Solving Manufacturing Problems

1. 8D Problem Solving Methodology
2. Containment
3. Defect Characterization
4. Failure Analysis
5. Defect Characterization Case Study
6. Root Cause Analysis Methodology
7. Prioritizing Corrective Actions
8. Validate that Corrective Actions Prevent Problem Recurrence
9. Leverage Countermeasures to Similar Products and/or Processes
10. Root Cause Analysis Case Study
11. References
12. Internet Resources
Problem Solving Approach – 8D

- The Ford Motor Company developed the 8D (8 Disciplines) Problem Solving Process

- Ford created the 8D Process to help teams deal with quality control and safety issues; develop customized, permanent solutions to problems; and prevent problems from recurring

- First published it in their 1987 manual, *Team Oriented Problem Solving (TOPS)*

- In the mid-90s, Ford added an additional discipline, D0: Plan

- The process is now Ford's global standard, and is called Global 8D

- Although the 8D Process was initially applied in the manufacturing, engineering, and aerospace industries, it is useful and relevant in any industry.
8D Problem Solving Methodology

Eight Disciplines (8D) of problem solving:

- D0 Plan for Solving the Problem
- D1 Establish Team
- D2 Define Problem and Scope
- D3 Implement and Verify Containment
- D4 Perform Root Cause Analysis
- D5 Implement Corrective Actions
- D6 Validate Corrective Actions
- D7 Leverage Corrective Actions to Similar Products/Processes
- D8 Congratulate the Team
8D Flow Chart

**D0:** Recognize that a Problem Exists

**D1:** Establish the Investigating Team

**D2:** Define Problem and Scope

**D3:** Contain the Problem – Identify All Goods Which are Affected and Freeze the SKUs

**D4:** Perform Root Cause Analysis

**D5:** Implement Corrective Actions

**D6:** Validate that Corrective Actions Prevent Problem Recurrence

**D7:** Leverage Corrective Actions to Similar Products and/or Processes

**D8:** Congratulate the Team
Root Cause Analysis
Root Cause Analysis Techniques

- Change Analysis
- Fishbone Diagram
- 5-Whys
- Apollo
- Kepner-Tregoe
- Fault Tree Analysis
- TapRooT
Fastest Root Cause Analysis Tool

Root Cause Analysis

- A powerful technique for increasing equipment reliability is to understand the failure modes of your critical equipment through Root Cause Analysis (RCA)

- Root Cause Analysis is like a crime scene investigation

- It consists of asking the right questions and performing the right analyses to drill down to the root cause of component failure

- Once the root cause has been isolated a countermeasure can be implemented which could include one or more of the following.

  1) Modification of component operating parameters
  2) Installation of component monitoring sensors & alarms
  3) Modification of equipment operation check sheets
  4) Installation of component shielding
Root Cause Analysis

5) Installation of component overload protection
6) Change in component materials
7) Change in component design
8) Change in assembly, installation and/or start-up procedures
9) Relocation of component to another area of the plant
10) Installation of component contamination protection
11) Modification of PM strategy to include periodic fluid analysis, vibration analysis, thermal imaging, etc

• Root Cause Analysis should be conducted on any component failure which violates your plant’s established Asset Reliability Criteria

• As in a crime scene investigation, it is important to gather as much process data leading up to the component failure as possible

• It is also important to “freeze the crime scene” to facilitate autopsy of the failed component
Root Cause Analysis

• The most critical step of Root Cause Analysis is **Defect Characterization / Failure Analysis**

• If this step is not properly executed your team will be chasing butterflies in the night
Defect Characterization

• You cannot defeat your enemy until you intimately know your enemy
• Otherwise you don’t know what you are fighting and your Root Cause Analysis will be led down the wrong garden path
• Defect characterization allows you to gain this knowledge *systematically*
• Characterization describes and quantifies the size, shape, depth, location, color, frequency of occurrence, etc of the defect in order to point to the cause of the defect
• This extends to the microscopic level including chemical identification of foreign matter
• Let us consider the case of a metal part subassembly to understand the defect characterization process
GA4963 Scratch Defect
The morning production meeting at ABC Molding has just begun. The safety review and customer satisfaction review have been completed without issue. John Givens, the day shift production supervisor, now mentions a scratch defect that is occurring on the front face of the GA4963 gear assembly currently in production. The GA4963 gear assembly is a unique assembly manufactured for Precision Motor Co. Most gear assemblies have a plastic housing but the GA4963 housing is made of polished 316 stainless steel. Precision Motor uses this gear assembly within their premier product line and exterior scratches are unacceptable. John mentions some possible areas where the scratch could be coming from but indicates that his crew has not yet found the source of the scratch. Joe Spaulding, the 20 ton stamping press operator, volunteered that it could be the press since the defect is repeating in the same location. Henry James, the warehouse manager, countered this idea by mentioning that he thought he saw scratches on the 316 SS sheet stock. Soon, other members of the production meeting are providing their ideas on possible sources of the scratches.

