Reliability
Meets the necessary condition for LEAN

David J. Auda, CRE, CMQ/OE
Objectives

Presentation

• Raise awareness of the benefits of including Reliability
• Introduce the attendees to simple reliability calculations
• Offer a prescriptive approach to preventing possible problems

Materials

• Offer tools that are useful in improving capability
• Cost avoid issues rather than having to react to them later
Motivation

• Necessary condition must be met
• Cost avoidance
• Greater effectiveness
• Greater efficiency
• Greater availability
• Greater capability
Dynamic

Based on experience, most implementations of LEAN are treated as unique, without inclusion or regard of Quality and Reliability. It is also noted that in many enterprises there is a mistaken assumption that some how Reliability is included in the Q BoK, but Reliability is a separate discipline with it’s own BoK. The enterprise would be better served if Quality and LEAN practitioners were managed by Reliability engineers.
Agenda

- Definitions
- Value Stream – Ideal single piece flow
- Simple Reliability/Availability calculations
- Improvement tools
  - Theory of Constraints
  - Risk Assessment
  - FMEA (Failure Modes and Effects Analysis)
  - RCM (Reliability Centered Maintenance)
  - STPA (Systems Theoretic Process Analysis)
Definitions

LEAN
An operational strategy oriented toward achieving the shortest possible Cycle time by eliminating waste. It is derived from the Toyota Production System and its key thrust is to increase the value-added work by eliminating waste and reducing incidental work.

Quality
Subjective term for which each person has his or her own definition. In technical usage, Quality can have two meanings: 1) the characteristics of a product or service that bear in its ability to satisfy stated or implied needs, and 2) product or service free of deficiencies.

6σ
Methodology that provides businesses with the tools to improve the capability of their business processes by increasing performance and reducing process variation.
Reliability

• The probability that an equipment/process will perform its intended function, without failure, operating under specified conditions, and for a specified period of time

• The ability of an apparatus, machine, (person) or system to consistently perform its intended or required function or mission, on demand and without degradation or failure.

Mission Effectiveness
# Lean / 6σ / Reliability

<table>
<thead>
<tr>
<th>Key elements</th>
<th>LEAN</th>
<th>SIX SIGMA</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental principle</td>
<td>Optimize product flow</td>
<td>Optimize process capability</td>
<td>Optimize mission success</td>
</tr>
<tr>
<td>Primary Emphasis</td>
<td>Time &amp; product (material)</td>
<td>Quality</td>
<td>Overall effectiveness</td>
</tr>
<tr>
<td>Reduction of variation</td>
<td>Time</td>
<td>Product and process attributes</td>
<td>Equipment performance and repair times</td>
</tr>
<tr>
<td>Approach is by:</td>
<td>Product family</td>
<td>Strategic goals</td>
<td>Critical equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Critical missions</td>
</tr>
<tr>
<td>Primary driver is:</td>
<td>Cost reduction</td>
<td>Cost reduction</td>
<td>Cost reduction</td>
</tr>
<tr>
<td>Improvement structure</td>
<td>VSM</td>
<td>DMAIC</td>
<td>FMECA/SPS (Spare Parts Strategy)</td>
</tr>
<tr>
<td>(predominant)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on mission effectiveness</td>
<td>Moderate</td>
<td>Weak</td>
<td>Strong</td>
</tr>
<tr>
<td>Focus on connecting</td>
<td>Weak</td>
<td>Strong</td>
<td>Moderate</td>
</tr>
<tr>
<td>input variables to output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on turns, WIP</td>
<td>Strong</td>
<td>Moderate</td>
<td>Weak</td>
</tr>
</tbody>
</table>
Reliability meets the necessary condition for ideal LEAN implementation

When a LEAN value stream fails, all movement stops, and losses are multiplied, so unless the process, equipment and people are reliable, a true LEAN implementation is not achievable.
Necessary Condition

Must be there for the effect, the charge, to be true. If absent, cannot occur.

i.e.

No oxygen, no combustion
No seeds, no plants to grow
Car runs only if gas in tank

*No reliability, LEAN fails to meet its mission objective(s)*
Sufficient Condition

Whenever A is present, B will follow-

i.e.

