# Why do Machines and Equipment Continue to Fail?

***Let a Plant Wellness Way EAM System-of-Reliability halve your Annual Maintenance Costs***

**This white paper will teach you how to solve your plant and equipment reliability problems and improve your current plant and equipment reliability up to magnificent performance.**

Since the mid-1980's we have known exactly how to guarantee incredible equipment reliability. **Failure-free machinery and equipment is totally achievable** *(in fact it is remarkably straightforward to do)*. We have all the answer—we know all the science; we know all the engineering; all the necessary information is readily available. The research has long been completed. The correct solutions for magnificent reliability are practical and quite doable. **The problem that remains,** is that though we know exactly what needs to be done to get magnificently reliable machines, we cannot get companies to do it right. The limitation to achieving magnificent reliability is not technical. The limitation now seems to be organisational, cultural, and human factors related.

**The Plant and Equipment Wellness (PEW) life cycle asset management methodology was developed to help companies make magnificent reliability a 'business as usual' outcome.**

This paper is mostly pictorial in its introduction to the Plant Wellness Way (PWW). If you are to solve plant and equipment reliability problems, you need to start with understanding why machines fail and how you create and build magnificent reliability in your company.

## Why do Machines and Equipment Continue to Fail in Companies?

- *"We get reliability by creating and building a thing that can do the duty, and preventing its failure during use."* *(LRS uses Plant Wellness Way to do that.)*

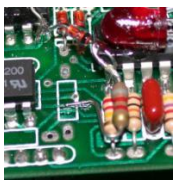
# What is Reliability?

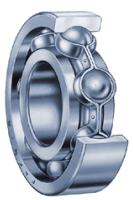
- *"Reliability is the **probability** that an item of plant will perform its **duty** without **failure** over a designated **time**."* *(Formal Definition)*
- *"Reliability is the **chance** of completing the mission."* *(Military Definition)*
- *"Reliability is the **chance of success**."* *(LRS Definition)*

- *"We get reliability by creating and building a thing that can do the duty, and preventing its failure during use."* *(LRS uses Plant Wellness Way to do that.)*



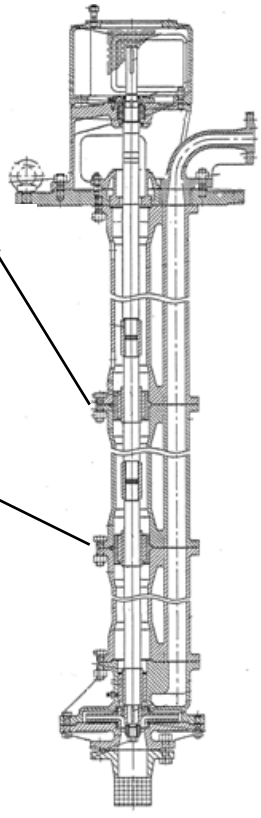
# Machines Fail because their Parts Fail First





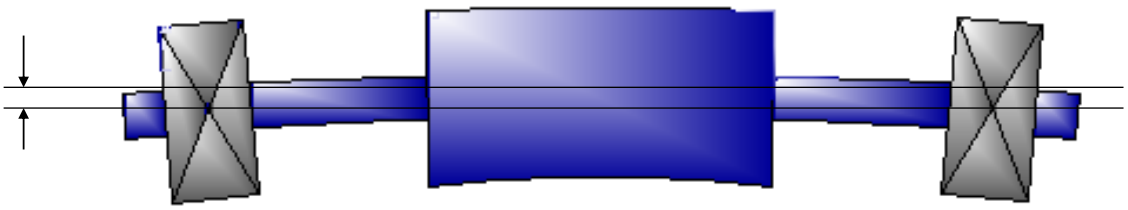
2nd bearing sleeve 2nd bearing bush

1st bearing sleeve 1st bearing bush



# The Unforgiving Nature of Machine Design

**How far off-center did the designer allow the shaft to move?**
**How much movement/angle did the bearing designer allow?**
**How much distortion before the parts overload and fail?**

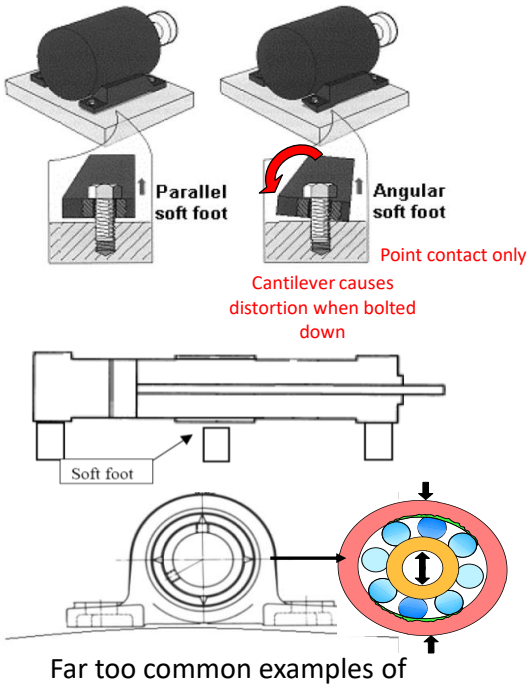


The parts' engineering clearances mean that everything has to be exactly as the designer planned it to be. The whole machine needs to run precisely as it should. If parts are deformed outside of their tolerance, like in this sketch, then the bearings will fail in a matter of hours, and not the years that they should last in a machine that is working as it was designed to operate.

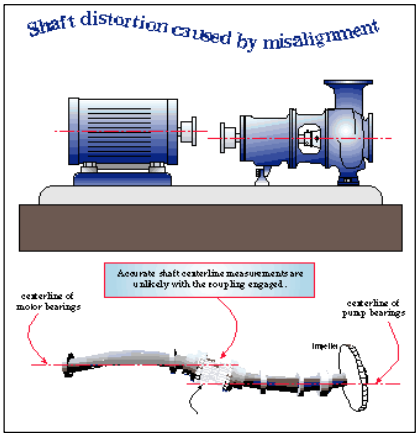
**Remember: The Limit of Machine Distortion is set by Design Tolerances – *don't let a machine or its parts get twisted out of shape!***



# Stress from Distortion



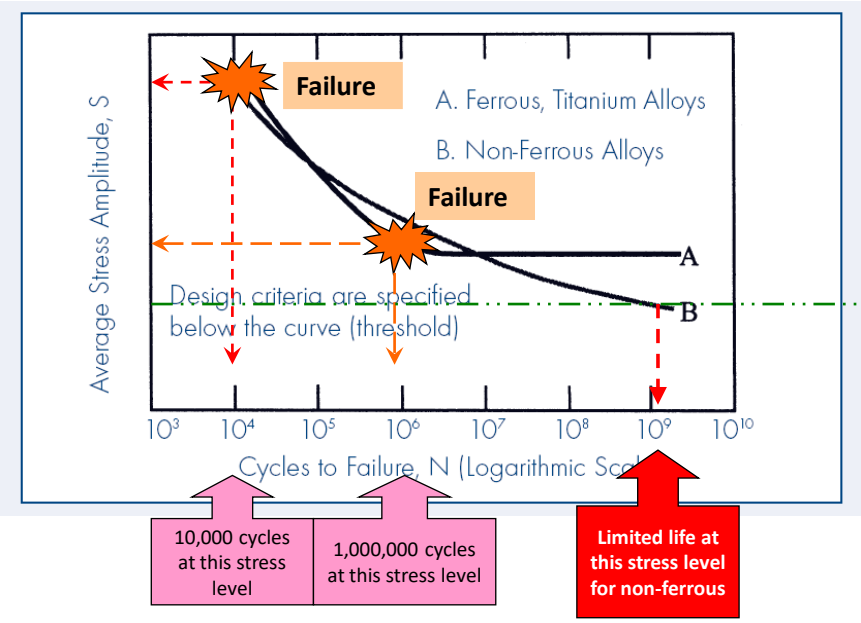

Far too common examples of soft-foot problems!




