Managing FLAB with Proactive and Precision Maintenance

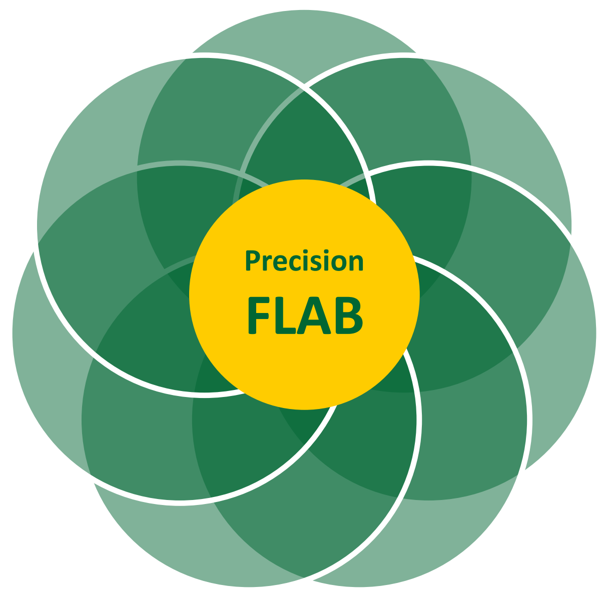
An Introduction

Drew D. Troyer, CRE, CMRP

Principal

T.A. Cook

FLAB Connects the Dots Between Other Key Reliability Elements and Puts it on the Plant Floor!



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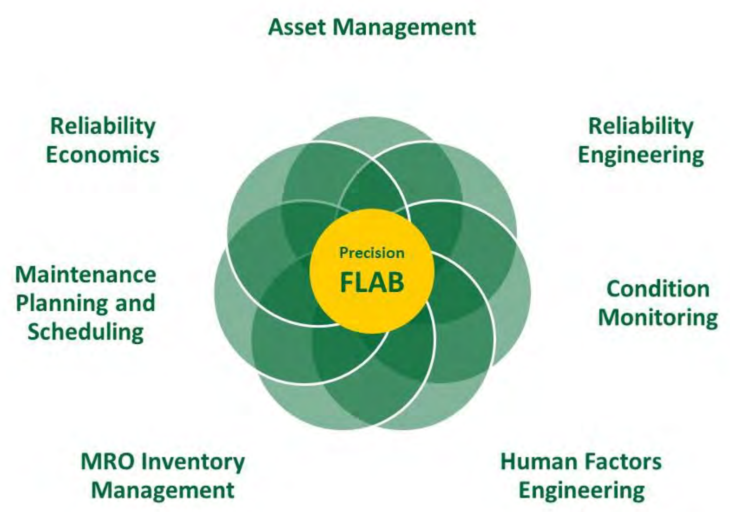
FLAB – Actionable Reliability

"It's easier to act your way into a new way of thinking than to think your way into a new way of acting."

Millard Fuller



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Course Overview

FLAB Core

FLAB Foundation
- Asset Mgmt.
- FLAB Fundamentals
- Physics of Failure
- Reliability Eng.
- Human Factors
- Condition Monitoring

Fasteners
- Threaded Fasteners
- Belt and Chain Tension
- Gas Leak Management
- Liquid Leak Management
- Welded Fasteners
- Electrical Connectors

Lubrication
- Lube Base Oil
- Lube Additives
- Grease Thickeners
- Contamination Control
- Lube Storage
- Lubricant Application
- Lube Maintainability

Alignment
- Shaft Alignment
- Sheave Pulley Alignment
- Total Harmonic Distortion
- Electrical Discharge Erosion

Balance
- Relative Centrifugal Force
- Mechanical Shop Balance
- Mechanical Field Balance
- Voltage, Current, Inductive and Resistive Balance

FLAB Execution
- Work Mgmt.
- Procedures
- FLAB Economics
- FLAB SWOT Analysis
- FLAB Training, Coaching and Mentoring
- Creating Culture Change

