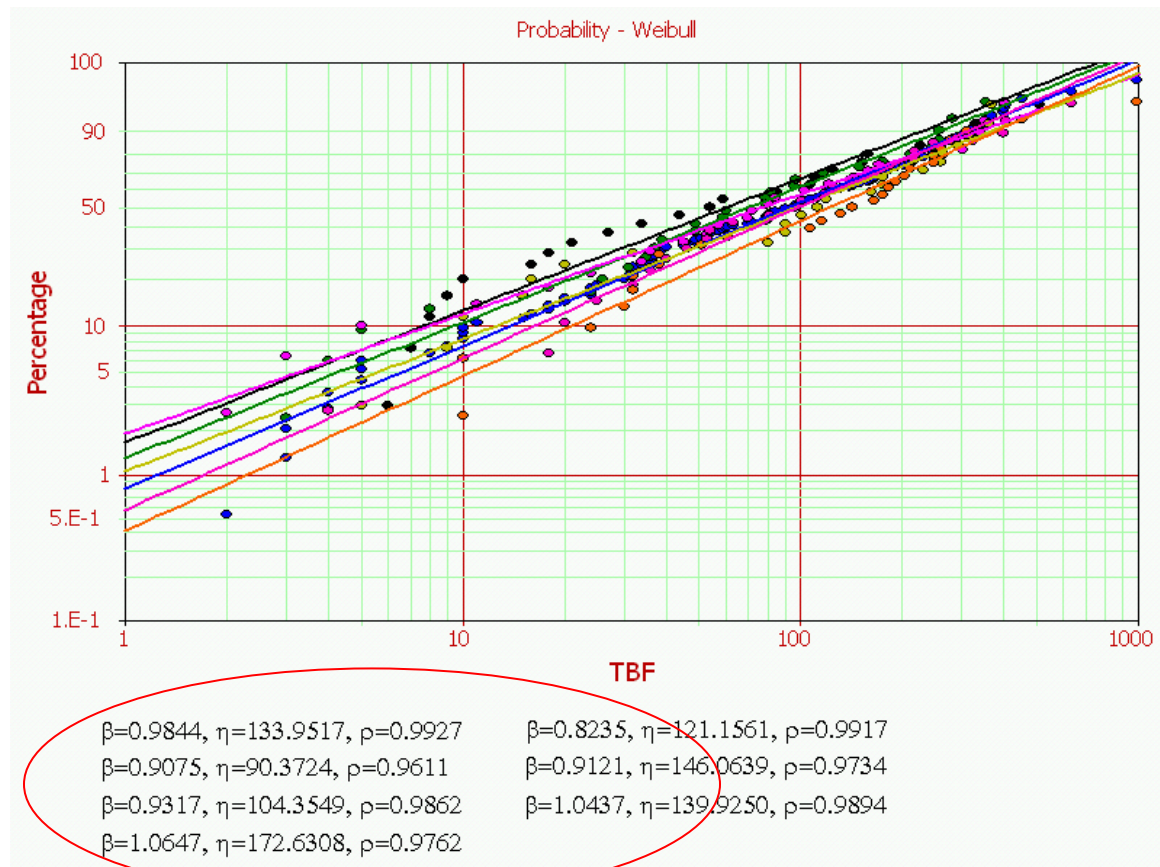
Air-conditioning Unit TBF Data

Reliability – Modeling, Prediction, and Optimization, W. R. Blischke and D. N. P. Murthy, John Wiley & Sons, Inc., 2000



Load-haul-dump Machines TBF Data

Reliability – Modeling, Prediction, and Optimization, W. R. Blischke and D. N. P. Murthy, John Wiley & Sons, Inc., 2000