Shaft misalignment distorts and bends shafts which in turn overloads the shaft bearings

**Source:** Shaft Alignment Handbook, John Piotrowski, CRC Press

# Fatigue Limit of Parts' Material of Construction

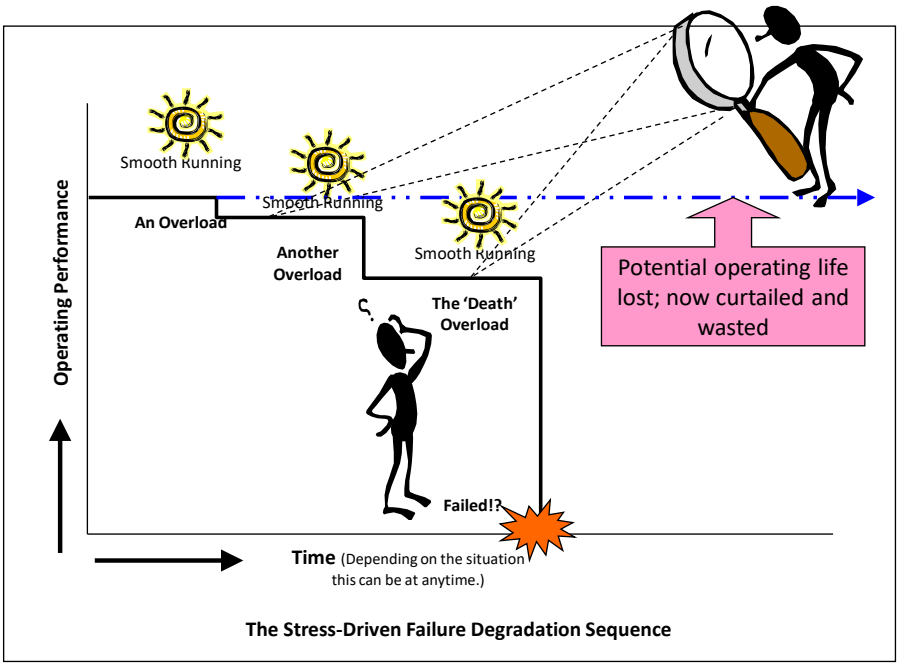



We must know what our equipment parts are made of and prevent high stress in those with infinite life but replace those of finite life before they fail.

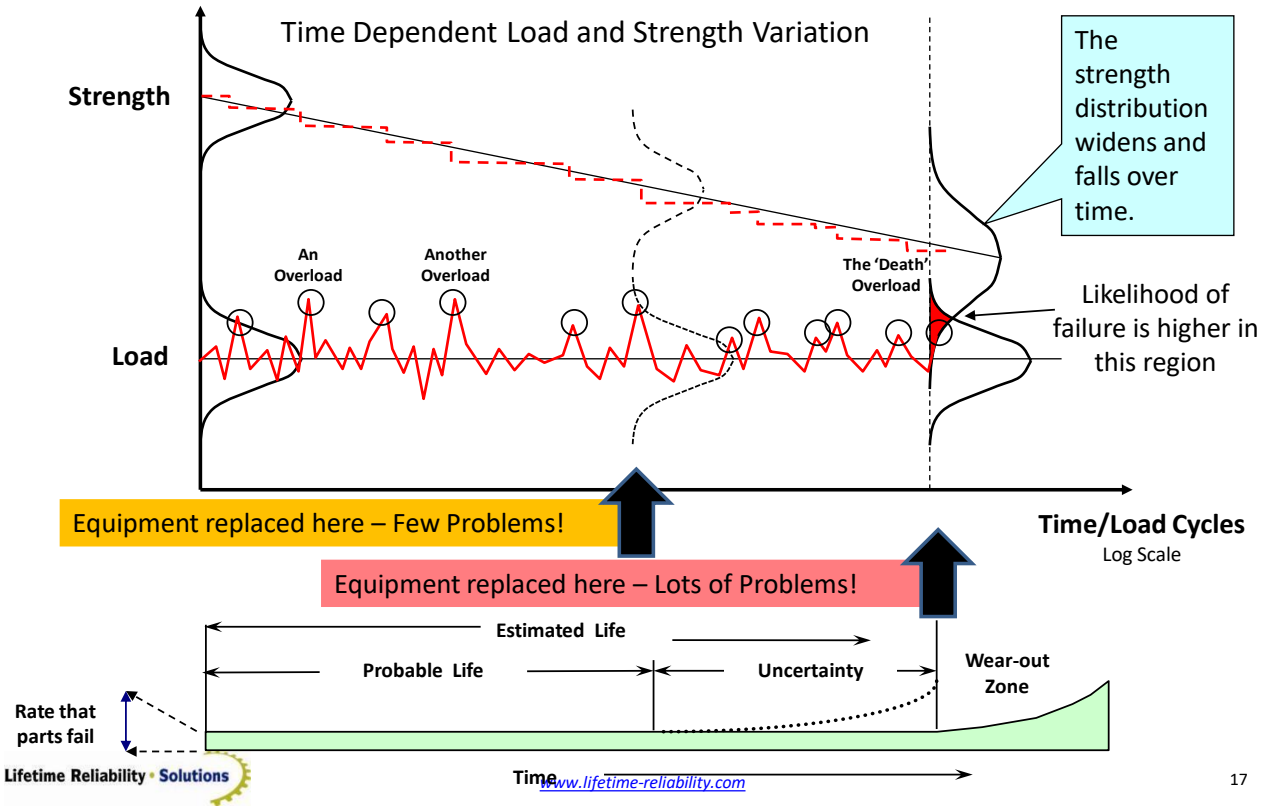


# The Operating Overload Cycle

Many parts fail without exhibiting warning signs of a coming failure – they show no evidence of degradation; there is just sudden catastrophic failure. In such cases the parts were too weak for the loads they had to take. In virtually every case those loads are imposed by human error.