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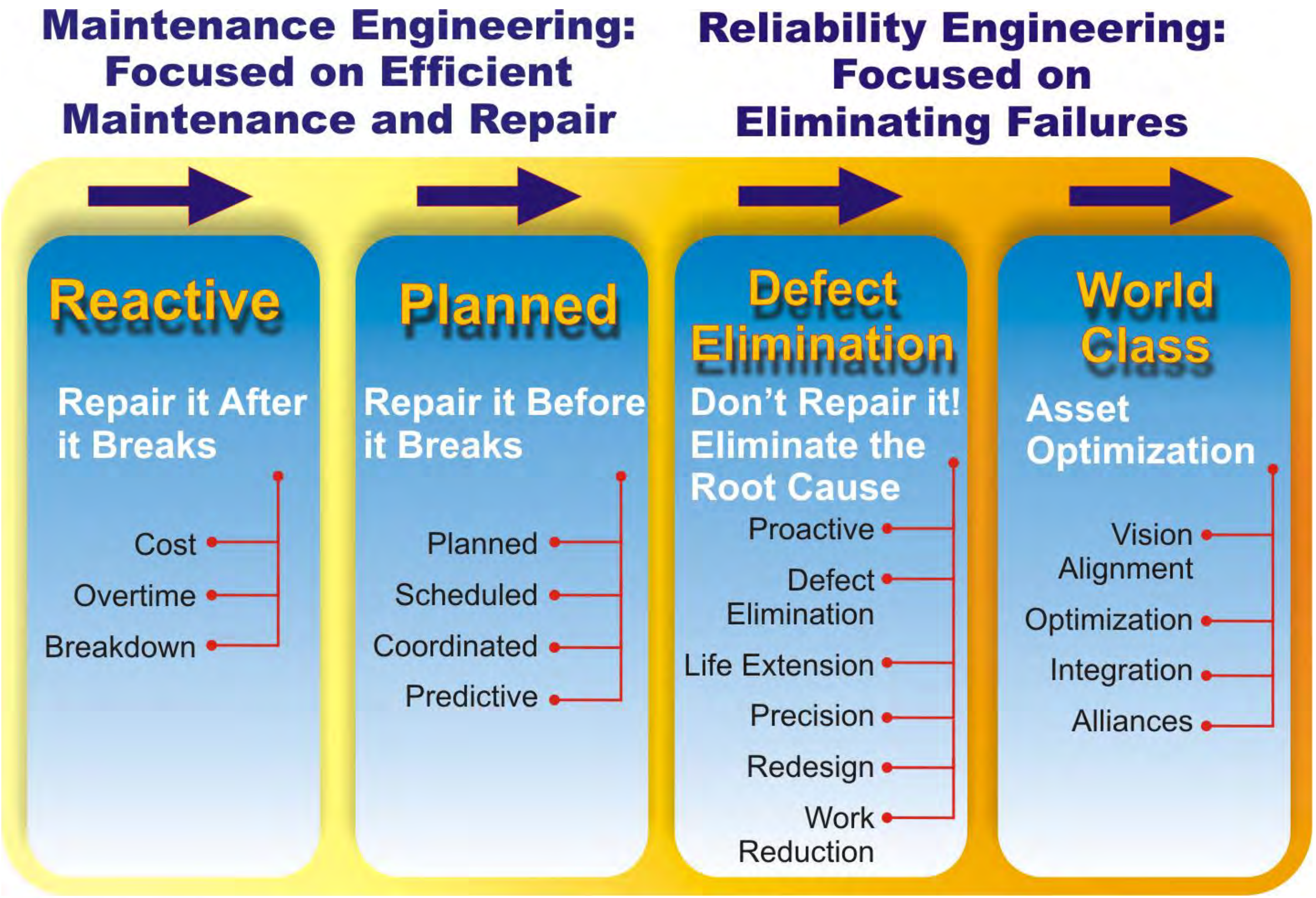
The Journey to World-class Maintenance