Frank Anderson, the production superintendent, who is typically a soft-spoken man unless he is speaking about his beloved Tennessee Titans, capitalizes on a lull in the discussion to intervene “You all are talking about this defect as if it were a phantom, with phantom causes. But I don’t see that an example part with this defect has been brought into this room and I don’t see that a Defect Characterization Form has been completed for this issue. Let’s grab a few parts from the production line and characterize this defect together.”
# Defect Characterization Case Study

## Defect Characterization Form

*Instructions*: Use this template to visually characterize a part defect which is representative of a defect spike condition.

<table>
<thead>
<tr>
<th>Plant Name:</th>
<th>Hartford</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department Name:</td>
<td>Bldg 10 Fabrication</td>
</tr>
<tr>
<td>Product Type:</td>
<td>Gear Assembly</td>
</tr>
<tr>
<td>Model No.:</td>
<td>GA4963</td>
</tr>
<tr>
<td>Lot No.:</td>
<td>CT1010B09A</td>
</tr>
<tr>
<td>Defect Type:</td>
<td>Scratch</td>
</tr>
<tr>
<td>Date Characterized:</td>
<td>Feb 9</td>
</tr>
<tr>
<td>Characterized by:</td>
<td>John Givens</td>
</tr>
<tr>
<td>Approx Defect Rate (%):</td>
<td>27%</td>
</tr>
<tr>
<td>Date/Time First Detected:</td>
<td>Feb 9 06:45</td>
</tr>
</tbody>
</table>

*Draw part showing defect location*
Defect Characterization Case Study

**Defect Location**

- $x$: 39 mm from Thru hole A
- $y$: 120 mm from Thru hole A

**Defect Description**

- **Length**: 18 mm
- **Width**: 10 mm
- **Depth**: 120 microns
- **Color**: Orange at bottom of scratch
- **Comments**: Orange/Brown particles at bottom of scratch

- ✓ Repeating defect
- ✓ Sharp, well-defined edges
- ✓ Single defect
- ✓ Clustered defect
- ✓ Raised area
- ✓ Evidence of contamination

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**Form No.:** PRD0247  **Revision No.:** 0  **Date of Revision:** Oct 23  **Reason for Revision:** New
Defect Characterization Case Study

The drawing was not a work of art. It didn’t need to be. It merely needed to serve as a communication tool. Drawings, sketches, diagrams are the universal language. As the defect characterization form was projected on the screen Tim Westlake, the maintenance manager, commented “Wait a minute … I have seen that hexagonal pattern before. It looks like the base metal on the gripper pads on the pick and place. We had to replace the air cylinder last week.”

As it turned out, the air cylinder pressure on the pick and place was set too high causing the rubber gripper pads to wear out exposing the bare case-hardened steel base. This was the source of the scratches. This simple example demonstrates the importance of characterizing defects to identify root causes. If, for example, the hexagonal pattern of the gripper base was not known, analysis of the particulates at the bottom of the scratches might have pointed to the deteriorating rubber gripper pads. Today, we have a multitude of instrument analysis techniques available which can be used to characterize both inorganic and organic contaminants.
Root Cause Analysis

- The size of the RCA Team depends on the scope of the failure incident.
- If it is a simple component failure with limited scope the RCA team could consist of just one person.
- If personnel safety or the environment were compromised, or there was significant economic impact from the failure incident the RCA team would consist of representatives from key departments.
- The *Root Cause Analysis Template* on the next slide includes a collection of typical questions to ask with implications to root cause and ultimately, your PM strategy.
- The relevant questions depend on the type of component which has failed and the failure mode, thus, blanks have been added for your team to add more specific RCA questions.
Root Cause Analysis - Template