# Cause of Aging Failures

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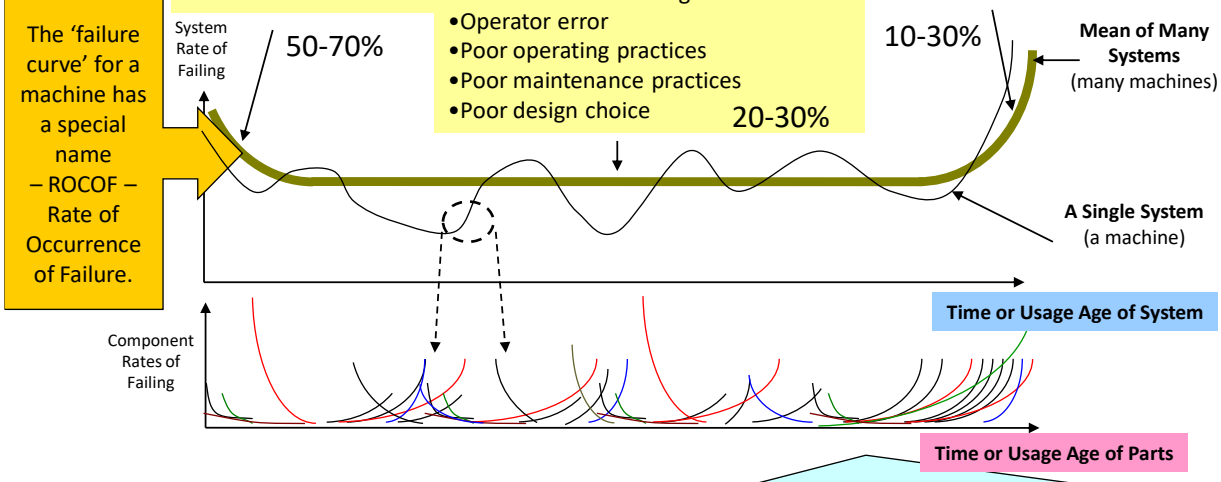
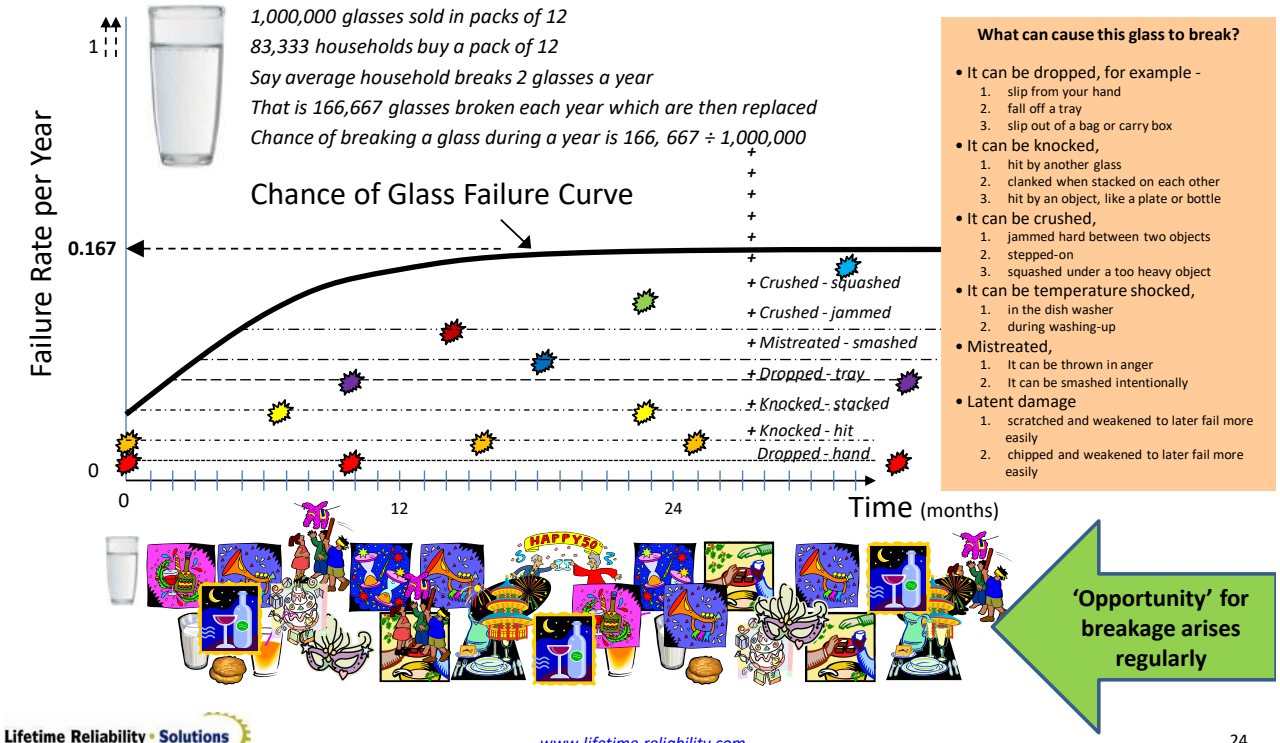
# Machine Reliability = Sum of Parts' Reliability

| Failure from Error | Failure from Induced Stress | Failure from Usage |
|---|---|---|
| •Defective parts<br>•Poor quality assembly<br>•Manufacture error | •Operating overload<br>•Rapid aging of some parts<br>•Local environment degradation<br>•Operator error<br>•Poor operating practices<br>•Poor maintenance practices<br>•Poor design choice | •Too many aging parts<br>•Many parts degraded |




Parts put together into machines form a system of parts. **When a working part fails the machine fails.** Hence the reliability of a machine is less than the reliability of its worst part. The ROCOF curve for a machine reflects what happens to its parts, and moves up and down as parts fail. But when we take many identical machines and collect their parts' failure history together, we get a 'steady average' ROCOF, which is representative of the reliability of the machine design, and its use and care over its lifetime.