Ref: DuPont, GT

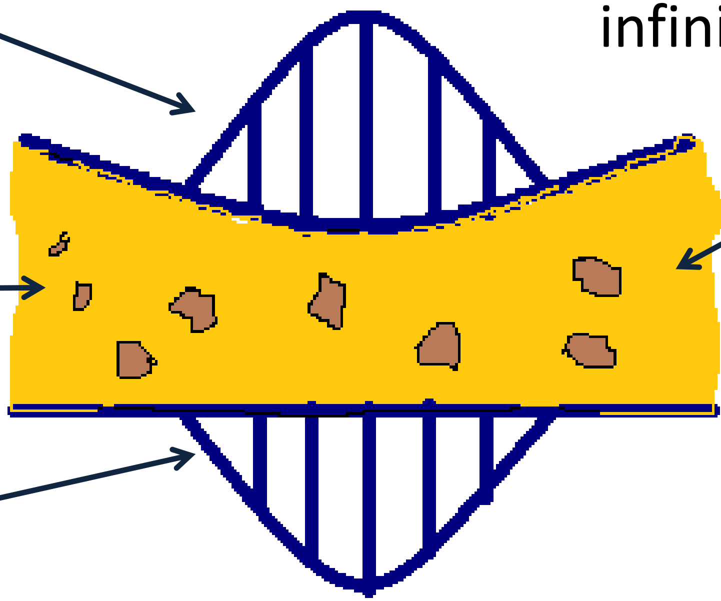
Proper FLAB Management Reduces Cost and Increases Uptime

Under these conditions, a bearing can have an infinite life!

Rolling element load distribution

Clean oil - particles are too small to cause damage

Race way load distribution



1-5 μm lube film

Presumes:

- **F**astener Integrity
- **L**ubrication Effectiveness
- **A**lignment
- **B**alance
- Proper Operation

Cutting the **FLAB** is your best weapon to reduce wear and failure!

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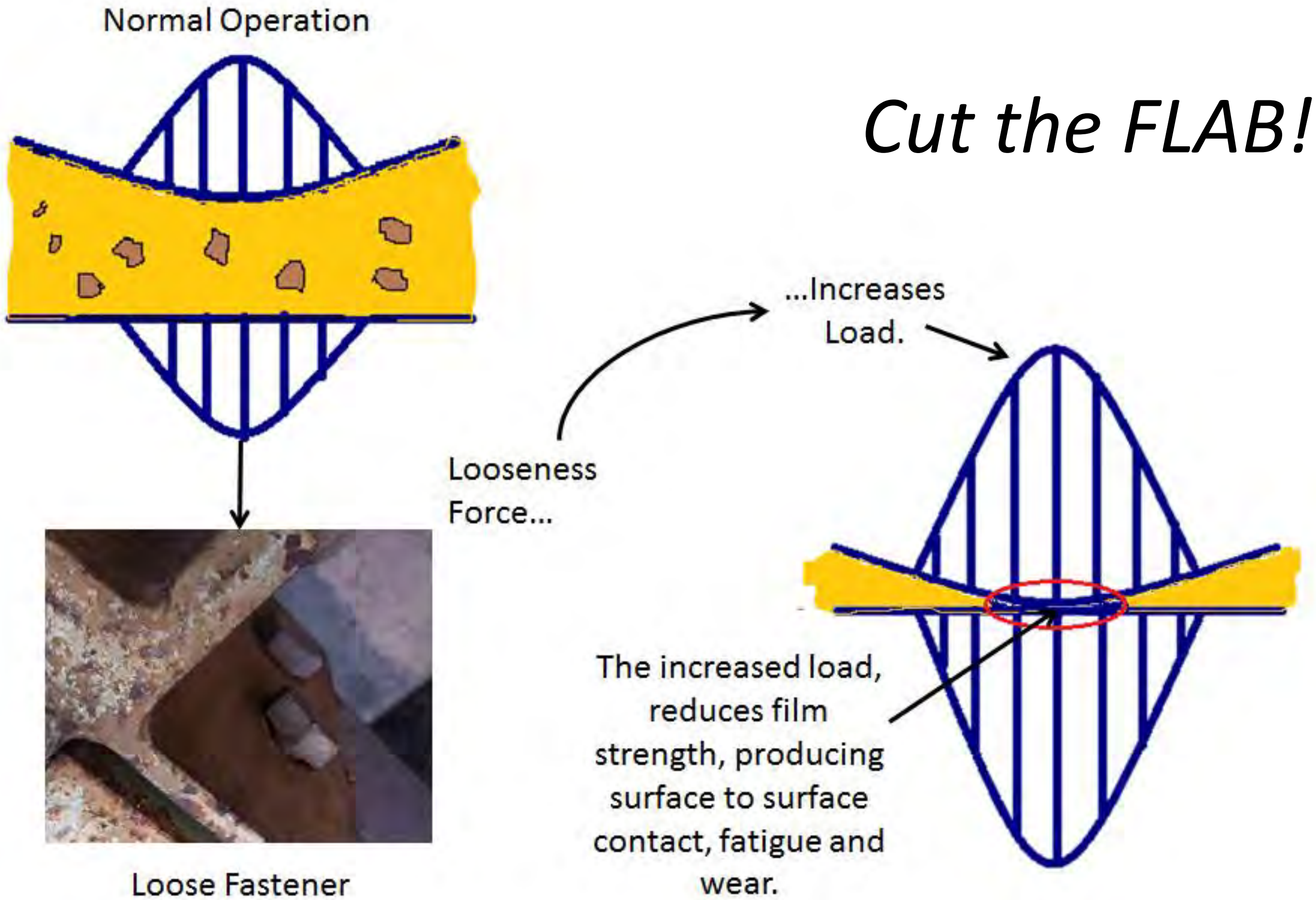
How Loose Fasteners Cause Wear and Failure