Numerically-controlled Milling Tool

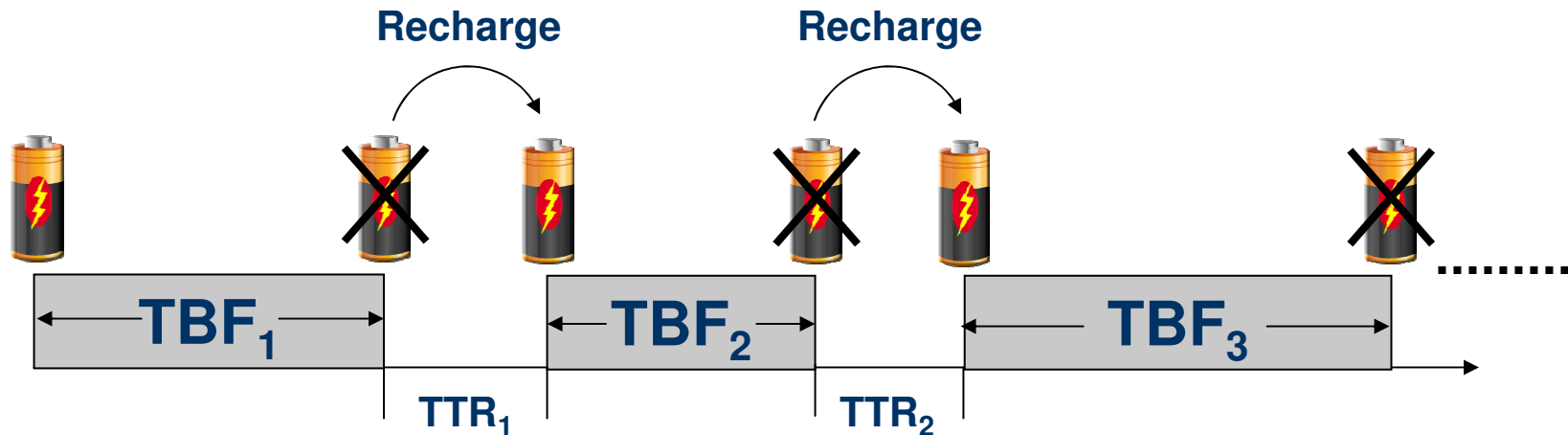
David W. Jacobson and Sant Ram Arora, “A *Nonexponential Approach to Availability Modeling*”, 1995 RAMS

TBF history data “characterized by a Weibull probability distribution, ..., estimated the shape parameter to be beta = 0.97 ...”

Multiple-part Simple Series Systems

- A superposition of the n renewal processes
 - System steady-state may exist (all TBF_i are *i.i.d*)
 - System reliability performance can be described by system TBF and TTR (their distributions).
 - System TBF tends to be the exponential.
 - The exponential assumption for part TBF & TTR seems fine numerically. However, more details on part TBF / TTR may be needed, (for example, design for reliability purpose)
 - Correlated to a failure mode or mechanism
 - Consider PM effect
- Field data seem to confirm the simulation results
- Most multiple-part systems in real world are not a simple system
 - Not independent
 - Not perfect renewal