# Chance of Failure for a Drinking Glass

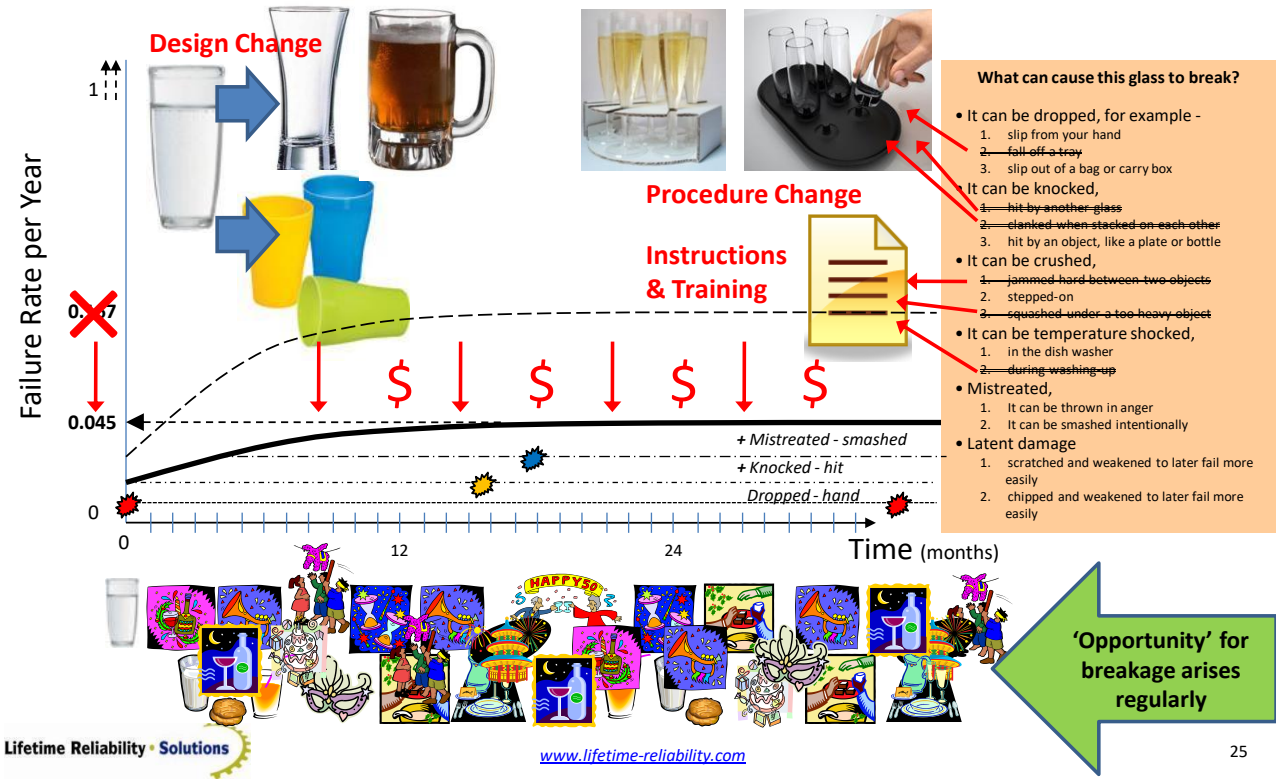



**What can cause this glass to break?**

- It can be dropped, for example -
  1. slip from your hand
  2. fall off a tray
  3. slip out of a bag or carry box
- It can be knocked,
  1. hit by another glass
  2. clanked when stacked on each other
  3. hit by an object, like a plate or bottle
- It can be crushed,
  1. jammed hard between two objects
  2. stepped-on
  3. squashed under a too heavy object
- It can be temperature shocked,
  1. in the dish washer
  2. during washing-up
- Mistreated,
  1. It can be thrown in anger
  2. It can be smashed intentionally
- Latent damage
  1. scratched and weakened to later fail more easily
  2. chipped and weakened to later fail more easily



# Stop Failure = Remove Failure Causes

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# PEW SOLUTION: Reduce the Chance of Failure

*Chance of Failure = 1 – Chance of Success*

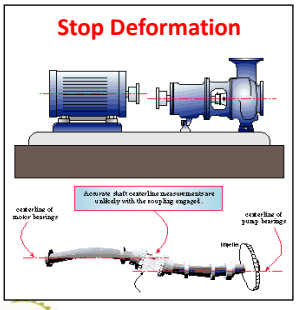
*Chance of Failure = 1 – Reliability*

***Risk** = Consequence $ x Chance /yr*

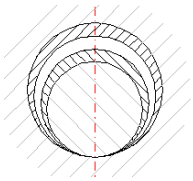
***Risk** = Consequence $ x [Freq of Opportunity /yr x Chance of Failure at Each Opportunity]*

***Risk** = Consequence $ x [Freq of Opportunity /yr x {1 – Reliability}]*

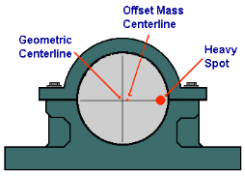
Excellent Lubricant Cleanliness




Correct Fastener Torque



Proper Fits and Tolerance




No Unbalance

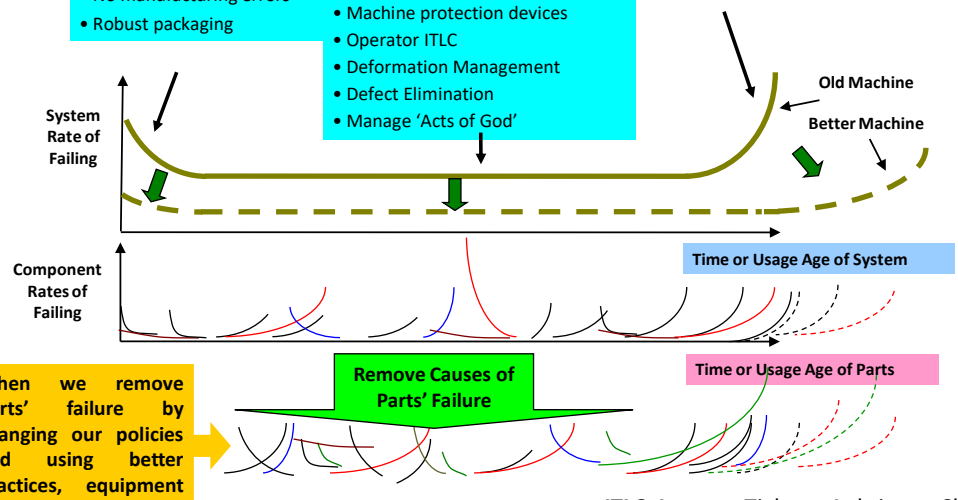
*Here are some opportunities…*

Lifetime Reliability • Solutions



"Equipment reliability is malleable by **choice of policy** and **quality of practice**."

| ERROR INDUCED ZONE | STRESS INDUCED ZONE | USAGE INDUCED ZONE |
|---|---|---|
| • Better quality control | • Condition Monitoring | • More parts on renewal PM |
| • Higher skills training | • Better operator training | • Better material choices |
| • Precision assembly | • Total Productive Maintenance | • Considerate operation |
| • Precision installation | • Precision Maintenance | • Degradation Management |
| • No substandard material | • Better design/application choice | • Timely maintenance |
| • No manufacturing errors | • Stronger material choices | |
| • Robust packaging | • Machine protection devices | |
| | • Operator ITLC | |
| | • Deformation Management | |
| | • Defect Elimination | |
| | • Manage 'Acts of God' | |

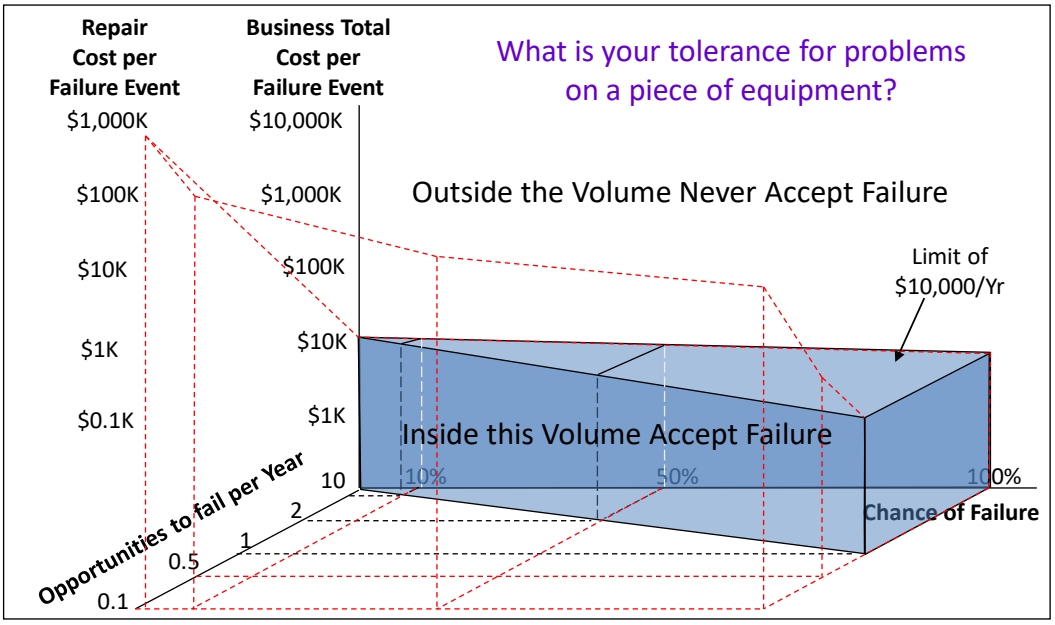



When we remove parts' failure by changing our policies and using better practices, equipment becomes more reliable