Cut the FLAB!



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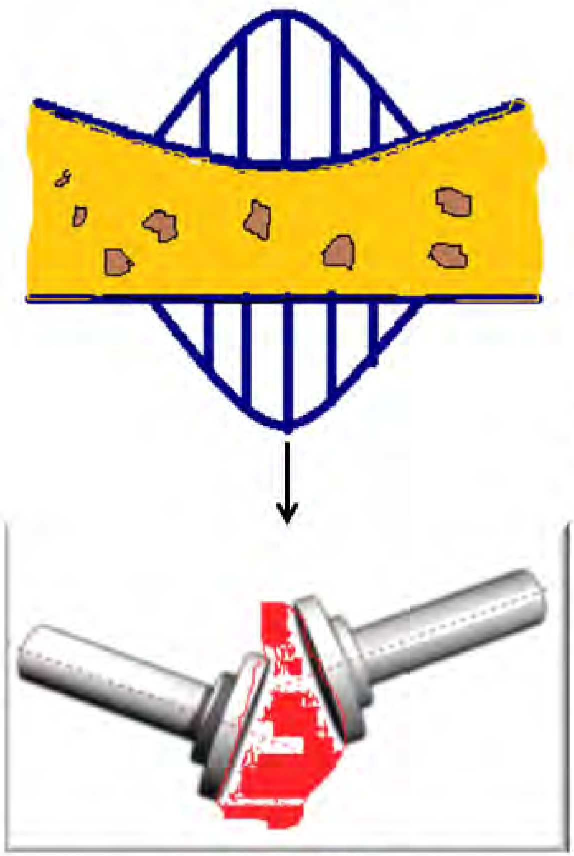
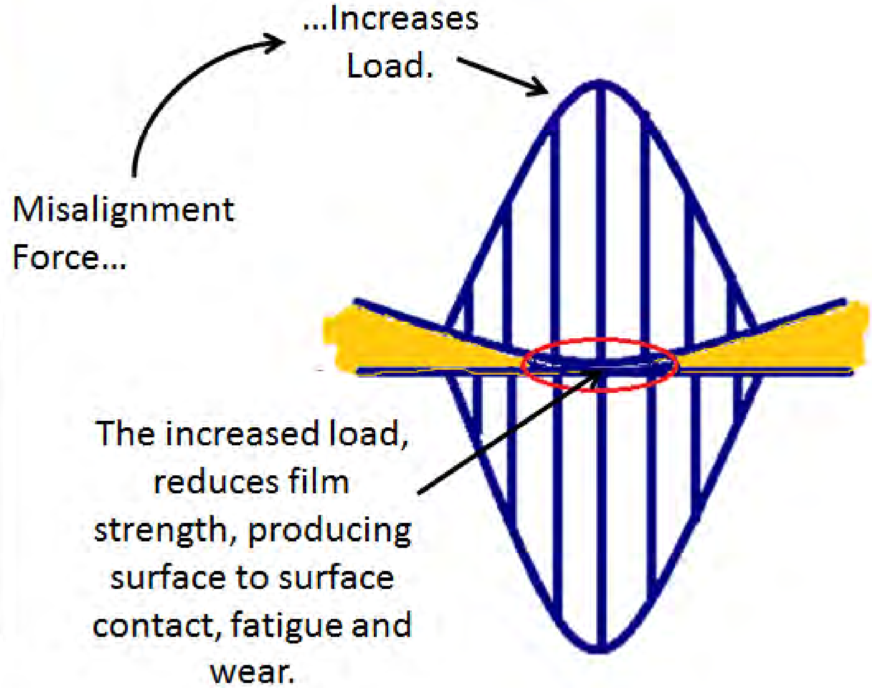
How Misalignment Causes Wear and Failure

