The Processes and People of Reliability Improvement

BHP Billiton Reliability Forum 2010 Presentation
By
Mike Sondalini
www.lifetime-reliability.com
The Odds are Against Doing it Right!

Only one way to disassemble

40,000+ ways to incorrectly reassemble!
Your machines are components in series

Electric motor drive end bearing
Series arrangements are at high risk

Motor parts shown as a series

“Any one part fails; all fails”

This is why clean lubricant is so important:
It gets between all the parts and becomes a series component many time over!

www.lifetime-reliability.com
Calculating series reliability

Reliability is the **chance** that an item will last long enough to do its duty.

\[
R_{\text{series}} = R_1 \times R_2 \times R_3 \times \ldots R_n
\]

**Example Calculations:**

- **Any poor, all poor**
  
  \[
  R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 = (0.99)^9 = 0.91 \text{ (or 91%)}
  \]

- **Any fails, all fails**
  
  \[
  R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.5 \times 0.99 \times 0.5 \times 0.99 \times 0.99 = 0.23
  \]

  “Any poor, all poor”

  “Any fails, all fails”
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.


<table>
<thead>
<tr>
<th>Error rate (per task)</th>
<th>Read/ reason</th>
<th>Physical operation</th>
<th>Everyday yardstick</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplest possible task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to respond to annunciator</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.00001</td>
</tr>
<tr>
<td>Overfill bath</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to isolate supply (electrical work)</td>
<td>0.0002</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
<tr>
<td>Read single alphanumeric wrongly</td>
<td>0.0003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read 5-letter word with good resolution wrongly</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select wrong switch (with mimic diagram)</td>
<td>0.0005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to notice major cross-roads</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Routine simple task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read a checklist or digital display wrongly</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Set switch (multiposition) wrongly</td>
<td>0.001</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>Calibrate dial by potentiometer wrongly</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Check for wrong indicator in an array</td>
<td>0.003</td>
<td>0.004</td>
<td>0.005</td>
</tr>
<tr>
<td>Wrongly carry out visual inspection for a defined criterion (e.g. leak)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to correctly replace PCB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select wrong switch among similar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complicated non-routine task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fail to notice adverse indicator when reaching for wrong switch or item</td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Fail to recognize incorrect status in roving inspection</td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>New workshift – fail to check hardware, unless specified</td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>General (high stress)</td>
<td></td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td>Fail to notice wrong position of valves</td>
<td></td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Fail to act correctly after 1 min in emergency situation</td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
</tbody>
</table>

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).
Your work processes are a series of tasks

\[
R_{\text{job}} = R_1 \times R_2 \times R_3 \times R_4 \times R_5
\]

\[
R_{\text{series}} = R_1 \times R_2 \times R_3 \ldots
\]

What is the chance that the whole job will done right?
Risks to work quality and machine reliability

Task Reliability is the chance that a task will be performed to its required quality.

\[
R_{\text{job}} = R_1 \times R_2 \times R_3 \times R_4 \times R_5
\]

A five task job.

Complicated non-routine tasks

\[
0.9 \rightarrow 0.9 \rightarrow 0.9 \rightarrow 0.9 \rightarrow 0.9 \rightarrow 0.59
\]

10 tasks 20 tasks 50 tasks
\[
0.35 \quad 0.12 \quad 0.05
\]

Controlling human error is the greatest challenge to reliability
But where do your failures start?

Your problems start with chance variation...

Standard deviation for ‘Feel’ is ±12%, and you need maximum of ±10% for sure fastening.

Fastener Tension

- 35% + 35%

100% Required Torque

- 15% + 15%

± 35% ± 25% ± 15% ± 10% ± 3 - 5% ± 1%

Accuracy

Relative Cost

1 1.5 3 3.5 15 20

Number of Events

Feel – Operator judgement
Torque Wrench
Turn-of-the- Nut
Load Indicating Washer
Fastener Elongation
Strain Gauges

Ajax Fastener Handbook 1999

www.lifetime-reliability.com
What chance variation does to machines

High Vibration:

Deformation:

Misalignment:

Fastener Torque Error:

Unclean Lubricant:

Unbalance:

Extract from 'Shaft Alignment Handbook', Piotrowski
Cause and effect of your equipment failures

Infant Mortality

- Component Failure Rate
- Usage

Infant Mortality

- The ‘failure curve’ for a machine has a special name – ROCOF – Rate of Occurrence of Failure.
- Cause: Incorrect Processes (controlled by management)
  - Defective parts
  - Poor assembly
  - Manufacture error
  - Poor start-up

Random

- Component Failure Rate
- Usage

Random

- Cause: Induced Stress (controlled by people)
  - Operating overload
  - Stress aging of some parts
  - Local environment degradation
  - Operator error
  - Poor operating practices
  - Poor maintenance practices
  - Poor design choice

Wear-out

- Component Failure Rate
- Usage

Wear-out

- Cause: Accumulated Fatigue (controlled by people)
  - Many aging/used parts
  - Many parts degraded

System Rate of Failing

Component Rates of Failing

Time or Usage Age of System

Time or Usage Age of Parts

Mean of Many Systems (machines)