Lifetime Reliability • Solutions

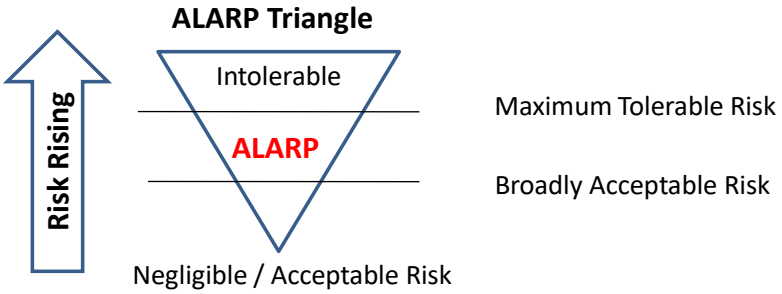
# Acceptable Equipment Failure Domain

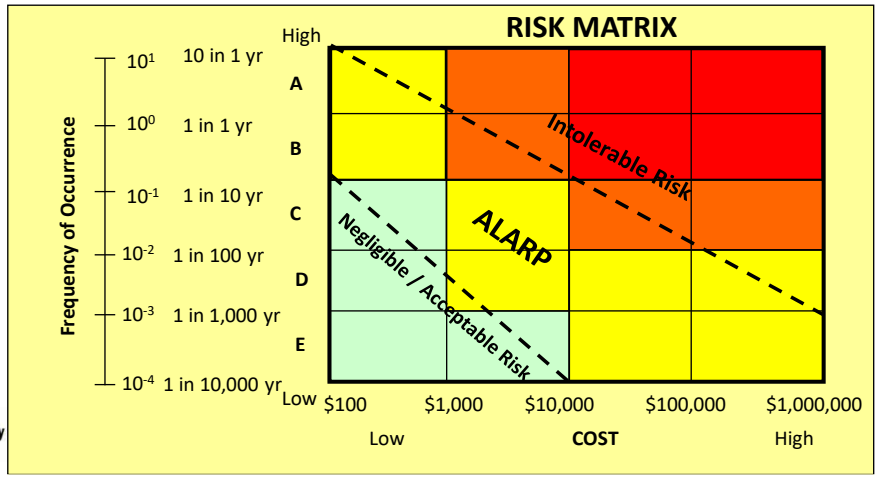
***Risk** = Consequence x [Frequency of Opportunity x Chance of Failure at Each Opportunity]*



