O&M Cost Model

Quantifying the Influence of Reliability

Wind Turbine Reliability Workshop

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Overview

- How does reliability influence O&M costs?
- What are the reliability assumptions?
- How are these assumptions derived?
- How can they be improved?

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Reliability Affect on O&M Cost

- Downtime (lost revenue)
  - Response time, troubleshooting, MTTR
- Penalties
- Part Cost
- Crane Cost
- Labor
- Logistics

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Reliability Estimate Challenges

- Variable historical data
  - 100 kW to 3 MW turbines, 3 to 20 years old
  - Simple stall-regulated vs. complex variable-speed
  - Various OEM and component manufacturers
- Reluctance to release data
  - Warranty period and $ generally ‘off limits’
  - Knowledge is a competitive advantage
- Moving Target
  - Product maturity – incorporating ‘lessons learned’
  - Innovation – higher reliability or higher risk?

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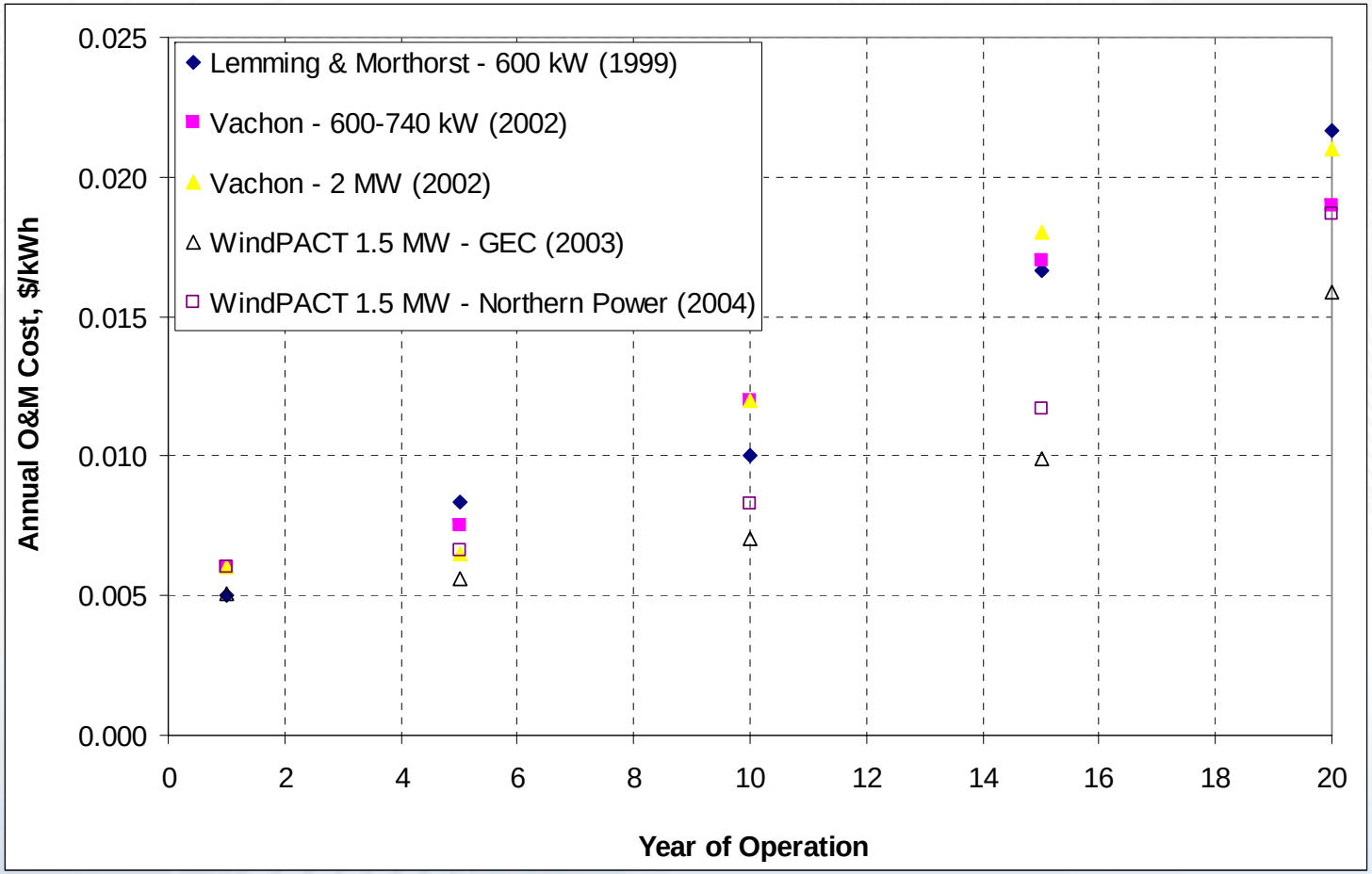
Several O&M Cost Estimates