Plant:
Component Code/Descr:

Component Location:
Failure Mode:
Date of Failure:

Instructions:
Compile as much process information leading up to the component failure as possible. Assemble a small team of operating and maintenance personnel who are intimately familiar with the operation of the component in question. Include personnel that were on shift at the time of the failure. Ask the following questions in order to direct the failure analysis to the root cause.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Don't Know</th>
<th>Root Cause Analysis Question</th>
<th>Root Cause Implication</th>
<th>PM Strategy Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Was the failure preceded by a process interruption?</td>
<td>Investigate details of process interruption</td>
<td>Modify startup procedure &amp; checklist</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 Was the failure preceded by a process spike (eg temperature, pressure, flow rate, concentration, etc)?</td>
<td>Investigate details of process spike</td>
<td>Consider additional process controls and/or alarms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 Did the component fail during the time frame of another component failure?</td>
<td>Investigate which failure has occurred first</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 Was the component operated outside of process specifications?</td>
<td>Investigate reason for non-standard operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 Was there a change in utilities (air, steam, water, electricity, etc) prior to component failure?</td>
<td>Investigate details of utility change</td>
<td>Consider additional utility controls and/or alarms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6 Was there a dramatic change in the ambient environment (eg temp fell below freezing, thunderstorm, high humidity, high temp) prior to component failure?</td>
<td>Investigate details of ambient environment change</td>
<td>Consider insulating component from ambient environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7 Is the component brand new?</td>
<td>Infant mortality, warranty claim</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 Has this same component failed in the last 6 months?</td>
<td>Component under-specified, start-up, shut-down and/or operation procedure inappropriate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9 Was the component recently rebuilt?</td>
<td>Rebuild procedure, install procedure</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 Did the component fail suddenly?</td>
<td>Fatigue failure, contamination, thermal overload</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>11 Did the component performance degrade over time?</td>
<td>Dirt accumulation, component deterioration, lubrication failure</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12 Is the component performance requirement at or above its design limit?</td>
<td>Component under-specified</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13 Did the component exhibit any external signs prior to failure (eg vibration, temperature build-up, leaking, noise, odor, etc)?</td>
<td>Use external sign to focus root cause detection during autopsy</td>
<td></td>
</tr>
</tbody>
</table>
# Root Cause Analysis - Template

**Plant:**

**Component Code/Descr:**

**Component Location:**

**Failure Mode:**

**Date of Failure:**

**Instructions:**
Compile as much process information leading up to the component failure as possible. Assemble a small team of operating and maintenance personnel who are intimately familiar with the operation of the component in question. Include personnel that were on shift at the time of the failure. Ask the following questions in order to direct the failure analysis to the root cause.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Don't Know</th>
<th>#</th>
<th>Root Cause Analysis Question</th>
<th>Root Cause Implication</th>
<th>PM Strategy Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>Is there evidence of external damage to component?</td>
<td>Component may have been accidentally damaged</td>
<td>Consider installing protective shielding</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>Does autopsy indicate component corrosion as failure mode?</td>
<td>Material selection inappropriate for process fluid</td>
<td>Increase frequency of wall thickness &amp; corrosion check</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>Does autopsy indicate incorrect assembly or missing parts?</td>
<td>Warranty claim or inadequate rebuild/install procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td>Does autopsy indicate excessive wear for the service time of the component?</td>
<td>Material selection inappropriate, lubrication insufficient</td>
<td>Consider adding periodic lubricant analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>Does autopsy indicate external particulate contamination?</td>
<td>Component requires particulate contamination protection</td>
<td>Consider installing protective shielding and/or filtration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19</td>
<td>Does autopsy indicate presence of foreign liquid?</td>
<td>Identify source of foreign liquid and eliminate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>Does autopsy indicate seal failure?</td>
<td>Seal material/design, seal fluid system</td>
<td>Add seal fluid check to Operator Round Sheets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>21</td>
<td>Does autopsy indicate electrical system failure?</td>
<td>Identify failed component and potential sources of failure</td>
<td>Consider adding electric power supply controls-conditioning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22</td>
<td>Does autopsy indicate loose electrical connections or shielding failure?</td>
<td>Connector and/or shielding design and thickness</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23</td>
<td>Does autopsy indicate wear parts have fallen below their acceptable tolerance?</td>
<td>Material selection inappropriate or component under-specified</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td>Does autopsy indicate damaged internal parts?</td>
<td>Identify source of internal damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>Does autopsy indicate jammed or slow-moving internal parts?</td>
<td>Identify source of internal friction or jam</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>26</td>
<td>Does autopsy indicate nothing wrong?</td>
<td>Intermittent failure - conduct bench top stress tests</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Root Cause Analysis

