Why do Machines and Equipment Continue to Fail in Companies?
(and how the Plant Wellness Way lets you build magnificent reliability.)

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
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!

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

Time Dependent Load and Strength Variation

The strength distribution widens and falls over time.

Likelihood of failure is higher in this region.

Equipment replaced here – Few Problems!

Equipment replaced here – Lots of Problems!

Strength

Load

Time/Load Cycles

Log Scale

Estimated Life

Probable Life

Uncertainty

Wear-out Zone

Probable Life

Rate that parts fail

Lifetimes Reliability Solutions

Machine Reliability = Sum of Parts’ Reliability

Failure from Error

Failure from Induced Stress

Failure from Usage

- Defective parts
- Poor quality assembly
- Manufacture error

- Operating overload
- Rapid aging of some parts
- Local environment degradation

- Operator error
- Poor operating practices
- Poor maintenance practices
- Poor design choice

- Too many aging parts
- Many parts degraded

The ‘failure curve’ for a machine has a special name – ROCOF – Rate of Occurrence of Failure.

System Rate of Failing

Component Rates of Failing

Time or Usage Age of System

Time or Usage Age of Parts

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

1,000,000 glasses sold in packs of 12
83,333 households buy a pack of 12
Say average household breaks 2 glasses a year
That is 166,667 glasses broken each year which are then replaced
Chance of breaking a glass during a year is 166,667 ÷ 1,000,000
0.167

Chance of Glass Failure Curve

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

What can cause this glass to break?
• It can be dropped, for example -
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Design Change

Procedure Change

Instructions & Training

‘Opportunity’ for breakage arises regularly
PEW SOLUTION: Reduce the Chance of Failure

*Chance of Failure = 1 – Chance of Success*
*Chance of Failure = 1 – Reliability*

\[
\text{Risk} = \text{Consequence} \times \text{Chance} / \text{yr}
\]

\[
\text{Risk} = \text{Consequence} \times [\text{Freq of Opportunity} / \text{yr} \times \text{Chance of Failure at Each Opportunity}]
\]

\[
\text{Risk} = \text{Consequence} \times [\text{Freq of Opportunity} / \text{yr} \times (1 – \text{Reliability})]
\]

“Equipment reliability is malleable by choice of policy and quality of practice.”

**ERROR INDUCED ZONE**
- Better quality control
- Higher skills training
- Precision assembly
- Precision installation
- No substandard material
- No manufacturing errors
- Robust packaging

**STRESS INDUCED ZONE**
- Condition Monitoring
- Better operator training
- Total Productive Maintenance
- Precision Maintenance
- Better design/application choice
- Stronger material choices
- Machine protection devices
- Operator ITLC
- Deformation Management
- Defect Elimination
- Manage “Acts of God”

**USAGE INDUCED ZONE**
- More parts on renewal PM
- Better material choices
- Considerate operation
- Degradation Management
- Timely maintenance

**ITLC: Inspect, Tighten, Lubricate, Clean**
Acceptable Equipment Failure Domain

\[ \text{Risk} = \text{Consequence} \times [\text{Frequency of Opportunity} \times \text{Chance of Failure at Each Opportunity}] \]

Want ALARP – As Low As Reasonably Practicable

ALARP Triangle

- Intolerable
- Maximum Tolerable Risk
- ALARP
- Broadly Acceptable Risk
- Negligible / Acceptable Risk

RISK MATRIX

- Frequency of Occurrence
- Cost

Lifetime Reliability Solutions

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

PEW is a process to lower operating risks with least necessary engineering, operation and maintenance life cycle mitigations

Inadequate Effort and Focus

Correctly Matched Focus with Least Effort

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

Stress Removal FMEA/RGCA
Business Wide DAFT Costs
ACE 3T Lifetime Risk Reduction

Life Cycle Operating Risk Reduction Strategies

MAINTENANCE
• Planned Preventive Maintenance
• Planned Condition Monitoring
• Planned Reliability Improvements
• Precision Maintenance skills and equipment
• Precision Breakdown Repair
• Standardise best practices