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GEC O&M Cost Model

- Bottom-up approach
- Uses historical data, ‘industry’ data
- Builds ‘virtual’ turbine from components
- Failure rates based on component type
- Repair costs normalized to capacity
- Site/labor costs based on size and number
- Integrates contributors to get annual cost

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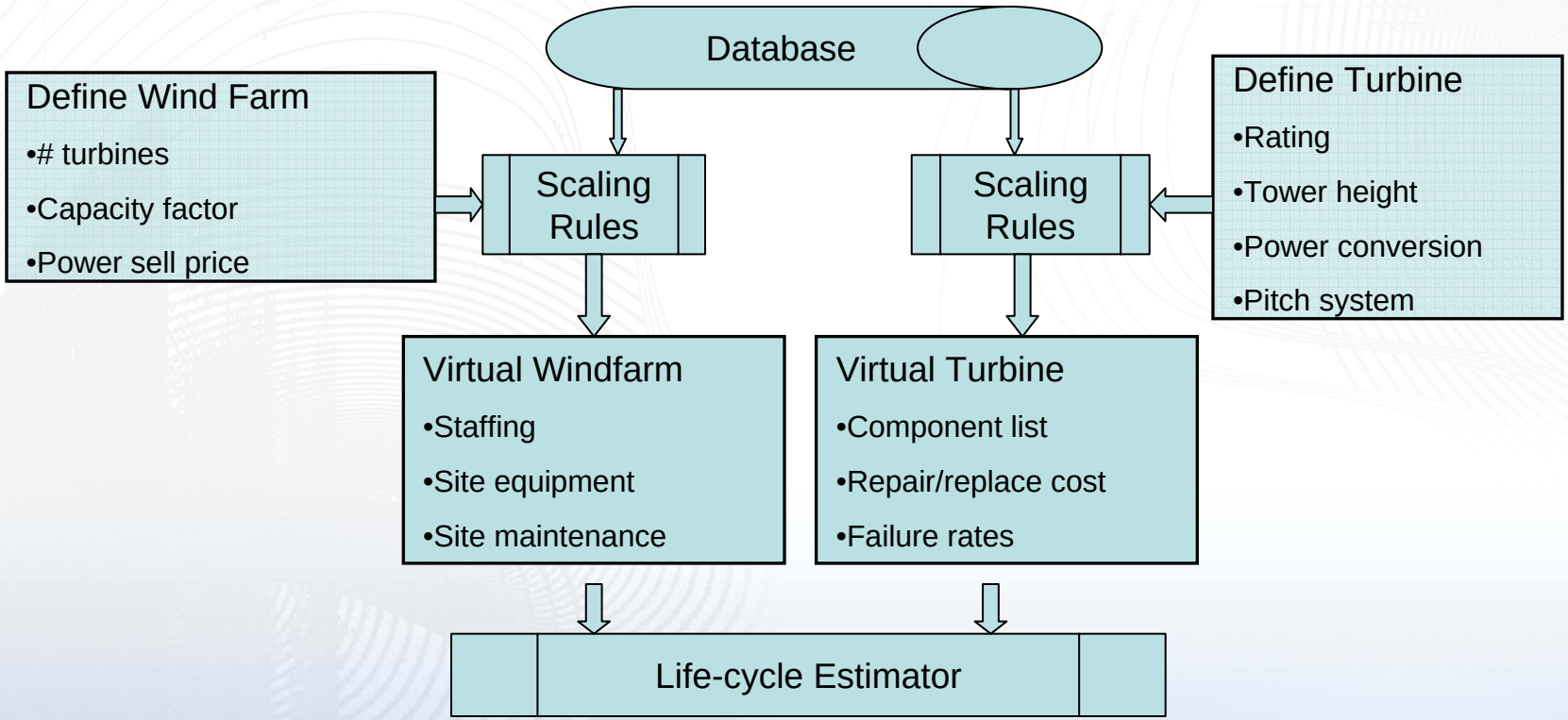
Cost Model Flow Chart