Normal Operation



Misaligned Shaft

Cut the FLAB!



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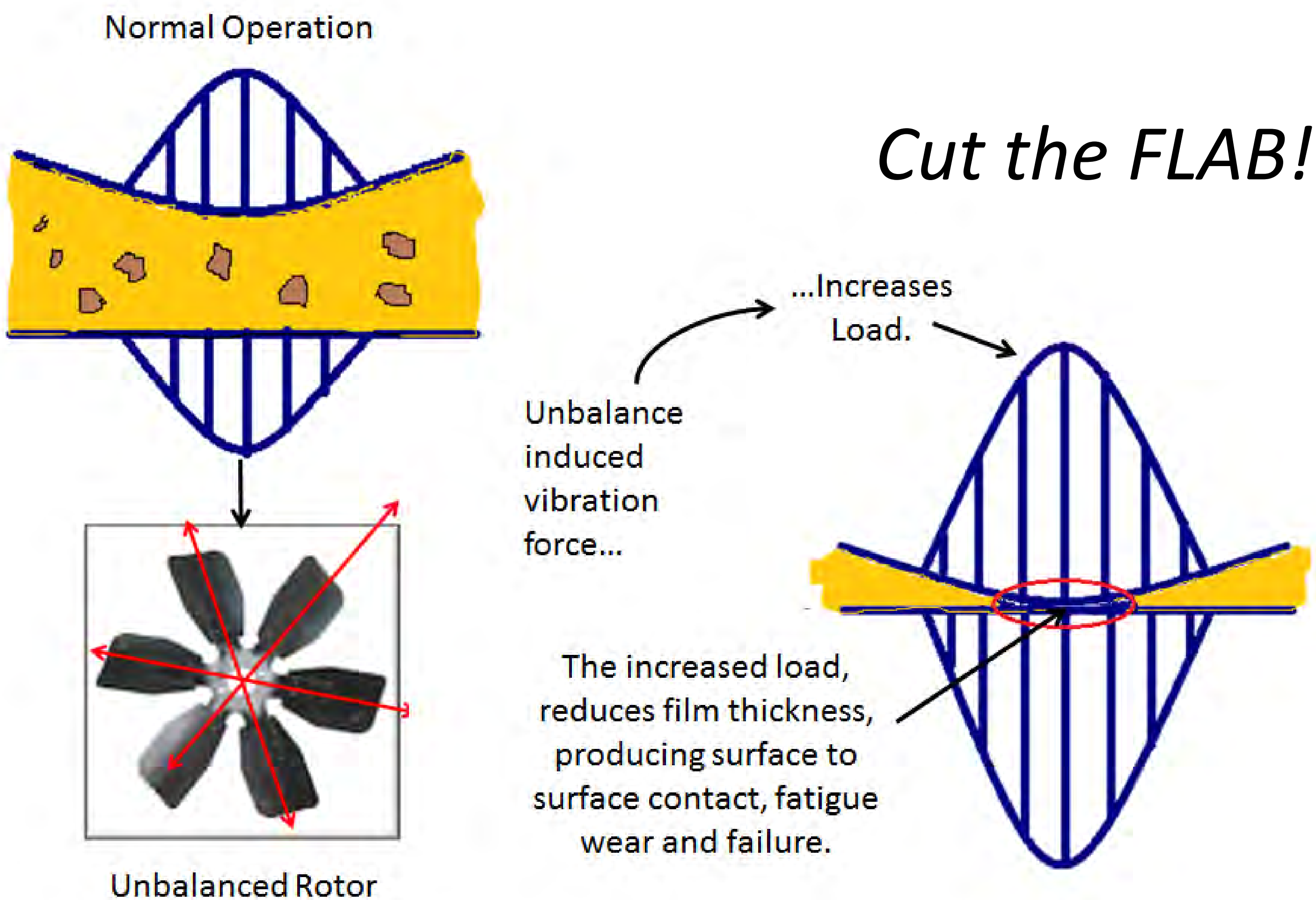
How Unbalance Causes Wear and Failure