• The root cause analysis should be drilled down to the level at which a countermeasure can be effectively implemented to prevent reoccurrence of the failure

• In certain circumstances it may be beneficial to involve the OEM component manufacturer and/or an outside failure analysis laboratory in the root cause analysis

• The Apollo™ method of Root Cause Analysis is an effective way to drill down to the root cause of failures

Apollo Root Cause Analysis
Training, Consulting, and Software
Apollo Root Cause Analysis

**Root Cause Analysis** – Any structured process used to understand the causes of past events for the purpose of preventing recurrence

**An effective root cause analysis must:**

1. Define the Problem
   a. Include the significance or consequence to the stakeholders

2. Define the causal relationships that combined to cause the defined problem
   a. Provide a graphical representation of the causal relationships
   b. Define how the causes are interrelated
   c. Provide evidence to support each cause

3. Describe how the solutions will prevent recurrence of the defined problem

4. Provide a report that clearly presents all of the above

5. Link to a corrective action tracking system to ensure that solutions are validated for effectiveness
Problem Solving Phases:

1. Define the Problem
   a. What is the problem?
   b. When did it happen?
   c. Where did it happen?
   d. What is the significance of the problem?

2. Create Reality Chart

3. Identify Effective Solutions

4. Implement the Best Solutions
Apollo Root Cause Analysis

Principles of Creating a Reality Chart:

1. For each primary effect, ask “why”
2. Look for causes in actions and conditions
3. Connect all causes with “Caused By”
4. Support all causes with evidence
5. End each cause path with a “?” or a reason for stopping

<table>
<thead>
<tr>
<th>Primary Effect</th>
<th>Conditional Cause</th>
<th>Evidence</th>
<th>Action Cause</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire</td>
<td>Flammable Liquid</td>
<td>Security Guard noticed strong odor</td>
<td>Oxygen</td>
<td>Present in air</td>
</tr>
<tr>
<td>Ignition Source</td>
<td>Truck drove into area to investigate</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Center for Chemical Process Safety

_process safety beacon_, September 2009
Problem Statement:
High thrust-bearing temperature on an 800 Hp river water pump motor

Proposed Solutions
Cool another way:
(8) Use air cooling
(3) Use different water source

Proposed Solutions
Keep debris out of water:
(1) Use traveling water screens
(2) Use separator
(3) Use different water source

Proposed Solutions
Remove need for pressure reduction:
(4) Increase cooling coil design pressure
(5) Redesign piping to act as separator and pressure reducer
(6) Schedule periodic Y-strainer cleaning
(7) Find a low-pressure water source
Prioritizing Solution Alternatives

PICK Chart

Low pressure, alternate water source to cool thrust bearing is most effective solution

1 Developed by Lockheed Martin
Root Cause Analysis Case Study

The Failure of Pump CP4826
Root Cause Analysis Case Study

The Story

Background

Pump CP4826 is a 25 Hp centrifugal pump used in the Waste Water Treatment Plant (WWTP) to recirculate the contents of the primary digestion tank T3759. CP4826 recirculates the process fluid through eductor nozzles at the bottom of tank T3759 to promote aeration of the tank and to prevent solids settling. It is considered a critical component since extended periods of time without tank recirculation will cause not only tank fouling with solids but more importantly, oxygen-deficient stratification layers within the tank causing depletion of the aerobic bacteria necessary for the digestion process.

The mechanical seal on pump CP4826 has been a constant headache for the maintenance department. The seal has failed three times in the last 12 months and had just been replaced 30 days ago. This chronic seal failure has prompted the Maintenance Manager, Jim Phillips to proclaim “those darn John Crane seals are no good ... I’ve always had better luck with Chesterton seals!” The seal fluid, as recommended by the manufacturer, is a 50/50 mixture of propylene glycol and water.