Decapitation is sufficient for death.
Getting a B in the course is sufficient for passing.
Infrastructure

Manpower
Machines
Materials
Measures
Methods
Environment

Suppliers
Raw materials

products
Services
Illustration

CD drive
R=0.9

Amplifier
R=0.999

Speakers
R=0.95
\[ R_{3\text{steps}} = 0.854 \]
\[ R_{6\text{steps}} = 0.729 \]
Theory of Constraints

TOC promotes “Systems Thinking”: *global optimization* (not *local optimization*)

A system’s constraint(s) determine its output

The Five Step Focusing Process of TOC

Step 1: Identify the System’s Constraint(s)
Step 2: Decide how to Exploit the System’s Constraints
Step 3: Subordinate Everything Else to that Decision
Step 4: Elevate the System’s Constraints
Step 5: If a Constraint Was Broken in Previous Steps, Go to Step 1

*Dependent Events and Statistical Fluctuations*
Improving Reliability

CD drive \( R = 0.9 \)

Amplifier \( R = 0.999 \)

Speakers \( R = 0.95 \)

Pump #1 \( R = 0.9 \)

Pump #2 \( R = 0.999 \)

Pump #3 \( R = 0.95 \)

\[ R_{sys} = 0.854 \]

\[ R_{sys} = R_1 R_2 R_3 \]

\[ R_{sys} = 0.9999 \]

\[ R_{sys} = 1 - U_1 U_2 U_3 \]

Where \( U = 1 - R \)
Reliability Bathtub Curve

- Early failure period
- Constant failure rate period
- Wear-out failure period
Reliability Bathtub Curve

- **Decreasing Failure Rate**
- **Constant Failure Rate**
- **Increasing Failure Rate**

- **Failure Rate**
  - Early "Infant Mortality" Failure
  - Observed Failure Rate
  - Constant (Random) Failures
  - SW updates
  - Wear Out Failures

- **Time**
Risk Assessment

Requirements/Specifications
Team Staffing
Technology
Program
Manufacturability / Process Infrastructure
External Dependencies and Resources
Quality / Reliability / Legal
Response Times

- Response to stimuli
- Excluded region ≈ 0.150 sec
- Stimulus-Response fn
- Cognitive function

Time scales:
- msecs
- seconds
- minutes
- days
Process FMEAs are not recommended for mature processes.

- New PFMEA for the modified process
  - Previous FMEAs may be inadequate
  - Reviewing historical FMEAs (if done right) can take more time than simply doing a new one.
  - These need to be team a effort with an appropriate team, to capture the relevant practices
  - The new AIAG/VDA approach is not recommended
# PFMEA example

<table>
<thead>
<tr>
<th>Item-Part / Process step</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Potential Cause(s) / Mechanism(s) of Failure</th>
<th>Current Process Controls - Prevention</th>
<th>Current Process Controls - Detection</th>
<th>Dated</th>
<th>Score</th>
<th>RPN</th>
<th>Recommended Action(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Assemble part A to B</td>
<td>R1.1 failure to properly align</td>
<td>M: no discernable effect at this station, not detected until later station resulting in line stoppage</td>
<td>6 6 failed to follow procedure</td>
<td>training, SOP, Work Instructions</td>
<td>operator observation, unrecoverable fault</td>
<td></td>
<td></td>
<td></td>
<td>design and implement a fixture to guarantee proper alignment</td>
</tr>
<tr>
<td>P1.2 Must be torqued to spec</td>
<td>R2.1 under torqued</td>
<td>M: no discernable effect</td>
<td>1 10 pneumatic torque wrench out of calibration</td>
<td>PM schedule, calibration schedule, operational checks of calibration cert at start of shift.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>valid calibration certificate to be recorded at beginning of shift.</td>
</tr>
</tbody>
</table>
PFMEA example

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<td></td>
<td></td>
<td></td>
<td>design and implement a fixture to guarantee proper alignment</td>
</tr>
<tr>
<td>P1.R1 must be properly aligned</td>
<td>R1.1 failure to properly align</td>
<td>P: None</td>
<td>4</td>
<td>pneumatic torque wrench out of calibration</td>
<td>PM schedule, calibration schedule, operational checks of calibration cert at start of shift</td>
<td>valid calibration certificate to be recorded at beginning of shift</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1.R2 Must be torqued to spec</td>
<td>R2.1 under torqued</td>
<td>M: no discernable effect</td>
<td>1</td>
<td>pneumatic torque wrench out of calibration</td>
<td>PM schedule, calibration schedule, operational checks of calibration cert at start of shift</td>
<td>valid calibration certificate to be recorded at beginning of shift</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1.R2 Must be torqued to spec</td>
<td>R2.1 under torqued</td>
<td>P: Part A and Part B will loosen and potential fall apart</td>
<td>10</td>
<td>pneumatic torque wrench out of calibration</td>
<td>PM schedule, calibration schedule, operational checks of calibration cert at start of shift</td>
<td>valid calibration certificate to be recorded at beginning of shift</td>
<td></td>
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</tbody>
</table>
Reliability Centered Maintenance Analysis

Developed by the US Navy and commercial airlines in the 1960s and 70s to improve the reliability of their aircraft. RCM virtually defines the maintenance program for the asset, and defines the spare parts stocking strategy.