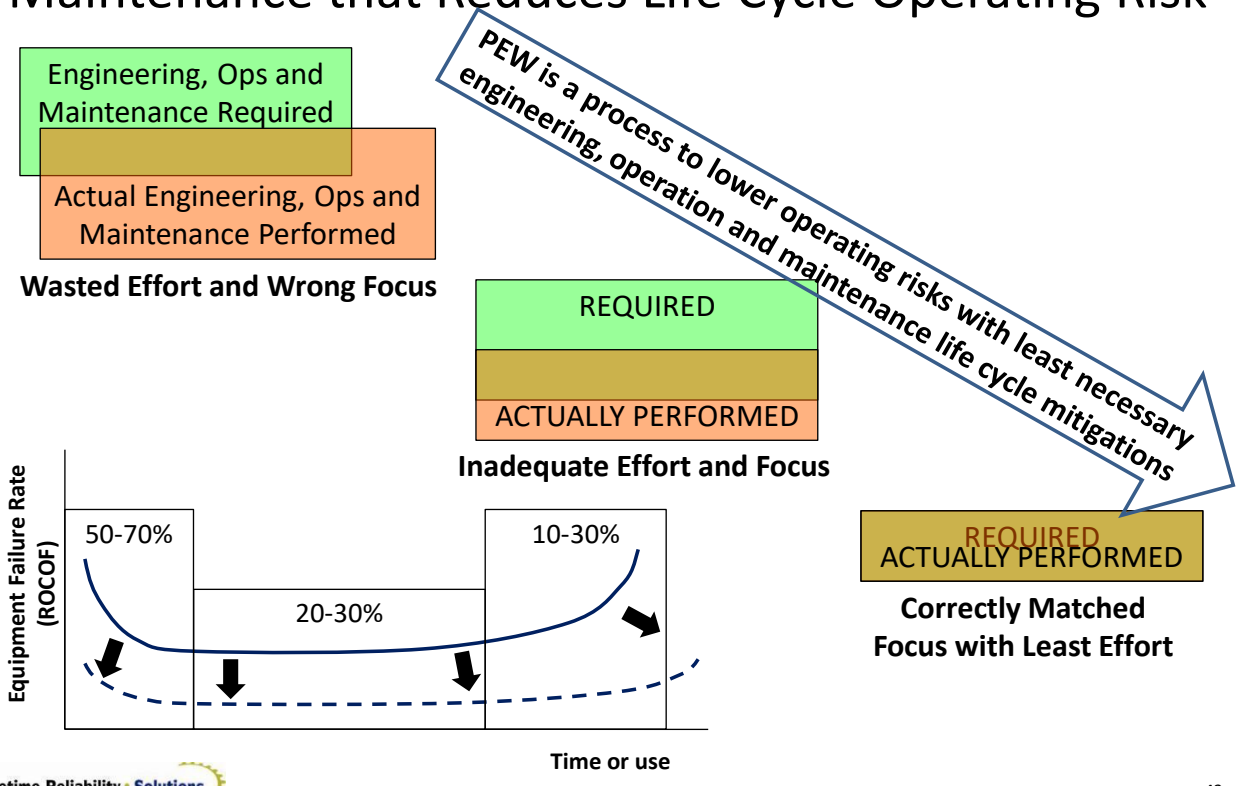



# Want ALARP – As Low As Reasonably Practicable



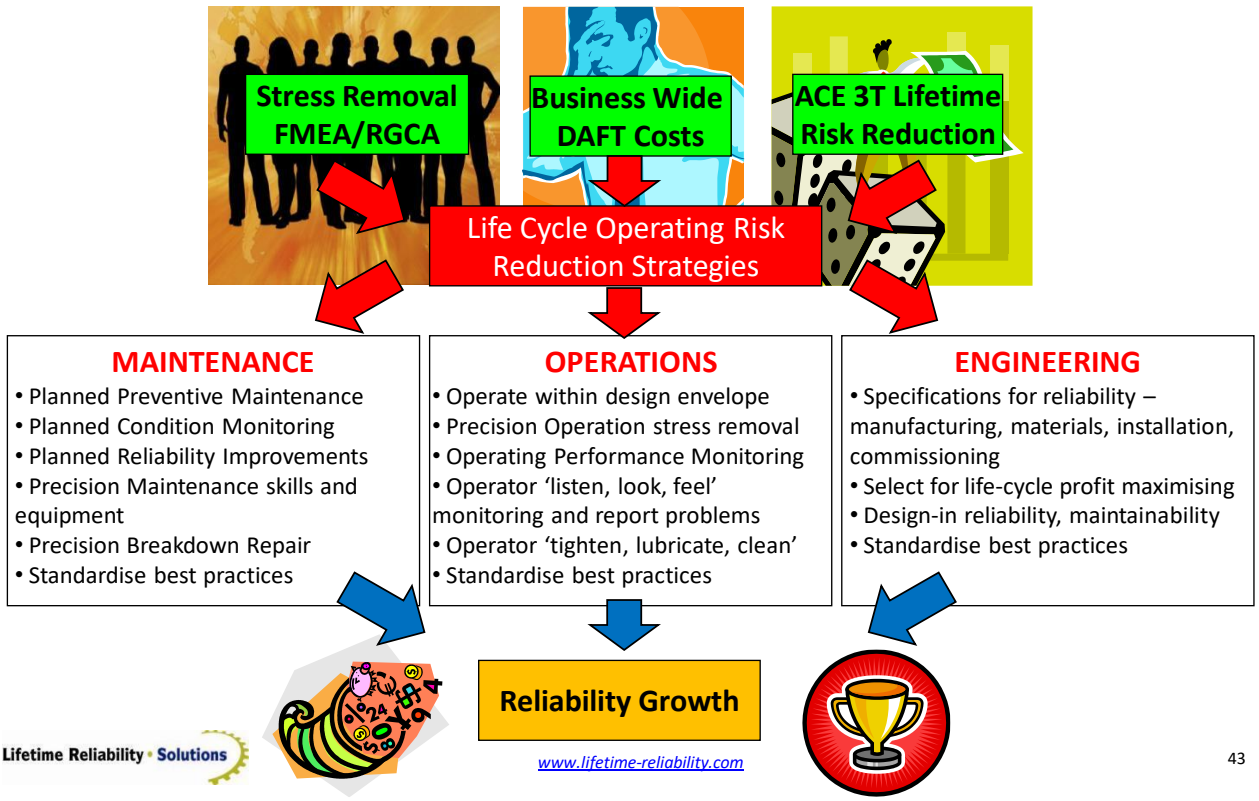



# PEW SOLUTION: Asset Engineering, Operations and Maintenance that Reduces Life Cycle Operating Risk






# PEW SOLUTION: Use a Process to Create Reliability by Reducing the Chance of Machine Component Failure



# PEW SOLUTION: Tracking Risk Matrix Used to Prove Asset Operating Risk Reduction

| Likelihood of Equipment Failure Event per Year | | | | DAFT Cost per Event | $30 | $100 | $300 | $1,000 | $3,000 | $10,000 | $30,000 | $100,000 | $300,000 | $1,000,000 | $3,000,000 | $10,000,000 | $30,000,000 | $100,000,000 | $300,000,000 | $1,000,000,000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Event Count / Year | Time Scale | Descriptor Scale | Historic Description | | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 |
| 100 | Twice per week | | | 2 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 | 11 |
| 30 | Once per fortnight | | | 1.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 | 10.5 |
| 10 | Once per month | Certain | | 1 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | 10 |
| 3 | Once per quarter | | | 0.5 | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 |
| 1 | Once per year | Almost Certain | Event will occur on an annual basis | 0 | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 |
| 0.3 | Once every 3 years | Likely | Event has occurred several times or more in a lifetime career | -0.5 | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 |
| 0.1 | Once per 10 years | Possible | Event might occur once in a lifetime career | -1 | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 7 | 7.5 | 8 | |
| 0.03 | Once per 30 years | Unlikely | Event does occur somewhere from time to time | -1.5 | | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 |
| 0.01 | Once per 100 years | Rare | Heard of something like it occurring elsewhere | -2 | | | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 |
| 0.003 | Once every 300 years | | | -2.5 | | | | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 |
| 0.001 | Once every 1,000 years | Very Rare | Never heard of this happening | -3 | | | | | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 |
| 0.0003 | Once every 3,000 years | | | -3.5 | | | | | | | | | | | | 3.5 | 4 | 4.5 | 5 | 5.5 |
| 0.0001 | Once every 10,000 years | Almost Incredible | Theoretically possible but not expected to occur | -4 | | | | | | | | | | | | | 3.5 | 4 | 4.5 | 5 |

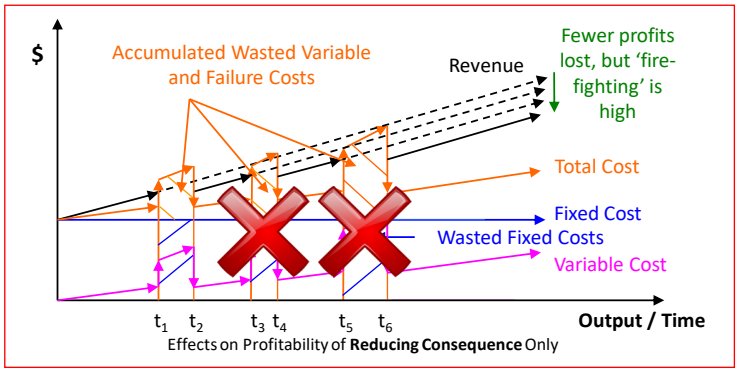
CM oil condition analysis
CM cable thermographs
PM oil filtration
PM oil change
PM oil leaks from TX
PM water ingress paths
PM oil breather contamination
PM cable connections

Note: Risk Level
Red = Extreme
Amber = High
Yellow = Medium
Green = Low
Blue = Accepted

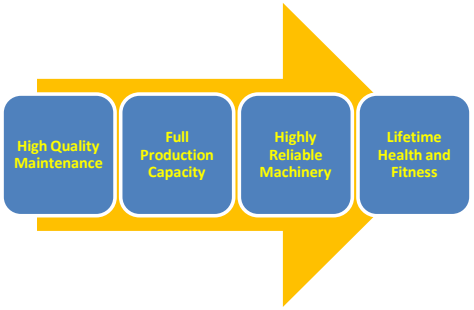
1) Risk Boundary 'LOW' Level is set at total of $10,000/year
2) Based on HB436:2004-Risk Management
3) Identify 'Black Swan' events as B-S (A 'Black Swan' event is one that people say 'will not happen' because it has not yet happened)
4) DAFT Cost (Defect and Failure True Cost) is the total business-wide cost from the event.