Incident Description

On Tuesday morning, at 5:15 am, Kevin Walters, the WWTP Operator, was just completing his hourly rounds and had returned to the WWTP control room. Kevin noticed a critical alarm on the alarm management screen of his DCS monitor. A high pressure indication was being registered by pump CP4826 within the tandem seal buffer cavity. Kevin went out to physically inspect the pump and when he arrived at the pump location he described the scene as such “there was seal fluid everywhere, and the pump was making a high pitch squeal like metal grinding on metal!” Kevin immediately shut down the pump and alerted his supervisor.
Root Cause Analysis Case Study

Incident Investigation

Since this was the fourth seal failure for this pump, Dave Sutherland, the Operations Manager formed a Root Cause Analysis Team to investigate this most recent failure. It was found that the damage was more severe than the last three failures. The main bearing of the pump had seized causing scoring to the drive shaft. This accounted for the “high pitch squeal” which Kevin reported. Kevin has not been with the company long (only three months) but he is recognized as a conscientious worker. Kevin was interviewed the same morning of the incident and he mentioned that the temperature in the pump house was unusually cold during his shift. A cold front had moved in during the night reducing temperatures below freezing. This is a rare occurrence for the plant’s geographical location. Kevin said there were no process upsets which occurred during his shift except an electrical power outage which happened at 2:00 am for less than 30 seconds. This is a common occurrence at the plant since it is supplied from a residential power grid. Kevin mentioned that he thought the pump was making more noise and vibrating more than usual on his hourly rounds but it was difficult to tell because the pump room is so noisy. He also mentioned that he thought he noticed that the pump housing was warm to the touch but he did not have a thermometer to measure it.

The failed mechanical seal was sent to John Crane Industries who performed an autopsy. They responded in their failure analysis report that the seal had an unusual oval wear pattern indicative of eccentric loading on the seal. The report did not elaborate further on possible causes of eccentric loading.

The failed bearing was sent to SKF Bearings for failure analysis. They found debris within the bearing from the bearing material itself. The bearing material was sent to their metallurgical laboratory which concluded that the bearing material had failed due to fatigue. Fatigue failure could be caused by a combination of high temperature and high vibration brought on by misalignment of drive and pump shafts.

The maintenance mechanic, David Williams, who typically works on pump CP4826 was interviewed. He reported that he had to replace the motor last year because it had burnt out. When asked how he aligned the motor drive and pump shaft he responded that he doesn’t have any tools to align shafts. He does the best he can to line up the shafts by eye and by feel.
## Root Cause Analysis Questions

### Plant: Baton Rouge  
**Component Code/Descr:** CP4826 Centrifugal Pump 25 Hp  
**Component Location:** WWTP Pump House  
**Failure Mode:** Seal Failure/Bearing Failure  
**Date of Failure:** 1/12/10 5:15 AM

### Instructions:
Compile as much process information leading up to the component failure as possible. Assemble a small team of operating and maintenance personnel who are intimately familiar with the operation of the component in question. Include personnel that were on shift at the time of the failure. Ask the following questions in order to direct the failure analysis to the root cause.