OPERATIONS
• Operate within design envelope
• Precision Operation stress removal
• Operating Performance Monitoring
• Operator ‘listen, look, feel’ monitoring and report problems
• Operator ‘tighten, lubricate, clean’
• Standardise best practices

ENGINEERING
• Specifications for reliability – manufacturing, materials, installation, commissioning
• Select for life-cycle profit maximising
• Design-in reliability, maintainability
• Standardise best practices

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

<table>
<thead>
<tr>
<th>Event Count / Year</th>
<th>Time Scale</th>
<th>Descriptor Scale</th>
<th>Historic Description</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Twice per week</td>
<td>2</td>
<td>Rare</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>30</td>
<td>Once per fortnight</td>
<td>1.5</td>
<td>Unlikely</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Once per month</td>
<td>Certain</td>
<td>Event has occurred several times or in a lifetime career</td>
<td>1</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>Once per quarter</td>
<td>0.5</td>
<td>Possible</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>0.3</td>
<td>Once every 3 years</td>
<td>Likely</td>
<td>Event might occur once in a lifetime career</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>0.1</td>
<td>Once per 10 years</td>
<td>Possible</td>
<td>Event might occur once in a lifetime career</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>0.03</td>
<td>Once per 30 years</td>
<td>Unlikely</td>
<td>Event doesn’t occur anywhere from time to time</td>
<td>-1</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>0.01</td>
<td>Once per 100 years</td>
<td>Rare</td>
<td>Event doesn’t occur anywhere from time to time</td>
<td>-1</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>0.003</td>
<td>Once every 300 years</td>
<td>Very Rare</td>
<td>Never heard of this happening</td>
<td>-3</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>0.001</td>
<td>Once every 1,000 years</td>
<td>Very Rare</td>
<td>Never heard of this happening</td>
<td>-3</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>0.0001</td>
<td>Once every 10,000 years</td>
<td>Very Rare</td>
<td>Theoretically possible, but not expected to occur</td>
<td>-4</td>
<td>1.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Note: Risk Level

- Risk Boundary ‘LOW’ level is set at total of $10,000/year
- 1) Risk Boundary ‘LOW’ level is set at total of $10,000/year
- 2) Based on HB436:2004 Risk Management
- 3) Identified ‘Black Swan’ events as B 1) (A ‘Black Swan’ event is one that people say ‘will not happen’ because it has not yet happened)

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

Effects on Profitability of Reducing Consequence Only

- Fewer profits lost, but ‘firefighting’ is high
- More efficient operations
- Fewer maintenance costs

Effects on Profit of Reducing Chance Only

- Fewer profits lost
- More efficient operations
- Fewer maintenance costs

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

<table>
<thead>
<tr>
<th>Human Element Errors</th>
<th>Error Rate (per task)</th>
<th>Physical Operation</th>
<th>Everyday Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.0001</td>
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<td>0.004</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
</tbody>
</table>


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 mix and you get disaster.

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

Every process throughout the life cycle will create many defects.

**Path to Disaster**

- Defect and Failure Cost Scale
- Operating Plant Uptime and Throughput
- Product

- Higher Unit Cost,
- Poor Quality and
- Delayed Delivery

**Variability in each process causes defects which at times progress to ‘failure’.

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

Your Ideal Operational Excellence Asset Management System

Engineering, Maintenance, and Operational Life Cycle
Quality Processes
Construction, Operations and Maintenance Practices
Defect Elimination Strategy
Operating Risk Reduction
Machine Parts Health

Your Ideal Operational Excellence Asset Management System

Precision Standards
Quality Standards
Precision Skills
Materials of Construction
Environment Stress Reduction
Distortion Degradation Control
ATOMIC STRESS TO BUSINESS PROCESS MODEL

Component Distress (Atomic Structure Failure)

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

Best regards,

Mike Sondalini

Build Plant and Equipment Wellness for World Class Reliability