Extends beyond the results of a FMEA

- Is the tool of choice for a new/mature process
- Includes the operator(s)
- Features a flexible and relevant ranking criteria
- Combines logistics, diagnosis time and repair times
- Includes spare parts stocking strategy

**RCM will improve the reliability and availability of the assets as well as reduce maintenance costs...and that is significant!**
Overall Equipment Effectiveness

**OEE/TEEP**
Overall Equipment Effectiveness/Total Effective Equipment Productivity

<table>
<thead>
<tr>
<th>Planned losses</th>
<th>Operational losses</th>
<th>Quality loss</th>
<th>Speed loss</th>
<th>Good product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{OEE} = \frac{A}{B} \]
\[ \text{TEEP} = \frac{A}{C} \]

Includes FPY (First Pass Yield)
- Speed losses
- Quality losses
- Unscheduled downtime
- Scheduled downtime

C

B

Scheduled time

A
Failure Patterns

....the changing view of failures

Age related

Random failures
Typical Distribution

Work Type Benchmark

PM = Preventive Maintenance
PdM = Predictive Maintenance
PaM = Proactive Maintenance
Reactive Maintenance

The vicious cycle
Preventive Maintenance Study

- 30% do not add value
- 30% should be replaced by PdM
- 30% would add value if re-written
- 10% add value as written

**Graph:**
- Total # of maintenance tasks
- # of PM tasks
- # of PdM tasks

[Image of graph showing distribution of maintenance tasks]
Preventive Maintenance

Many equipment preventive maintenance schedules are based on the manufacturers recommendations.

- Are typically conservative
  - Preventive Maintenance can be invasive, and create problems
- Have not been updated to reflect the equipment use profile
  - Most capital assets are not being run per design intent
- Many machines have not been installed per the manufacturers requirements
  - No IQ/OQ/PQ
  - No formal accreditation of asset to the manufacturing floor
...it is not possible to produce fault free software

Time →

Failure rate →

Fault avoidance
Fault detection
Fault tolerance

High quality requirements
Configuration control
Robust integration testing
1st shift
Line A – run 200 parts, 60 needed rework...then 60/200 = 0.3 rework rate
Line B – run 100 parts, 29 needed rework...then 29/100 = 0.29 rework rate

2nd shift
Line A – 100 parts... 0.4 rework rate (40 bad)
Line B – 200 parts... 0.39 rework rate (78 bad)

given that we have limited resources....which line do we focus our resources on?

Line A ttl 300 parts, 100 parts reworked...then 100/300 = 0.3
Line B ttl 300 parts, 107 parts reworked...then 107/300 = 0.357
Availability

**Inherent Availability (Ai)**
- The probability that a system or equipment, when used under stated conditions in an ideal support environment, will operate satisfactorily at any point in time as required.
- Excludes preventive or scheduled maintenance actions, logistics delay time and administrative delay time.

**Achieved Availability (Aa)**
- The probability that a system or equipment, when used under stated conditions in an ideal support environment, will operate satisfactorily at any point in time.
- Preventive (scheduled) maintenance is included.
- Excludes logistics delay time and administrative delay time.

**Operational Availability (Ao)**
- The probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon.
- Includes active maintenance time, logistics delay time and administrative delay time.
Availability

Let **Mean Time Between Maintenance Actions (MTBMA)** include preventive and corrective actions.

then

\[ A_0 = \frac{\text{MTBMA}}{\text{MTBMA} + \text{MDT}} \]

Where **MDT = Mean Down Time**
Value Stream Map (VSM) and Reliability Blocks
RCM Flowchart

**Start**

**Will failure be detected while the operator is performing their normal duties?**

- Yes → **Will Failure on Its own affect HSE?**
  - Yes → **Does this Effect HSE?**
    - Yes → **Establish a Failure Finding task**
    - No → **Consider redesign Of the: 1) Equipment or 2) Procedures or 3) Process to Reduce consequences To an acceptable level**
  - No → **Is there a failure finding task that would detect this failure?**
    - Yes → **Will Failure on Its own affect HSE?**
      - Yes → **Does this Effect HSE?**
        - Yes → **Establish a Failure Finding task**
        - No → **Consider redesign Of the: 1) Equipment or 2) Procedures or 3) Process to Reduce consequences To an acceptable level**
      - No → **Is there An on-condition Monitoring task That would detect The failure?**
        - Yes → **Would this Task be applicable and cost Effective?**
          - Yes → **Implement Predictive (on-condition) Maintenance task**
          - No → **No scheduled Maintenance Required, (Consequence Reduction Only)**
        - No → **Redesign of the 1) equipment Or 2) Procedures Or 3) Process is REQUIRED**
    - No → **Is there An on-condition Monitoring task That would detect this failure?**
      - Yes → **Would this Task be applicable and cost Effective?**
        - Yes → **Implement a Preventive Maintenance Task (scheduled Rework or Discard)**
        - No → **Redesign of the 1) equipment Or 2) Procedures Or 3) Process is REQUIRED**
      - No → **No scheduled Maintenance Required, (Consequence Reduction Only)**
  - No → **No scheduled Maintenance Required,**
RCM Flowchart

start

Will failure be detected while the operator is performing their normal duties?