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Vibration Robs Your Machines of Life and Reliability

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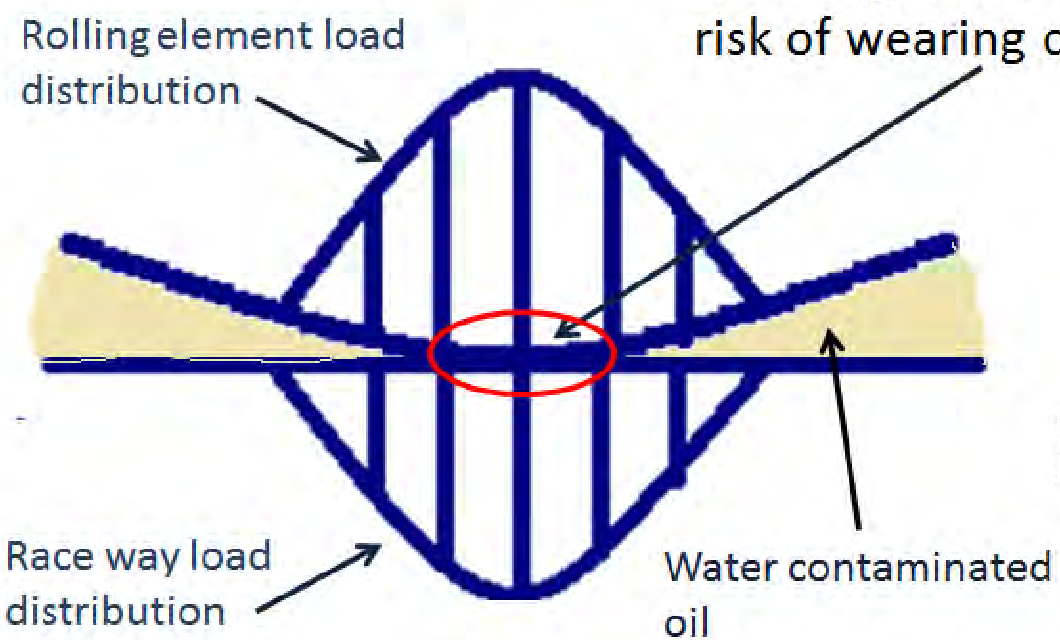
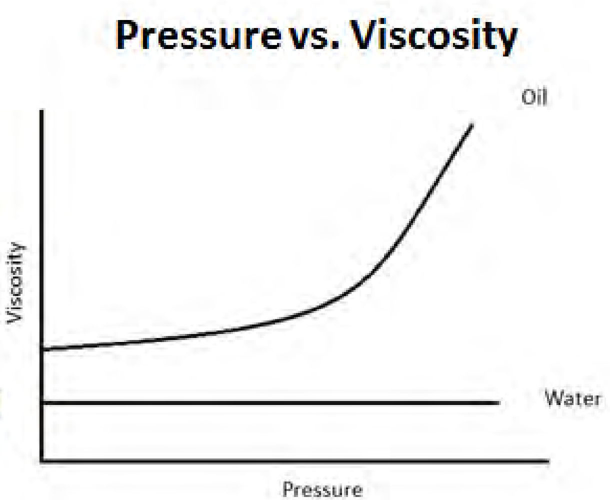
How Water Contaminated Lubricant Causes Wear and Failure

Even under normal load, water in the oil reduces the lubricant's film strength, thus reducing film thickness and increasing the risk of wearing contact.