### Root Cause Analysis Questions

<table>
<thead>
<tr>
<th>#</th>
<th>Root Cause Analysis Question</th>
<th>Comments</th>
<th>Root Cause Implication</th>
<th>PM Strategy Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Was the failure preceded by a process interruption?</td>
<td>Not really - but there was an electrical outage at 2:00 am</td>
<td>Investigate details of process interruption</td>
<td>Modify startup procedure &amp; checklist</td>
</tr>
<tr>
<td>2</td>
<td>Was the failure preceded by a process spike (eg temperature, pressure, flow rate, concentration, etc)?</td>
<td></td>
<td>Investigate details of process spike</td>
<td>Consider additional process controls and/or alarms</td>
</tr>
<tr>
<td>3</td>
<td>Did the component fail during the time frame of another component failure?</td>
<td></td>
<td>Investigate which failure has occurred first</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Was the component operated outside of process specifications?</td>
<td></td>
<td>Investigate reason for non-standard operation</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Was there a change in utilities (air, steam, water, electricity, etc) prior to component failure?</td>
<td>Yes - temperature in the pump house fell below freezing during the night</td>
<td>Investigate details of utility change</td>
<td>Consider additional utility controls and/or alarms</td>
</tr>
<tr>
<td>6</td>
<td>Was there a dramatic change in the ambient environment (eg temp fell below freezing, thunderstorm, high humidity, high temp) prior to component failure?</td>
<td>Yes - temperature in the pump house fell below freezing during the night</td>
<td>Investigate details of ambient environment change</td>
<td>Consider insulating component from ambient environment</td>
</tr>
<tr>
<td>7</td>
<td>Is the component brand new?</td>
<td></td>
<td>Infant mortality, warranty claim</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Has this same component failed in the last 6 months?</td>
<td>Yes - CP4826 pump seal has failed 3 times in the last 12 months</td>
<td>Component under-specified, start-up, shut-down and/or operation procedure inappropriate</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Was the component recently rebuilt?</td>
<td>Seal was replaced 12/14/09</td>
<td>Rebuild procedure, install procedure</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td>10</td>
<td>Did the component fail suddenly?</td>
<td>Seal should last longer than 30 days</td>
<td>Fatigue failure, contamination, thermal overload</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td>11</td>
<td>Did the component performance degrade over time?</td>
<td></td>
<td>Dirt accumulation, component deterioration, lubrication failure</td>
<td>Depends on autopsy</td>
</tr>
<tr>
<td>12</td>
<td>Is the component performance requirement at or above its design limit?</td>
<td></td>
<td>Component under-specified</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Did the component exhibit any external signs prior to failure (eg vibration, temperature build-up, leaking, noise, odor, etc)?</td>
<td>Pump seemed to be more noisy and vibrating more than usual during hourly rounds</td>
<td>Use external sign to focus root cause detection during autopsy</td>
<td></td>
</tr>
</tbody>
</table>
# Root Cause Analysis Questions

**Plant:** Baton Rouge  
**Component Location:** WWTP Pump House  
**Component Code/Descr:** CP4826 Centrifugal Pump 25 Hp  
**Failure Mode:** Seal Failure/Bearing Failure  
**Date of Failure:** 1/12/10 5:15 AM  

## Instructions:
Compile as much process information leading up to the component failure as possible. Assemble a small team of operating and maintenance personnel who are intimately familiar with the operation of the component in question. Include personnel that were on shift at the time of the failure. Ask the following questions in order to direct the failure analysis to the root cause.

<table>
<thead>
<tr>
<th>#</th>
<th>Root Cause Analysis Question</th>
<th>Comments</th>
<th>Root Cause Implication</th>
<th>PM Strategy Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☒</td>
<td>14</td>
<td>Is there evidence of external damage to component?</td>
<td>Component may have been accidentally damaged</td>
</tr>
<tr>
<td>☐</td>
<td>☒</td>
<td>15</td>
<td>Does autopsy indicate component corrosion as failure mode?</td>
<td>Material selection inappropriate for process fluid</td>
</tr>
<tr>
<td>☐</td>
<td>☒</td>
<td>16</td>
<td>Does autopsy indicate incorrect assembly or missing parts?</td>
<td>Warranty claim or inadequate rebuild/install procedure</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>17</td>
<td>Does autopsy indicate excessive wear for the service time of the component?</td>
<td>Seal had oval wear pattern. Bearing was totally seized. Material selection inappropriate, lubrication insufficient</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>18</td>
<td>Does autopsy indicate external particulate contamination?</td>
<td>Bearing has debris inside from the bearing material itself. Component requires particulate contamination protection</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>19</td>
<td>Does autopsy indicate presence of foreign liquid?</td>
<td>Identify source of foreign liquid and eliminate</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>20</td>
<td>Does autopsy indicate seal failure?</td>
<td>Primary seal has failed Seal material/design, seal fluid system</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>21</td>
<td>Does autopsy indicate electrical system failure?</td>
<td>Identify failed component and potential sources of failure</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>22</td>
<td>Does autopsy indicate loose electrical connections or shielding failure?</td>
<td>Connector and/or shielding design and thickness</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>23</td>
<td>Does autopsy indicate wear parts have fallen below their acceptable tolerance?</td>
<td>Unable to tell because bearing and seal have been badly torn up Material selection inappropriate or component under-specified</td>
</tr>
<tr>
<td>☒</td>
<td>☐</td>
<td>24</td>
<td>Does autopsy indicate damaged internal parts?</td>
<td>Main pump bearing has seized causing scoring to the drive shaft. Metallurgical report from SKF indicates that bearing has fatigue failure which could be caused by high temperature and high vibration conditions</td>
</tr>
</tbody>
</table>
Root Cause Analysis Questions