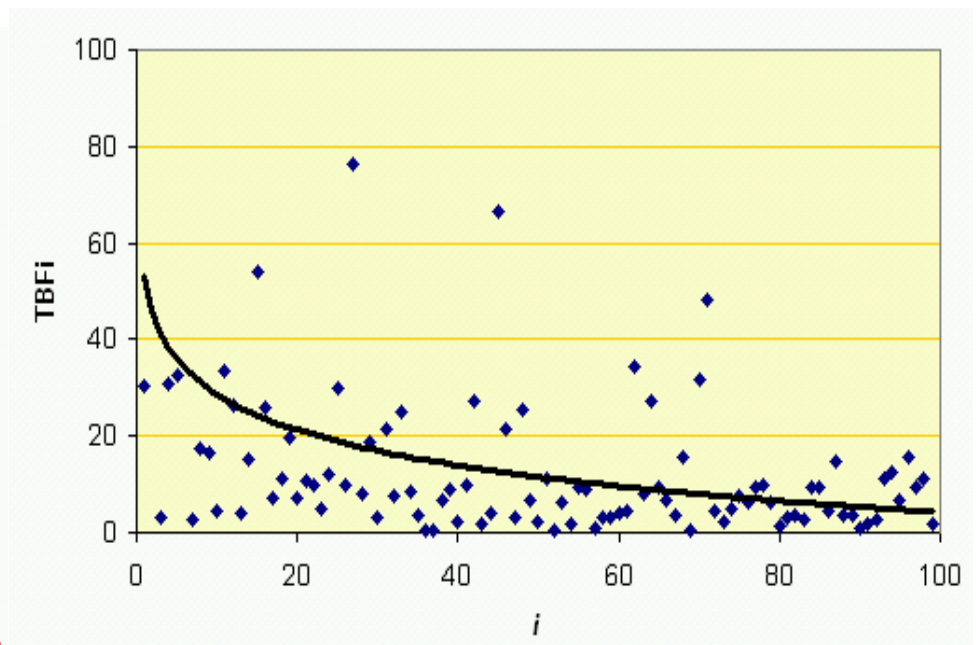
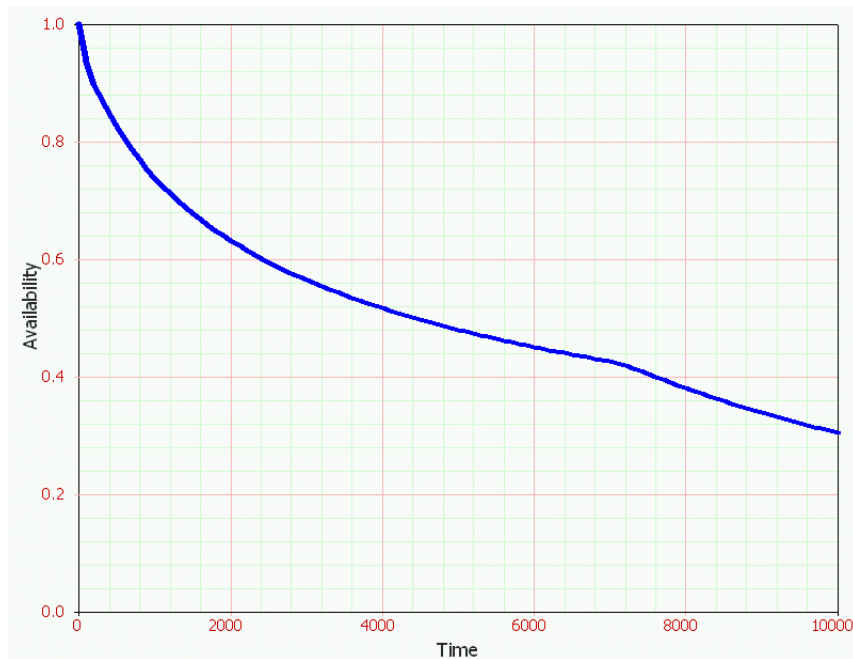
Part with CM (Repair)



- Imperfect maintenance
 - partially renewal
 - GRP
- TBF_{i+1} may differ from TBF_i
- Kijima proposed two “virtual age” models