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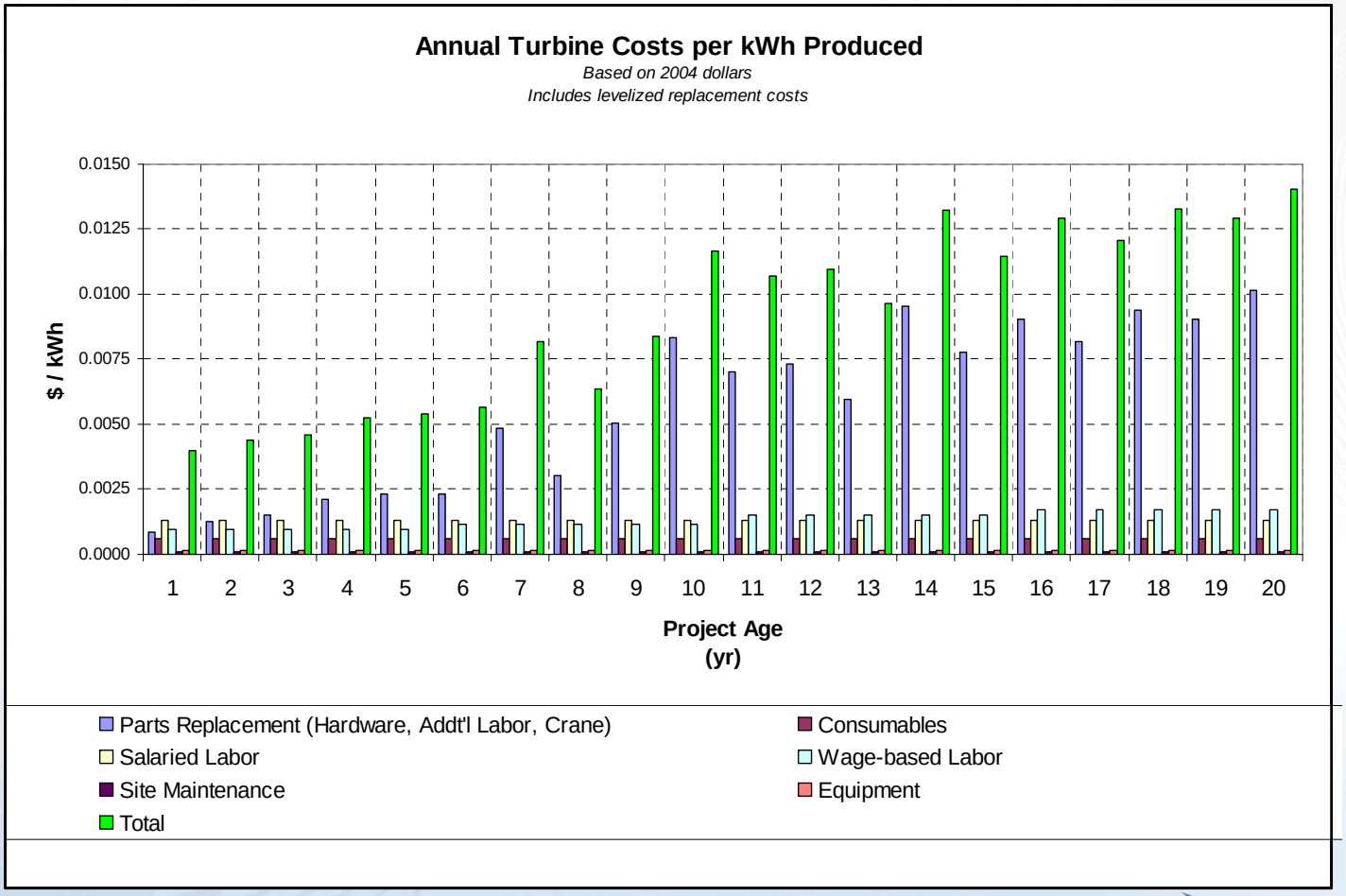
Estimated O&M Cost by Year