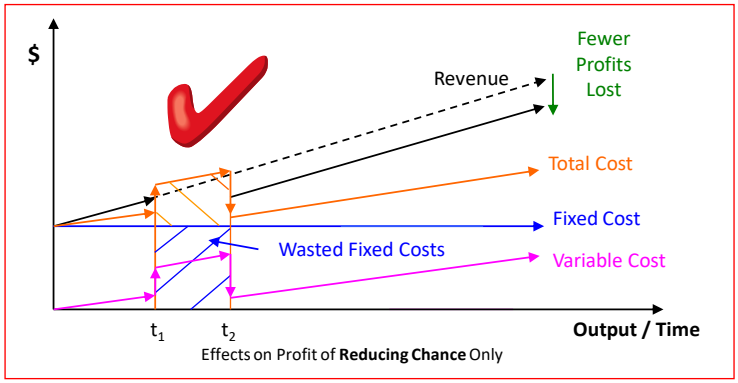


# PEW SOLUTION: Build a Life Cycle System that Creates Plant and Equipment Reliability Improvement



Effects on Profitability of **Reducing Consequence** Only



Effects on Profit of **Reducing Chance** Only

# PEW SOLUTION: Apply the Answers in the Human Error Rate Table to Reduce Human Error 10,000%

~5 sigma

~4.5 sigma

~4 sigma

~2 - 3 sigma

| | | Error rate (per task) | | |
|---|---|---|---|---|
| | | Read/ reason | Physical operation | Everyday yardstick |
| | *Simplest possible task* | | | |
| | Fail to respond to annunciator | 0.0001 | | |
| | Overfill bath | | | 0.00001 |
| | Fail to isolate supply (electrical work) | | 0.0001 | |
| | Read single alphanumeric wrongly | 0.0002 | | |
| 1 | Read 5-letter word with good resolution wrongly | 0.0003 | | |
| 3 | Select wrong switch (with mimic diagram) | | 0.0005 | |
| | Fail to notice major cross-roads | | | 0.0005 |
| | *Routine simple task* | | | |
| 2 | Read a checklist or digital display wrongly | 0.001 | | |
| | Set switch (multiposition) wrongly | | 0.001 | |
| | Calibrate dial by potentiometer wrongly | | 0.002 | |
| | Check for wrong indicator in an array | 0.003 | | |
| 2 | Wrongly carry out visual inspection for a defined criterion (e.g. leak) | 0.003 | | |
| | Fail to correctly replace PCB | | 0.004 | |
| | Select wrong switch among similar | | 0.005 | |

| | | Error rate (per task) | | |
|---|---|---|---|---|
| | | Read/ reason | Physical operation | Everyday yardstick |
| | Read analogue indicator wrongly | 0.005 | | |
| | Read 10-digit number wrongly | 0.006 | | |
| | Leave light on | | | 0.003 |
| | *Routine task with care needed* | | | |
| | Mate a connector wrongly | | 0.01 | |
| | Fail to reset valve after some related task | | 0.01 | |
| | Record information or read graph wrongly | 0.01 | | |
| | Let milk boil over | | | 0.01 |
| | Type or punch character wrongly | | 0.01 | |
| | Do simple arithmetic wrongly | 0.01–0.03 | | |
| | Wrong selection – vending machine | | | 0.02 |
| | Wrongly replace a detailed part | | 0.02 | |
| | Do simple algebra wrongly | 0.02 | | |
| 1 | Read 5-letter word with poor resolution wrongly | 0.03 | | |
| | Put 10 digits into calculator wrongly | 0.05 | | |
| | Dial 10 digits wrongly | 0.06 | | |
| | *Complicated non-routine task* | | | |
| 3 | Fail to notice adverse indicator when reaching for wrong switch or item | 0.1 | | |
| 2 | Fail to recognize incorrect status in roving inspection | 0.1 | | |
| | New workshift – fail to check hardware, unless specified | 0.1 | | |
| | General (high stress) | 0.25 | | |
| | Fail to notice wrong position of valves | 0.5 | | |
| | Fail to act correctly after 1 min in emergency situation | 0.9 | | |

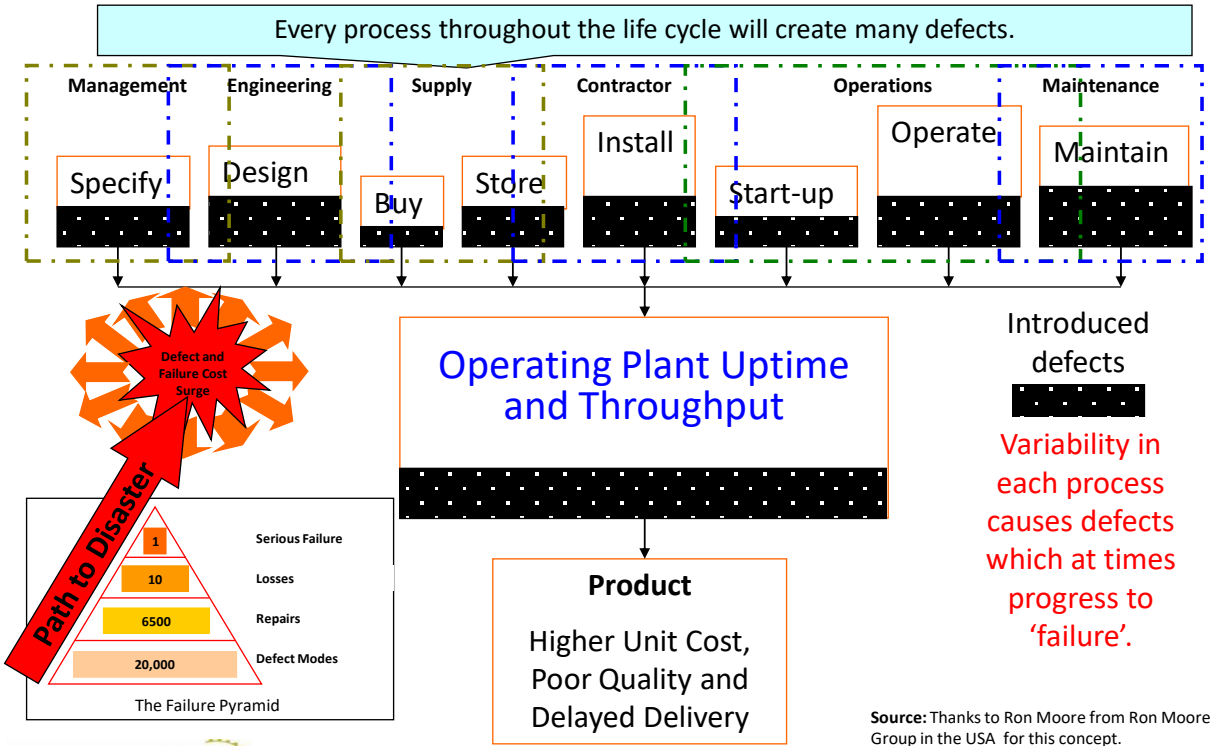
In failure rate terms the incident rate in a plant is likely to be in the range of $20 \times 10^{-6}$ per h (general human error) to $1 \times 10^{-6}$ per h (safety-related incident).

Source: Smith, David J., 'Reliability, Maintainability and Risk', Appendix 6, Seventh Edition, Elsevier – Butterworth Heinemann

The Table confirms that 'human element' error is real and unavoidable. We do not perform well when tasks are structured in ways that require care and we perform especially badly under complicated non-routine conditions. Add stress into that that mix and you get disaster.