With more parts, ROCOF becomes approximately constant

A Single System (machine)
Most Business make their Machines Break

This is a statistically stable process of breakdown creation – this business makes breakdowns as one of its ‘products’.
Understanding what it means to be ‘in control and capable’

Figure 83: Progression of a Process to Capability
Carpenter’s creed: ‘measure twice, cut once’

Get wood → Measure 1 → Mark wood → Cut wood

R = 0.995

1 error every 200 opportunities
~ 1 / wk

Get wood → Measure 1 → Mark wood → Cut wood

0.995 → 0.995

1 error every 5000 opportunities
~ 1 / 20 wk
The power of parallel proof-tests

\[ R_{\text{system}} = 1 - [(1 - R_1)x(1 - R_2)x(1 - R_3) \ldots] \]
\[ = 1 - [(1 - 0.9)x(1 - 0.99)] \]
\[ = 1 - [0.1 \times 0.01] \]
\[ = 0.999 \]

Original task reliability

Proof-test reliability

Equivalent series reliability
Remove the variability from your business processes – unless you want to run your business by luck!

In the end... reliability is a quality control issue.

The secret is to control variability to within the limits that bring benefits
Right Work = Right Results

Procedures and Training control accuracy of Task Performance. Focus on the content and quality of procedures and training.
Journey to 6 Sigma: Minimize Variability

- Fix the obvious; Do basics well
- Systematize processes; Standardize procedures
- ‘Living’ ISO 9001 QMS
- Total Quality Control (SPC)
- Accuracy Controlled Enterprise (ACE 3T)
- Perfect processes

Sources: David Burns, SIRF Roundtables Ltd, Melbourne, Australia

Errors per 100

1σ 2σ 3σ 4σ 5σ
69 31 7 0.6 0.023
The Processes and World-Class Skills of Precision

1. Accurate Fits and Tolerance – ISO/ANSI Shaft/Hole Tolerance Tables
2. Clean, Contaminant-Free Lubricant – ISO 4406
5. Accurate Alignment of Shafts – Shaft Alignment Handbook
6. High Quality Balancing of Rotating Parts – ISO 1940
10. Only In-specification Parts – OEM specifications, Machinery Handbook
11. Failure Cause Removal – ‘5 Why’; RCFA; Reliability Growth Cause Analysis
12. Proof of Precision – Measurements, Condition Monitoring at Start-up
13. A system to use the standards successfully – ACE 3T Procedures, ISO9001
Set work task standards to deliver the quality that produces the reliability you want
How do we apply it to our machines?

Electric motor drive end bearing

www.lifetime-reliability.com
USS Nimitz - Some keys to their success

Preoccupation with Failure

- Highlight, Analyse & Learn from failures and problems
- There is healthy challenge to constantly improve
- Turnover of people helps stop operations becoming stale
- Seeks deeper understanding of problem causes
- Sensitive to the smallest whisper of things going wrong

Reluctance to Simplify Problems

Deference to Expertise

- Expertise overrides rank. Decision-making pushed down
- When things go wrong, turn to experts to help resolve
- Team communication is far in excess of the norm
Control Your Processes by Converting your SOPs to 3T Accuracy Controlled Procedures

<table>
<thead>
<tr>
<th>Task Step No.</th>
<th>Task Step Owner</th>
<th>Task Step Name</th>
<th>Full Description of Task</th>
<th>Test for Correctness</th>
<th>Tolerance Range</th>
<th>Record Actual Result</th>
<th>Action if Out of Tolerance</th>
<th>Sign-off After Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Max 3 – 4 words)</td>
<td>(Include all tables, diagrams and pictures here)</td>
<td></td>
<td>Good</td>
<td>Better</td>
<td>Best</td>
<td></td>
</tr>
</tbody>
</table>

- Specify the 3Ts (Target, Tolerance, Test) for task precision and accuracy
- Describe in a measurable fashion what ‘good’, ‘better’ and ‘best’ are to challenge people to strive for excellence
- Advise what to do when out of tolerance – i.e. when not ‘it’s good enough’
- Get a signature when 3T done to tolerance so people are committed to precision
- Drive continual improvement by regularly introducing an even more precise ‘best’
Use condition monitoring as the proof test for task quality

CM is used only to extend equipment life to failure

CM is also used to reduce chance of failure

Life Extension Zone

Failure Elimination Zone

practical limit of availability

Operating Cost
Equipment reliability is malleable by choice of policy and quality of practice

- Better quality control
- More training
- Precision assembly
- Precision installation

- Condition Monitoring
- Better operator training
- Total Productive Maintenance
- Precision Maintenance
- Better design/material choices
- Machine protection devices

- More parts on PM
- Better materials
- Considerate operation

When we remove parts’ failure by changing our policies and using better practices, the old ROCOF falls to the new ROCOF.

Old ROCOF

New ROCOF

Remove Causes of Parts’ Failure
High equipment reliability is...

1 - Valuable... more time; more throughput; no losses

2 - Parts based... low stress, low fatigue, low contamination

3 - Malleable... by the risks you allow your parts to carry

4 - Dependent on stopping Variability

5 - Reliant on meeting world-class quality standards

6 - Provable by its precision... Measure; Condition Monitor