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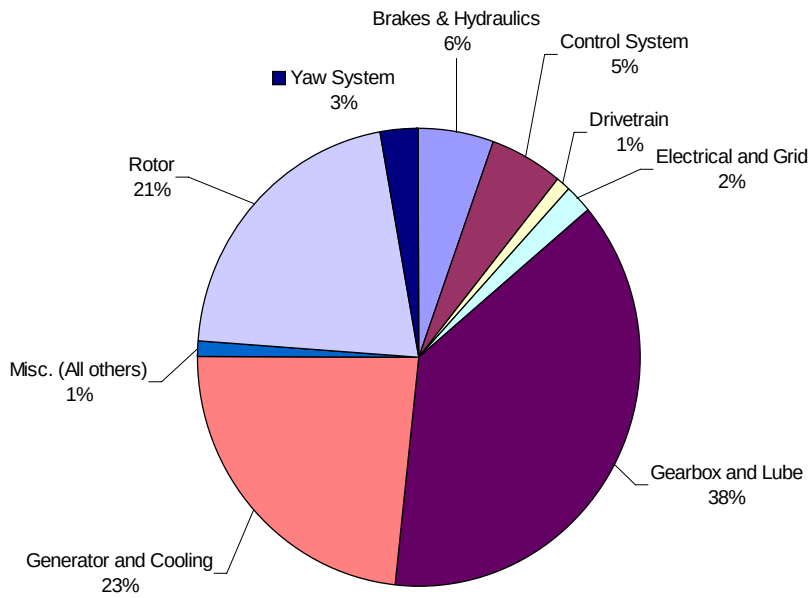
Estimated Parts Usage



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Mature Design Reliability Assumptions

- Structural parts don't wear out
  - Code-driven designs with sufficient safety factors
  - Blade design is tested
  - Manufacturing defects will be detected early on
- Relative-motion parts wear out but don't break
  - Bearings/motors/pumps/valves/cylinders/starters
  - Some can be rebuilt
- Electrical components deteriorate thermally
  - Solid-state switches/controller boards
- Some parts subject to random failures
  - Assembly oversights, maintenance errors, consequential damage