**Plant:** Baton Rouge  
**Component Code/Descr:** CP4826 Centrifugal Pump 25 Hp  
**Component Location:** WWTP Pump House  
**Failure Mode:** Seal Failure/Bearing Failure  
**Date of Failure:** 1/12/10 5:15 AM

**Instructions:**
Compile as much process information leading up to the component failure as possible. Assemble a small team of operating and maintenance personnel who are intimately familiar with the operation of the component in question. Include personnel that were on shift at the time of the failure. Ask the following questions in order to direct the failure analysis to the root cause.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Don't Know</th>
<th>#</th>
<th>Root Cause Analysis Question</th>
<th>Comments</th>
<th>Root Cause Implication</th>
<th>PM Strategy Implication</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td></td>
<td>25</td>
<td>Does autopsy indicate jammed or slow-moving internal parts?</td>
<td>Bearing has debris inside which could have jammed balls</td>
<td>Identify source of internal friction or jam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td></td>
<td>26</td>
<td>Does autopsy indicate nothing wrong?</td>
<td></td>
<td>Intermittent failure - conduct bench top stress tests</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td>27</td>
<td>When was last time drive motor or pump were replaced on CP4826?</td>
<td>Drive motor was replaced in Dec 2008 since it had burnt out</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
<td></td>
<td>28</td>
<td>Were any alignment tools used during motor installation to ensure that the drive shaft and pump shaft were in alignment?</td>
<td>There are no tools available. There is no procedure for drive/pump shaft alignment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Are there any other Root Cause Analysis Questions?**

**Next Steps:**

- **Create Reality Chart**
- **Add Proposed Solutions**
- **Rank Solution Alternatives using PICK Chart**
Problem Statement:
Centrifugal Pump CP4826 had to be shut down due to loss of seal fluid.
**Problem Statement:**
Centrifugal Pump CP4826 had to be shut down due to loss of seal fluid

---

**Proposed Solutions**
Eliminate mechanical seal:
1. Use magnetic drive pump

---

**Proposed Solutions**
Align drive and pump shafts:
1. Purchase laser alignment kit
2. Write alignment SOP
3. Train maintenance personnel
4. Subcontract alignment outside

---

**Proposed Solutions**
Provide WWTP Operator with predictive maintenance tools:
5. Infrared thermometer
6. Vibration analyzer
Rank Solution Alternatives using PICK Chart

Solutions 1, 2 & 3 or 4 are best alternatives
RealityCharting® is a powerful, user-friendly software solution created to help people better understand their problems and identify effective solutions that prevent recurrence.

Whether you are a professional incident investigator, facilitator or just one of many interested parties, RealityCharting® will help you understand and document your problem better than you ever have before.
### Incident Time Line

**Plant:** Baton Rouge  
**Component Code/Descr:** CP4826 Centrifugal Pump 25 Hp  
**Component Location:** WWTP Pump House  
**Failure Mode:** Seal Failure/Bearing Failure  
**Date of Failure:** 1/12/10 5:15 AM

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/12/10 12:00 AM</td>
<td>Round Check OK</td>
</tr>
<tr>
<td>1/12/10 1:00 AM</td>
<td>Round Check OK</td>
</tr>
<tr>
<td>1/12/10 2:00 AM</td>
<td>Plant-wide power outage for approx. 30 seconds.</td>
</tr>
<tr>
<td>1/12/10 3:00 AM</td>
<td>Round Check OK, Recovery from power outage OK.</td>
</tr>
<tr>
<td>1/12/10 4:00 AM</td>
<td>Round Check OK, CP4826 running rough (noisy and warm to touch).</td>
</tr>
<tr>
<td>1/12/10 5:00 AM</td>
<td>Round Check OK</td>
</tr>
<tr>
<td>1/12/10 5:15 AM</td>
<td>Low pressure alarm for CP4826 seal on DCS panel.</td>
</tr>
<tr>
<td>1/12/10 5:17 AM</td>
<td>K. Walters inspected CP4826 condition.</td>
</tr>
<tr>
<td>1/12/10 5:18 AM</td>
<td>K. Walters observed high pitch squeal and seal fluid leak around CP4826.</td>
</tr>
<tr>
<td>1/12/10 5:20 AM</td>
<td>CP4826 manually shut down at local panel.</td>
</tr>
<tr>
<td>1/12/10 5:25 AM</td>
<td>CP4826 locked and tagged-out</td>
</tr>
<tr>
<td>1/12/10 5:35 AM</td>
<td>Seal fluid spill contained and cleaned-up</td>
</tr>
<tr>
<td>1/12/10 8:00 AM</td>
<td>Root Cause Investigation Team formed.</td>
</tr>
</tbody>
</table>
Incident Report