Imperfect CM Part Reliability

○ → **TBF: Weib(2, 100)**
TTR: Weib(3, 10)
K-I, RF = 0.5 → ○



Multiple-part Systems

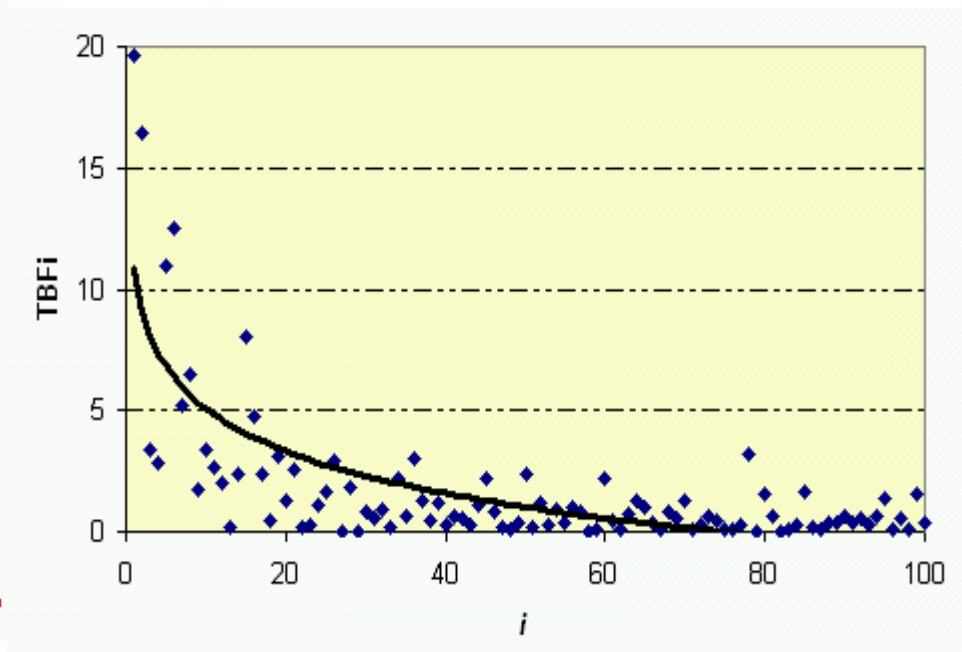
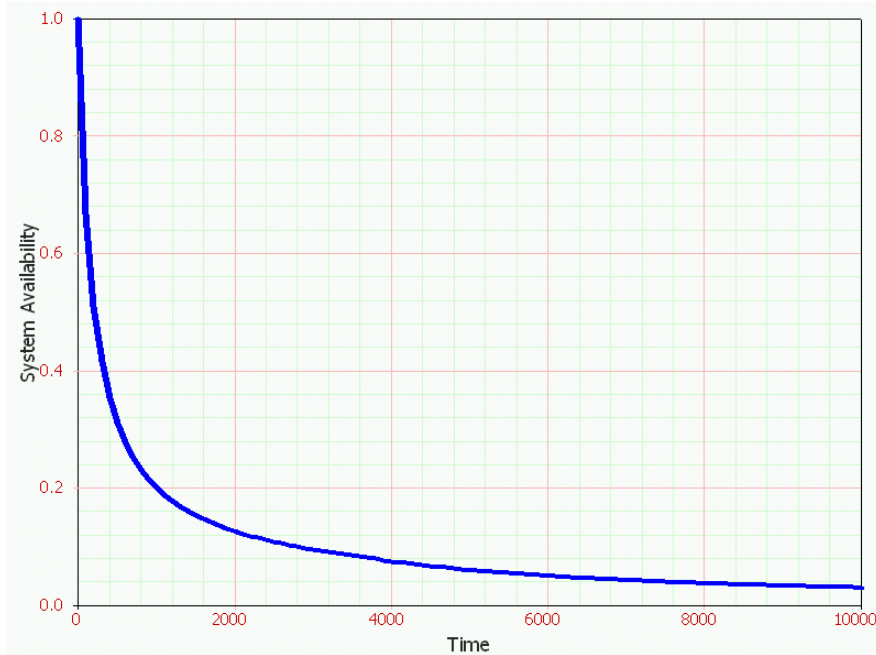


- Very often parts are NOT independent.
- Restorations may take place at part level and/or the system level with different maintenance schedules.
- A failed part will be restored back to an operable state, but may not fully renewed.
- System may not be renewed.