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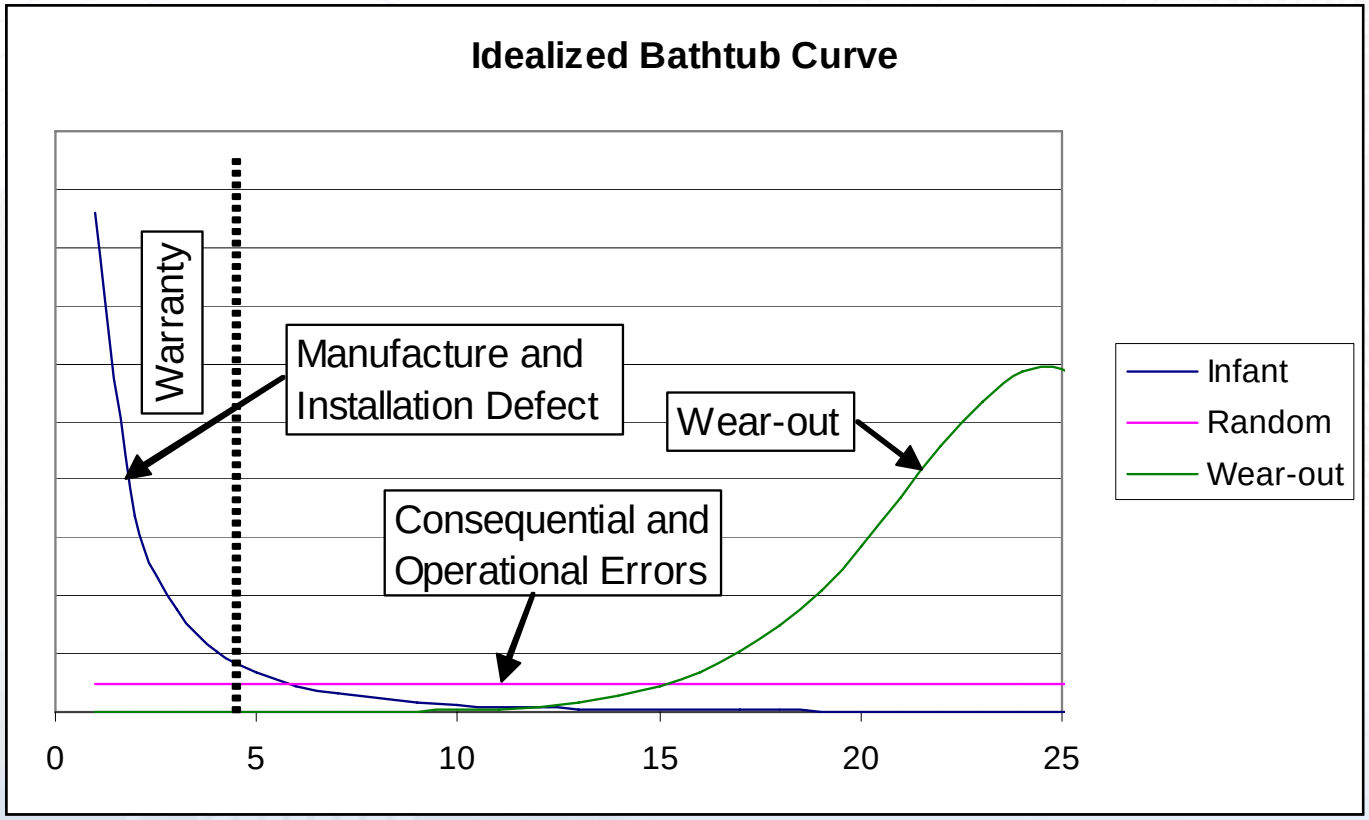
Mature Design Failure Pattern



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Failure Rate Assumptions

Component	GEC Model	Vachon [A]	Manufacturer Estimates	Weibull Database [B]
Blade	[C]	-	-	-
Gearbox	24	17	>20	14 -24
Generator	23	14	>20	28
Generator bearing replacement	15	-	15	14
Yaw drive	11	15	10	14 – 24
Yaw sliding pads	9	10	>20	42
Pitch bearing	[D]	10	>20	14
Main bearing	[E]	-	>20	14
Pitch cylinder	9	10	5 - 10	14
Hydraulic valve	11	10	10	26
Accumulator	5	10	5	16
Hydraulic pump	11		-	-
Brake caliper	8	20	20	14
Lube pump	11	-	10	10
Cooling fans	14	-	>20	28
Main contactor	17	-	-	-
Main circuit breaker	25	-	-	-
Control board, main	12	-	-	
Sensor, static	12	-	10 – 15	33
Sensor, dynamic	10	-	10 – 15	7
Power electronics	12	-	-	23
Soft starter	25	-	-	-