• The Incident Report should concisely communicate the conclusions and recommendations of the Root Cause Analysis Team

• The report should include the following elements
  ➢ Problem Definition
  ➢ Summary Statement of Causes
  ➢ Solutions, Action Items and Associated Causes
  ➢ Responsible Person and Completion Date
  ➢ Incident Timeline
  ➢ Laboratory/Failure Analysis Reports
  ➢ Your Reality Chart
  ➢ Cost Information
  ➢ Contact Name and Investigation Team Members
  ➢ Report Date
  ➢ Date Investigation Started
Apollo Incident Report

Incident Report
Purpose: To prevent recurrence, not place blame.

For Internal Use Only
Report Date: Feb. 12, 2010
Start Date: Jan. 12, 2010
Report Number: RCA2010-0004

I. Problem Definition
What: CP4826 Centrifugal Pump Failure
When: 1/12/10 5:15 am
Where: WWTP Pump House
Significance: Risk of solids settling in digestion tank T3759. Risk of aerobic bacteria depletion in tank. Safety: Slip hazard due to propylene glycol/water seal fluid spill on floor of WWTP Environmental: Risk of shutting down WWTP Revenue: Shutting down WWTP will result in production shut down.
Cost: Replacement pump, mechanical seal, drive shaft and installation labor $13,750
Frequency: 4 times in last 12 months

II. Realitychart Summary
Reality Chart has indicated that the action cause of improper alignment of CP4826 motor shaft and pump shaft led to the seal failure. We don't have the proper tools to perform the drive/pump alignment, the procedure or the training. We could have an outside company come in and do this on an as-needed basis but this would result in production delays. The RCA team decided that it is better to develop this knowledge and skill set in-house.

III. Solutions

<table>
<thead>
<tr>
<th>Causes</th>
<th>Solutions</th>
<th>Owner</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Alignment Procedure</td>
<td>Write alignment SOP</td>
<td>Jim Phillips</td>
<td>Feb. 5, 2010</td>
</tr>
<tr>
<td>No Alignment Training</td>
<td>Train maintenance personnel on alignment SOP</td>
<td>Jim Phillips</td>
<td>Feb. 10, 2010</td>
</tr>
<tr>
<td>No Alignment Tools</td>
<td>Purchase laser alignment kit</td>
<td>Jim Phillips</td>
<td>Jan. 29, 2010</td>
</tr>
</tbody>
</table>

IV. Team Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
<th>Member Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dave Sutherland</td>
<td></td>
<td>Operations Manager</td>
</tr>
<tr>
<td>Jim Phillips</td>
<td></td>
<td>Maintenance Manager</td>
</tr>
<tr>
<td>Kevin Walters</td>
<td></td>
<td>WWTP Operator</td>
</tr>
<tr>
<td>David Williams</td>
<td></td>
<td>Maintenance Mechanic</td>
</tr>
<tr>
<td>Bill Johnson</td>
<td></td>
<td>John Crane Representative</td>
</tr>
<tr>
<td>Fred Sylvester</td>
<td></td>
<td>SKF Bearings Representative</td>
</tr>
</tbody>
</table>

V. Notes
1. The Realitychart and Incident Report have been finalized.

13Dec2016
Ronald M. Shewchuk
References


Internet Resources

• Society of Maintenance and Reliability Professionals
  http://www.smrp.org/

• Plant Maintenance Resource Center
  http://plant-maintenance.com/

• Maintenance Technology Magazine
  http://www.mt-online.com/

• Apollo Root Cause Analysis
  http://www.apollorca.com/

• Reliability Engineering Resources
  http://www.weibull.com/

• GE Sensing & Inspection Technologies

• Laser Alignment Tool
  http://www.laser-alignment-tool.com/