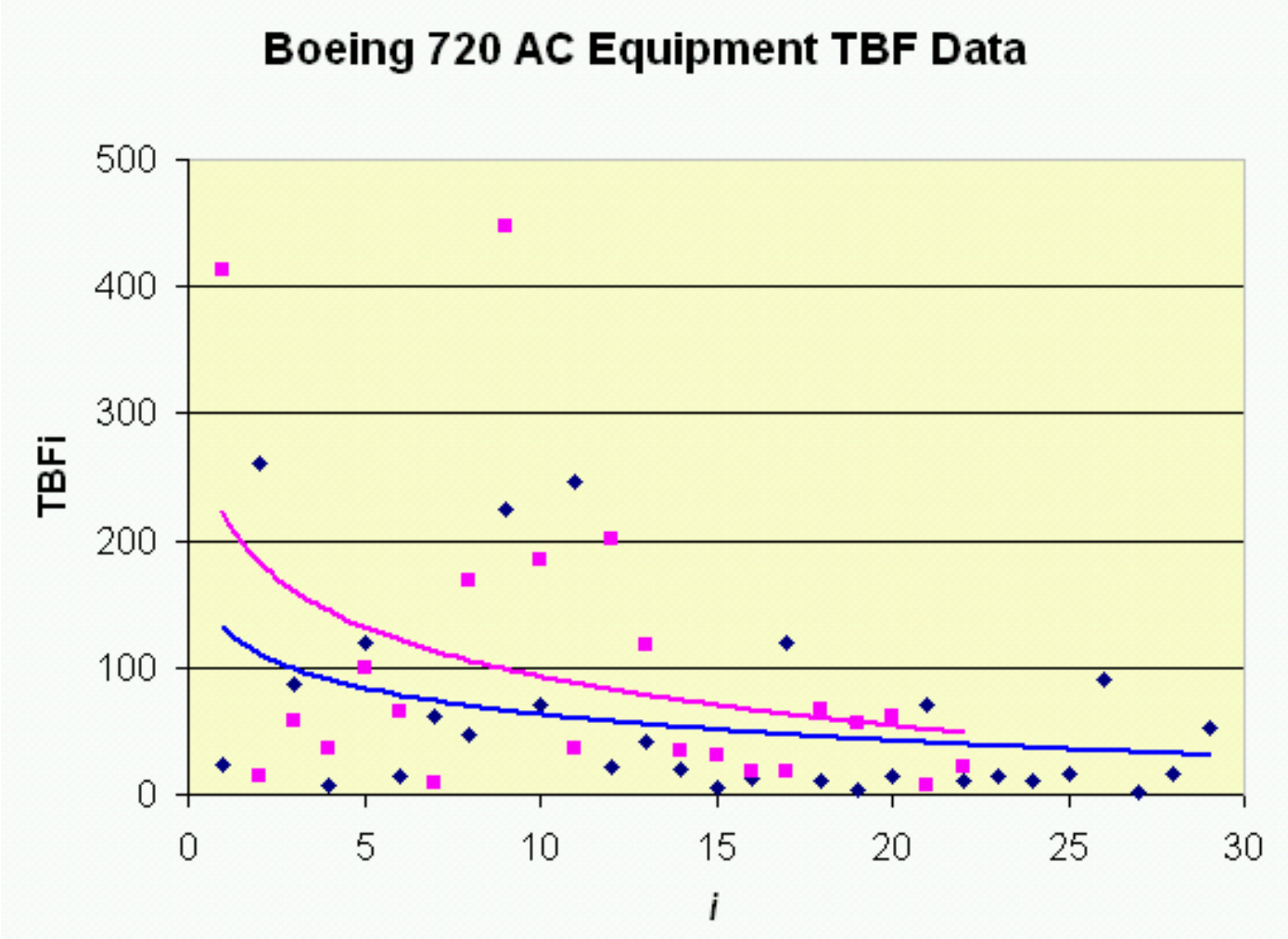
Systems with Imperfect CM Parts



Different RF's



Boeing 720 AC Equipment TBF Data



Multiple-Parts Reliability Performance

- System performance: an assembly of realizations for of all part performance
- Imperfect maintenance, dependency, system behavior and etc greatly complicate the system reliability performance.
- Steady state may **NOT** exist.
 - TBF_i may be different **statistically**.
- Still 2-state alternating process (may NOT stationary).
- Field data seem to confirm the simulation results.

Multiple-parts Reliability Measures

- Part level
 - TBF_i and TTR summarize its reliability?
 - Kijima virtual age models
 - TBF_i 's distributions or family
 - Generalized renewal process
- System level
 - System TBF_i and TTR describe its reliability?
 - Total Uptime distribution
 - Stochastic process (counting or regeneration process)
 - Mean Cumulative Function (MCF)
 - **Simulation approach**
 - System availability
 - Average availability? What's fundamental variables?
 - How to roll reliability performance up from part level?