Getting High Equipment Reliability

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High Reliability is a choice

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

1 - Reliability is highly profitable

2 - To control reliability you need to understand equipment behaviour down to its parts level

3 - Reliability is improved by eliminating the causes of parts failure

4 - Failure causes are eliminated by controlling the process variability that start the defects which lead to failures

5 - People’s actions are controlled by meeting precision standards selected to eliminate failure causes

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Valuing Reliability

“Time is Money” – *Benjamin Franklin*

**MTBF** - average time between failures

\[
\text{MTBF} = \frac{A + B + C}{3}
\]

Infant Mortality

- Component Failure Rate
- Usage
- Cause: Human Error

Random

- Component Failure Rate
- Usage
- Cause: Stress Induced (by humans)

Wear-out

- Component Failure Rate
- Usage
- Cause: Accumulated Fatigue (controlled by humans)
Unit Cost of Production

Unit Cost of Production ($/T) = \frac{\text{Operating Costs in the Period ($)}}{\text{Total Saleable Throughput (Tonne)}}
Equipment is components in series

Electric motor drive end bearing
High risk in a series arrangement

Parts shown as a series

“One fails, all fails”
Calculating series reliability

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

\[ R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.99 = (0.99)^8 = 0.92 \text{ (or 92%)} \]

\[ R_{\text{series}} = 0.99 \times 0.99 \times 0.99 \times 0.99 \times 0.5 \times 0.99 \times 0.99 = 0.47 \text{ (or 47%)} \]

“One poor, all poor”
When the parts fail, our machines fail

- ROCOF (Rate of Occurrence of Failure in a Machine System)
- Rate of Occurrence of Failure in a Machine System
- Time or Usage Age of System

- z(t) (Rate of Failure of Part)
- Rate of Failure of Part
- Time or Usage Age of Part

- Components: Shaft, Shaft Seal, Lock Nut, Inner Race, Roller bearing, Lock, Outer race, Housing Bore

Diagram showing the failure rates of various parts and their effects on machine systems.
Cause and effect of our equipment failures

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

- Defective parts
- Poor assembly
- Manufacture error
- Poor start-up

- Operating overload
- Aging of some parts
- Local environment degradation
- Operator error
- Poor operating practices
- Poor maintenance practices
- Poor design choice

- Many aging parts
- Many parts degraded

With more parts, ROCOF becomes approximately constant

Mean of Many Systems (machines)

A Single System (machine)

Time or Usage Age of System

Time or Usage Age of Parts

- Defective parts
- Poor assembly
- Manufacture error
- Poor start-up

- Operating overload
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- Local environment degradation
- Operator error
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- Many aging parts
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Equipment reliability is malleable by choice of policy and practice

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

- Do more preventive maintenance
- 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 reduces to the new ROCOF
Equipment Reliability Strategies

Strategies for the Infant Mortality Maintenance Zone

- How to Drive the Chance Curve Down?
- How to Push the Time of the Curve Back?
- How to Pull the Position of the Curve Lower?

Strategies for the Random Failure Maintenance Zone

- PM, PdM, Precision Operation
- How to Drive the Position of the Curve Lower?

Strategies for the Wear-Out Failure Maintenance Zone

- Replace Equipment, Add more components to renewal PM
- How to Lower the Curve Steepness?
- How to Push the Start of the Rising Curve Back?
But where do the failures start?

Variability leads to defects
The Problems start with chance variation

Variation in Torque on a Bolt

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

Accuracy
± 35%  
± 25%  
± 15%  
± 10%  
± 3 - 5%  
± 1%  

Relative Cost
1  
1.5  
3  
3.5  
15  
20  

Ajax Fastener Handbook 1999
Understanding what it means to be ‘in control and capable’

Figure 83: Progression of a Process to Capability
Control variability to beneficial limits

Only accept this range of outcomes because they give very low risk

Value of a Critical Parameter

Number of Events

Very Bad Outcome

Acceptable Outcome

Very Bad Outcome
The best strategy is to reduce the chance of failure in every stage of the life-cycle.