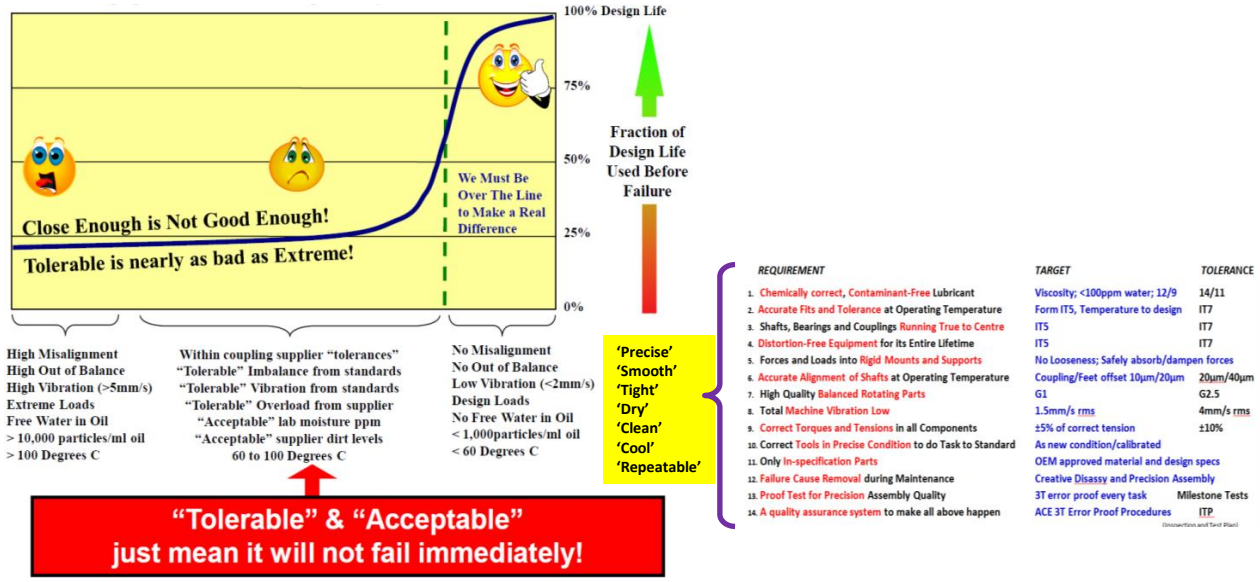


# PEW SOLUTION: Stop Variability and Defects Across the Business and Plant and Equipment Life Cycles




**Source:** Thanks to Ron Moore from Ron Moore Group in the USA for this concept.

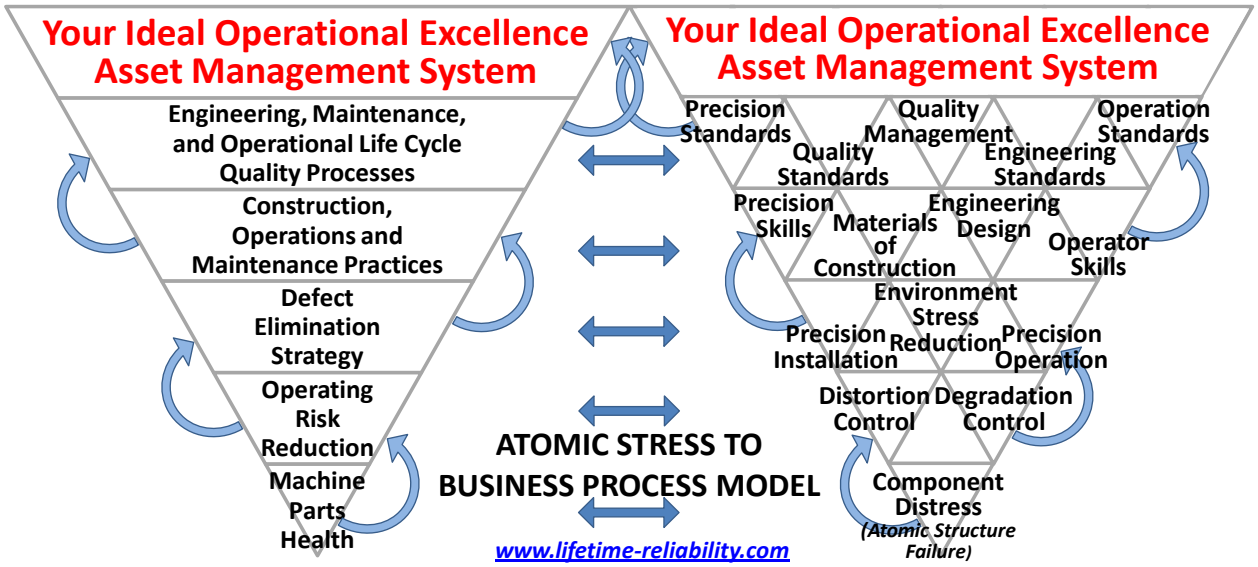
# PEW SOLUTION: World Class Standards produce World Class Equipment Reliability



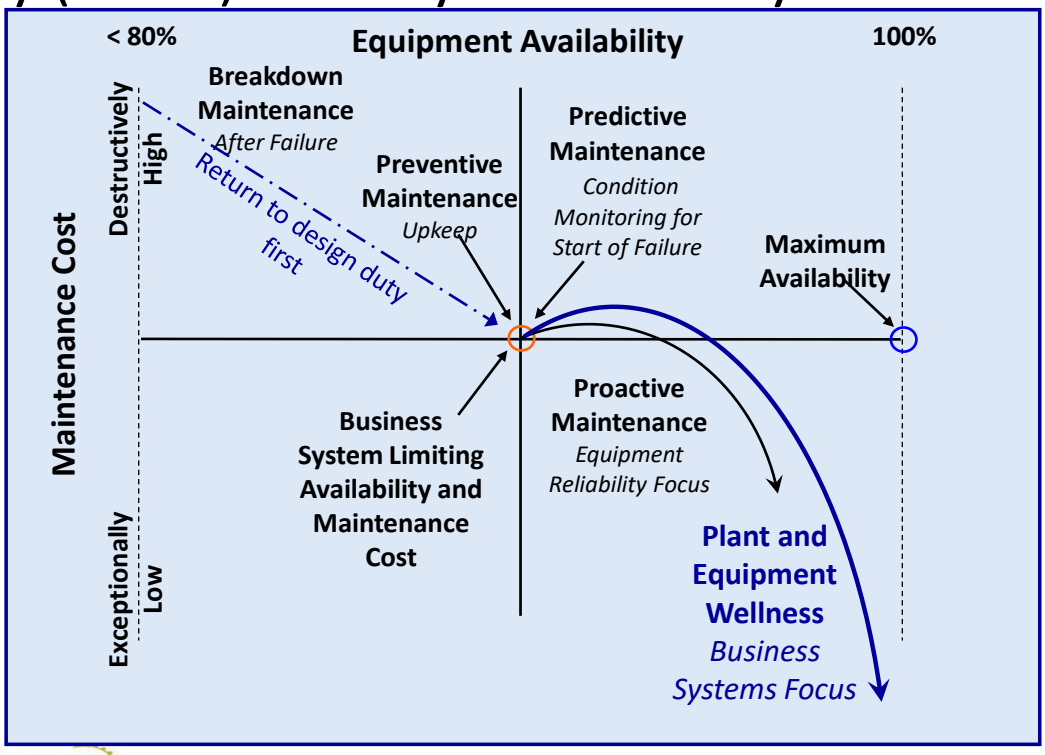

**"Only world class standards can produce world class results."**



# PEW SOLUTION: The Plant and Equipment Wellness Way to Operational Excellence



# PEW SOLUTION: A View of the Plant Wellness Way (PWW) Journey to Reliability Excellence






My best regards to you,

Mike Sondalini
www.plant-wellness-way.com