No

Is there a failure finding task that would detect this failure?

No

Does this Effect HSE?

No

Consider redesign of the:
1) Equipment
2) Procedures
3) Process

Establish a Failure Finding task

Yes

Will Failure on Its own affect HSE?

No

Is there an on-condition Monitoring task that would detect the failure?

No

Would this Task be applicable and cost effective?

No

Implement Preventive Maintenance task

Yes

First hint of failure
Clear indication of failure onset

Condition

P – F Curve

Time

catastrophic

Functional failure

Implement Predictive (on-condition) Maintenance task

Implement a Preventive Maintenance Task (scheduled Rework or Discard)

Redesign of the 1) equipment Or 2) Procedures Or 3) Process Is REQUIRED

No scheduled Maintenance Required. (Consequence Reduction Only)

redesign

Implement a Preventive Maintenance Task (scheduled Rework or Discard)

No

No scheduled Maintenance Required. (Consequence Reduction Only)

Implement a Preventive Maintenance Task (scheduled Rework or Discard)

redesign
Is there an early warning that the part may fail?

Is there a known age at which the part fails?

Can a replacement part be acquired before the failure occurs?

Is the part available from the supplier?

Does the downtime cost more than the parts?

Is the part already being carried in inventory?

Do not stock the part.

Find a replacement part or redesign.

Keep the part in inventory.

Spare parts risk analysis

<table>
<thead>
<tr>
<th>Risk</th>
<th>Probability</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>Do not stock</td>
<td>Part</td>
</tr>
</tbody>
</table>
Example

Reliability Centered Maintenance analysis
LASAG (Laser) weld operation

Process description:

The weld operation is operator assisted, loading, firing and unloading. The operation is designed to accomplish high integrity weld, free from defect and contamination. Existing FPY and OEE are considered and best case scenario is used to establish goal.

<table>
<thead>
<tr>
<th>Probability of failure</th>
<th>Consequence of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H  F &lt; 30 days</td>
<td>H  W &gt; 2 hrs</td>
</tr>
<tr>
<td>M  30 days ≤ F ≤ 90 days</td>
<td>M  .25 hrs ≤ W ≤ 2 hrs</td>
</tr>
<tr>
<td>L  F &gt; 90 days</td>
<td>L  W &lt; .25 hrs</td>
</tr>
</tbody>
</table>

$ > 300
$ 100 - 300
$ < 100
Example

Reliability Centered Maintenance analysis

GT (Generator-Turbine) 9F

Process description:

The GT operation is operator assisted; starting, unburdened full speed, loading, shutdown and standby must be predictable and reliable. The operation is designed to accomplish high output, free from assists, interventions and/or rescues. Similar equipment starting and OEE/TEEP are taken as baseline.

<table>
<thead>
<tr>
<th>Probability of failure</th>
<th>Consequence of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>H  F &lt; 1 in 500 st/m</td>
<td>H  W &gt; 2 hrs   $ &gt; 3000</td>
</tr>
<tr>
<td>M  500 st/m ≤ F ≤ 1000 st/m</td>
<td>M  .25 hrs ≤ W ≤ 2 hrs   $ 1000 - 3000</td>
</tr>
<tr>
<td>L  F &gt; 1000 st/m</td>
<td>L  W &lt; .25 hrs   $ &lt; 1000</td>
</tr>
</tbody>
</table>
## Typical RCM Chart

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>P</th>
<th>failure effect</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downtime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ parts cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTR</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Definitions

RCM – Reliability Centered Maintenance
TOC – Theory Of Constraints
IQ/OQ/PQ – Installation, Operation and Performance qualification
TTR - Time To Repair
PdM – Predictive Maintenance
PaM – Proactive Maintenance
PM – Preventive Maintenance
S-R – Stimulus Response
Moubray, John. Reliability-Centered Maintenance. 2nd ed. Industrial Press, Inc. 448pp
References


Conclusion

Raised awareness of the benefits of Reliability
Covered some simple Reliability calculations
Offered a systematic tool to make improvements (RCM)
Overviewed the cost avoidance approach over the reactive

Postscript: Reliability engineer on the organization chart is a step in the direction of establishing Reliability as a core competency in the organization.
Questions?