A – Vachon, W.A. "Modeling the Reliability and Maintenance Costs of Wind Turbines Using Weibull Analysis." Windpower '96 Conference Proceedings.
B – Barringer Associates, Inc. *Weibull Database*. http://www.barringer1.com/wdbase.htm
C – Assume 1 event per 50 turbines every 5 years due to damage
D – Assume 1 event per 50 turbines every 8 years due to damage
D – Assume 1 event per 50 turbines every 12 years due to damage

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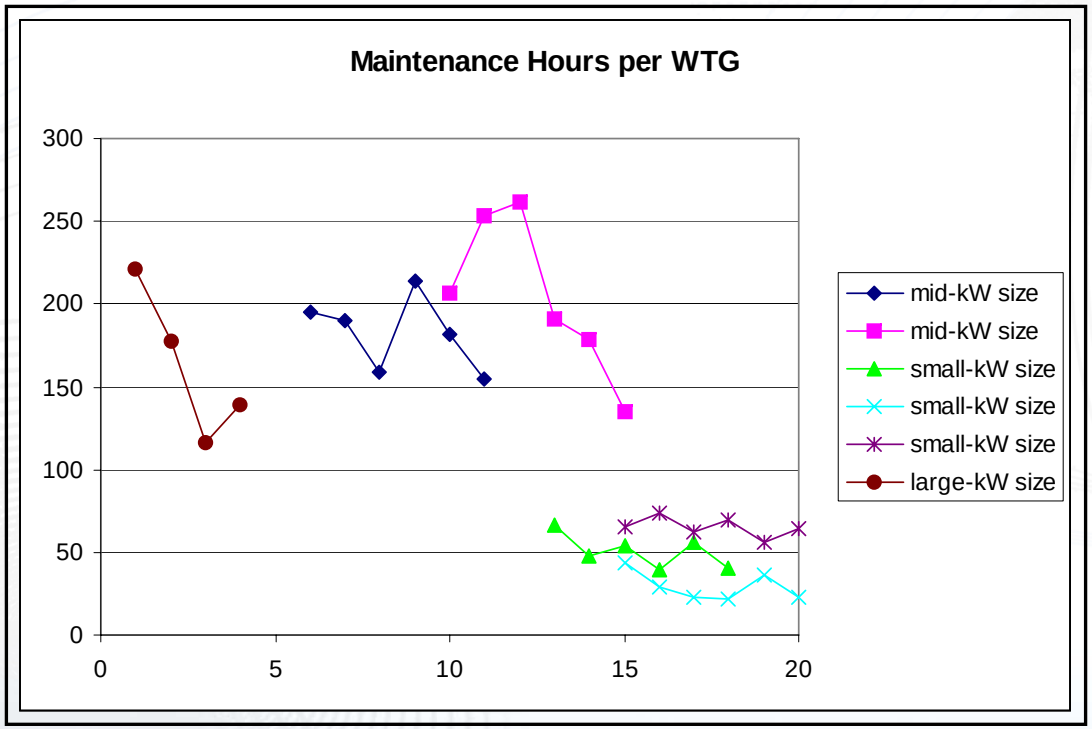
Does Reliability Deteriorate?



- Maintenance time increases with turbine size,
- …but not necessarily with age
- Smaller machines are less complex