**Risk = Chance x Consequence**

### Chance Reduction Strategies

*remove opportunity for failure to start*

- Engineering and Maintenance Standards
- Standard Operating Procedures
- Failure Mode Effects Criticality Analysis (FMECA)
- Hazard and Operability Study (HAZOP)
- Hazard Identification (HAZID)
- Root Cause Failure Analysis (RCFA)
- Precision Maintenance (shaft alignment, oil particle filtration, deformation prevention, etc)
- Training and Up-skilling
- Quality Management Systems
- Planning and Scheduling
- Continuous Improvement
- Supply Chain Management
- Accuracy Controlled Enterprise (ACE 3T SOPs)
- Design and Operations Cost Totally Optimised Risk (DOCTOR)
- Defect and Failure True Cost (DAFTC)
- De-rate/Oversize Equipment
- Reliability Engineering

### Consequence Reduction Strategies

*reduce the loss after a failure has started*

- Preventive Maintenance
- Corrective Maintenance
- Total Productive Maintenance (TPM)
- Non-Destructive Testing
- Vibration Analysis
- Oil Analysis
- Thermography
- Motor Current Analysis
- Prognostic Analysis
- Emergency Management
- Computerised Maintenance Management System (CMMS)
- Key Performance Indicators (KPI)
- Risk Based Inspection (RBI)
- Operator Watch-keeping
- Value Contribution Mapping (Process step activity based costing)
- Logistics, stores and warehouses
- Maintenance Engineering
Work is a series process of tasks

A Job

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

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

We can say ‘Task Reliability’ is the chance that a task will be performed to its required duty
Playing with task reliability

Task Reliability is the chance that a task will be performed to its required duty. This leads to two realisations...

- You must clearly know the required duty
- Control chance and you control reliability

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

A five task job.

Controlling human error is the greatest challenge to reliability

One fails… all fails!
One poor… all poor!

In a series arrangement we must be exact because there is no redundancy (back-up). In a series work process, the only way to do a 100% reliable job is to make sure every task in it is done 100% reliably.
Getting high task reliability

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

Because all our machines are a series of parts, and all our work are a series of activities, there are endless opportunities for variation – many of which will cause failures. Hence, we must set the correct standards of performance for every step in a series so that we deliver only those results that give us the right outcomes. This is quality. The more precisely we approach the standards; the better the quality; the more certain and reliable the series outcome.
The power of parallel proof-tests

Original task reliability

0.9 0.9 0.9 0.9 0.9 0.59

Proof-test reliability

0.99 0.99 0.99 0.99 0.99 0.95

Equivalent series reliability

0.999 0.999 0.999 0.999 0.999 0.995

\[ R_{\text{system}} = 1 - [(1 - R_1)(1 - R_2)(1 - R_3) \ldots] \]

1 - [(1 - 0.9)(1 - 0.99)]

1 - [0.1 \times 0.01]

1 - [0.001] = 0.999

We can use a parallel arrangement to improve the chance of producing precise results. By adding a proof test into each series task you vastly improve the reliability of the process outcome.
Carpenter’s creed: ‘measure twice, cut once’

The typical error rate in reading a tape measure is five times in every thousand you will misread it, or 995 times out of 1000, it will be right. Without the parallel task, the carpenter will cut the wood in the wrong spot about once every 200 times. It is not hard to imagine a carpenter doing 50 cuts a day. So about once a working week, they would cut the wood wrong and have to throw it away.

With the second test ‘measure’ added, the chance of getting the cut right rises to 99.998% and the error rate falls to twice in every 10,000 times. With 50 cuts a day, they will make an error once every 100 working days, or about once every 20 working weeks. Can you now see the power of paralleling test activities to every task, and ensuring that they are right? For our carpenter the simple addition of a check test produced twenty times fewer mistakes.
Continual learning and mastery of your discipline

Now we all know what ‘good enough is’!
# Convert 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>(Max 3 – 4 words)</td>
<td>(Include all tables, diagrams and pictures here)</td>
<td>Good</td>
<td>Better</td>
<td>Best</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Specify the 3Ts (Target, Tolerance, Test) for precision and accuracy
- Describe in a measurable fashion what ‘good’, ‘better’ and ‘best’ are.
- Make the SOP into a table of successive tasks in a column
- Range tolerance ‘good, better, best’ to challenge people to strive for excellence
- Provide columns for 3Ts and ranges
- 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’
6 Standards to Set, Use and Keep

**Vibration:**

**Deformation:**

**Alignment:**

**Fastener Torque:**

**Lubricant Cleanliness:**

**Balancing:**
Condition monitoring can be used to help you prevent failure

Life Extension Zone

Failure Elimination Zone

CM is used only to extend equipment life to failure

CM is also used to reduce chance of failure
How do we apply it to our machines?

Electric motor drive end bearing

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Getting high equipment reliability...

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

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

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

4 - Depends on stopping Variability in every stage of the life-cycle. *Know thy enemy... It is lack of quality!*

5 - Depends on getting the 6 basics right... find, set and work to world-class standards

6 - Needs Condition Monitor for proof of precision... "good enough never is!" *Tim Goshert, Cargill Reliability and Maintenance Manager*

High Equipment Reliability