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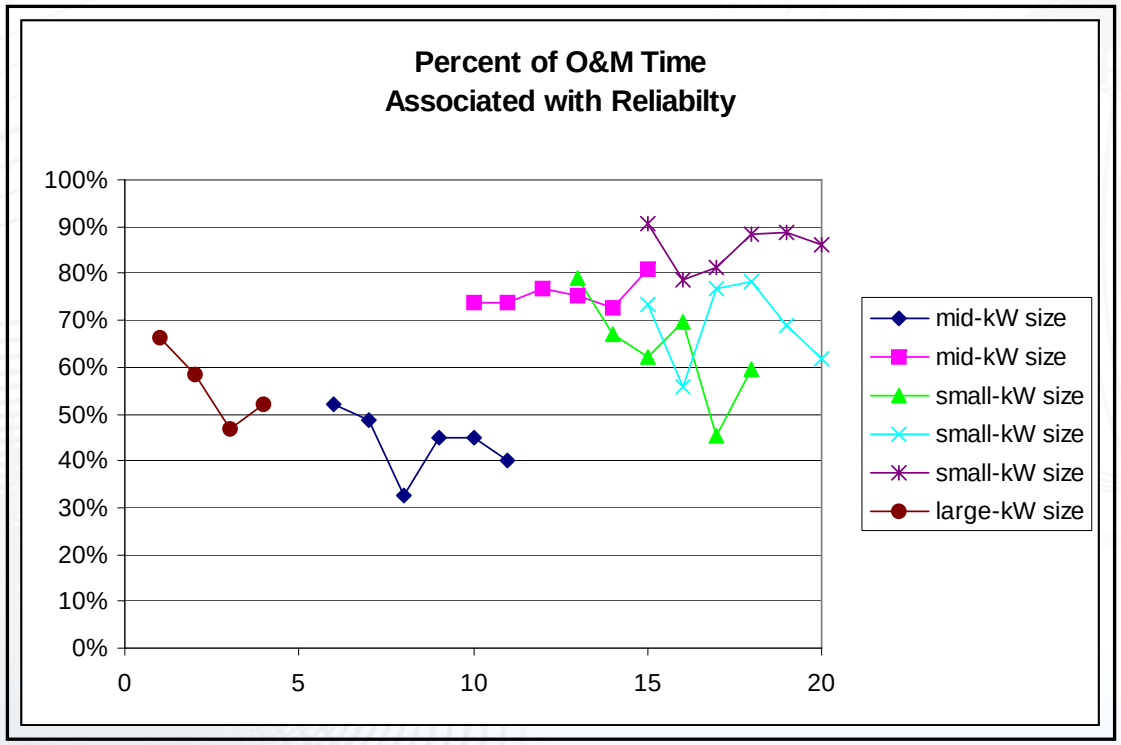
Reliability-related Maintenance Time



- Percentage of maintenance for repairs, resets, trouble-shooting

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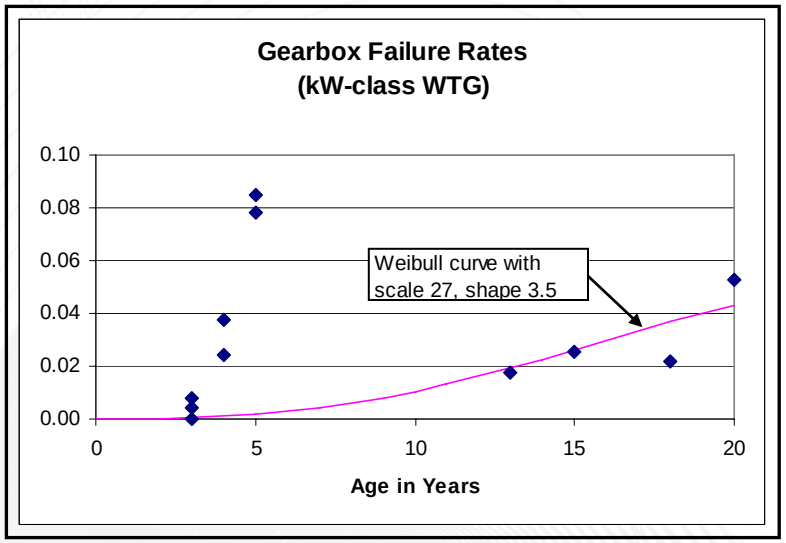
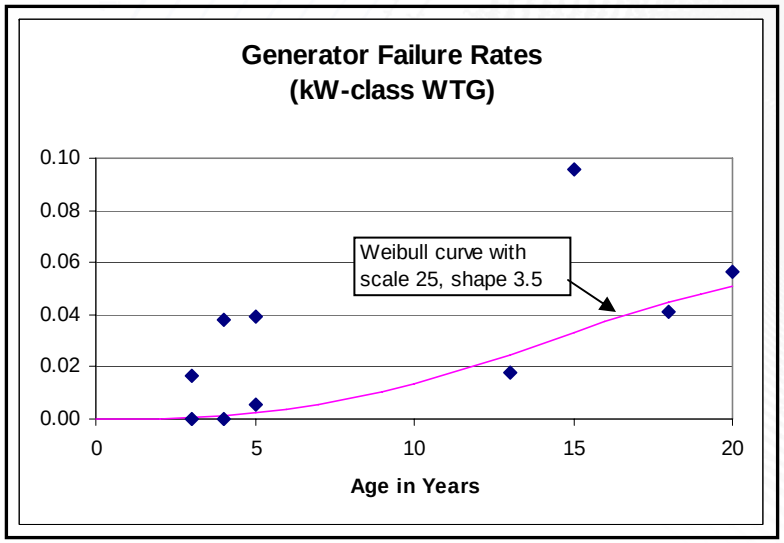
A Rose is a Rose is a Rose?





- Data represents various component designs
- Does a 10% failure rate indicate a ‘serial defect’?
- Does the trend line represent a ‘mature’ design?

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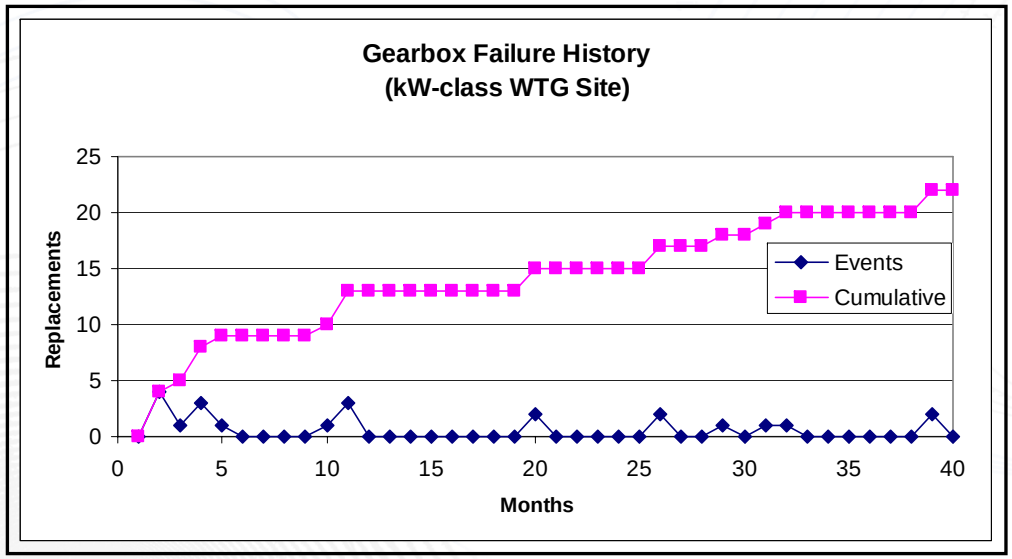
Meanwhile, back at the farm…



- Is there a trend?
- Are the 'infant' failures being weeded out?
- Is a re-design warranted?
- Wait until failure or campaign replacement?

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What do we need to know?

- How did the component fail?
  - Degraded performance or catastrophic?
  - Entire unit or sub-component?
- What was the history?
  - Run-time (ideally hours-at-load)
  - Monitoring record (temperatures, vibration levels)
- How was it fixed?
  - Replaced or repaired?
  - Direct costs (part, crane, labor)
  - Lost time, curtailment, time-to-repair
- Why did it fail?
  - Expected wear-out?
  - Maintenance or installation error?
  - Design error (wrong assumptions, misapplication)
  - Manufacturing defect
  - Control or operation error
- How will a future failure be prevented?
  - Redesign, increased maintenance, re-specification of part

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Conclusions

- The historical record of reliability data is inconsistent and of limited relevance to today's turbines
- Generic models are useful for first-cut estimates and 'what-if' scenarios
- An accurate model will be site-specific and dynamic
- A standard protocol for recording reliability data is highly desirable – and the sooner the better

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