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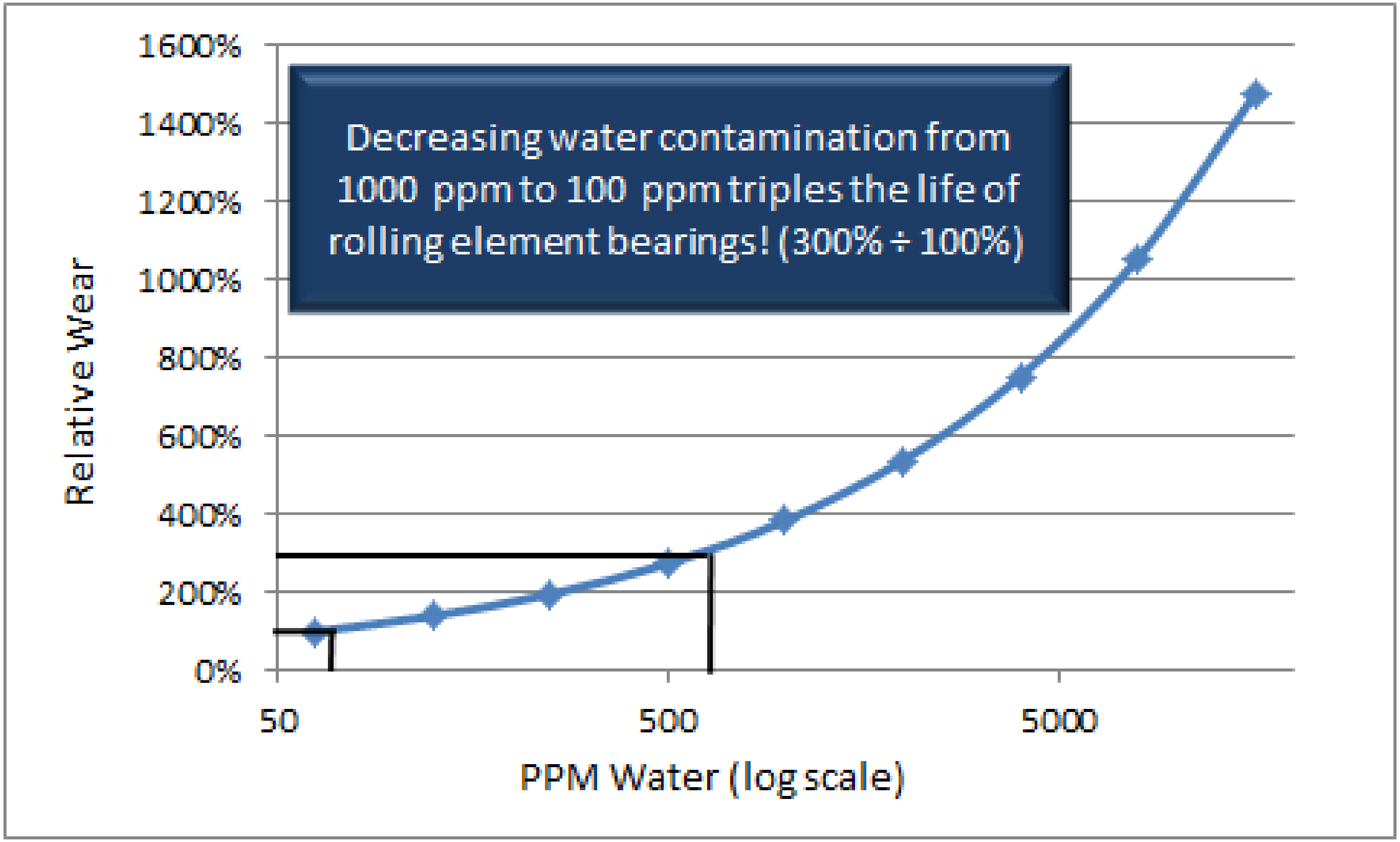
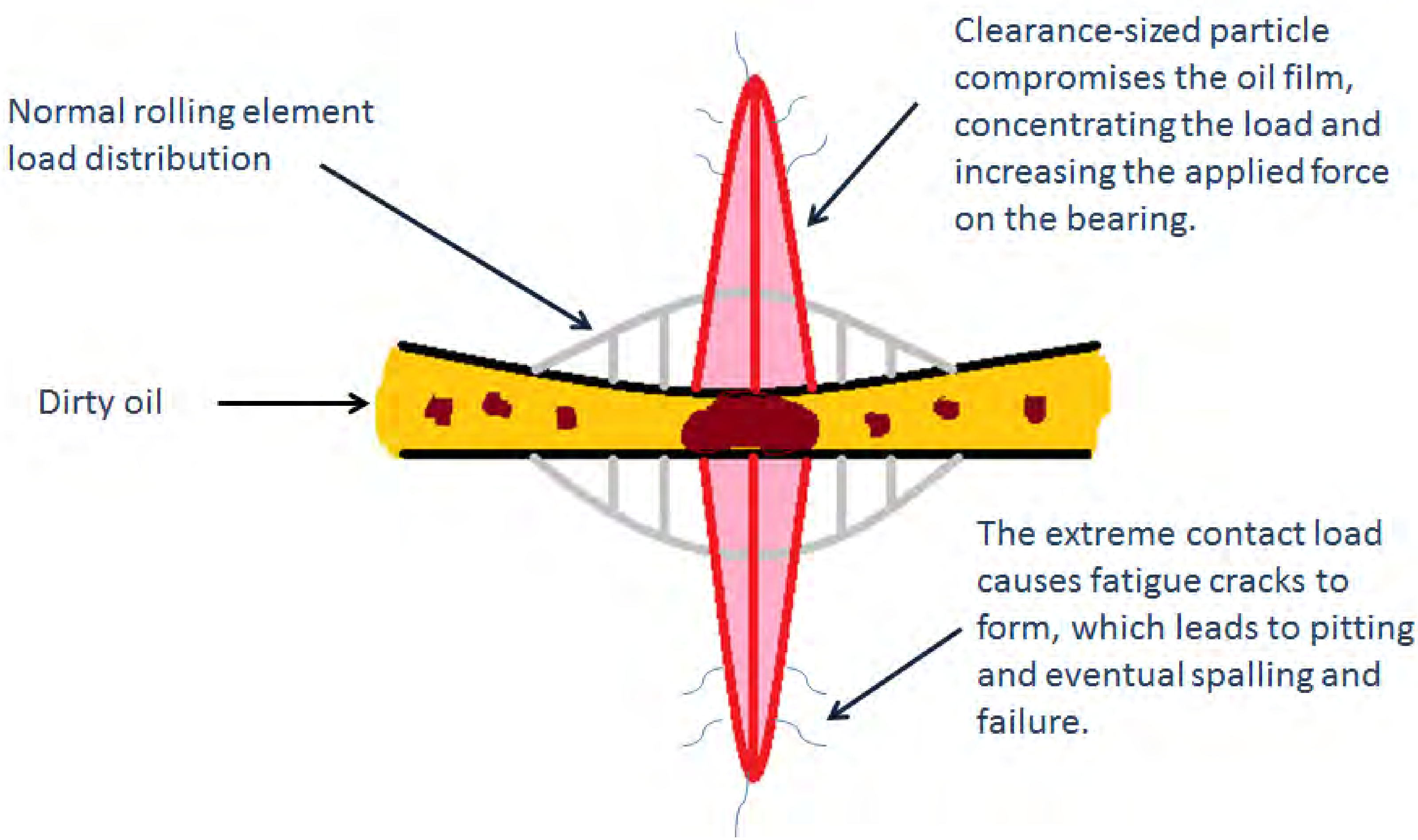
Increasing Component Life With Water Contamination Control



How Dirty Lubricant Causes Wear and Failure



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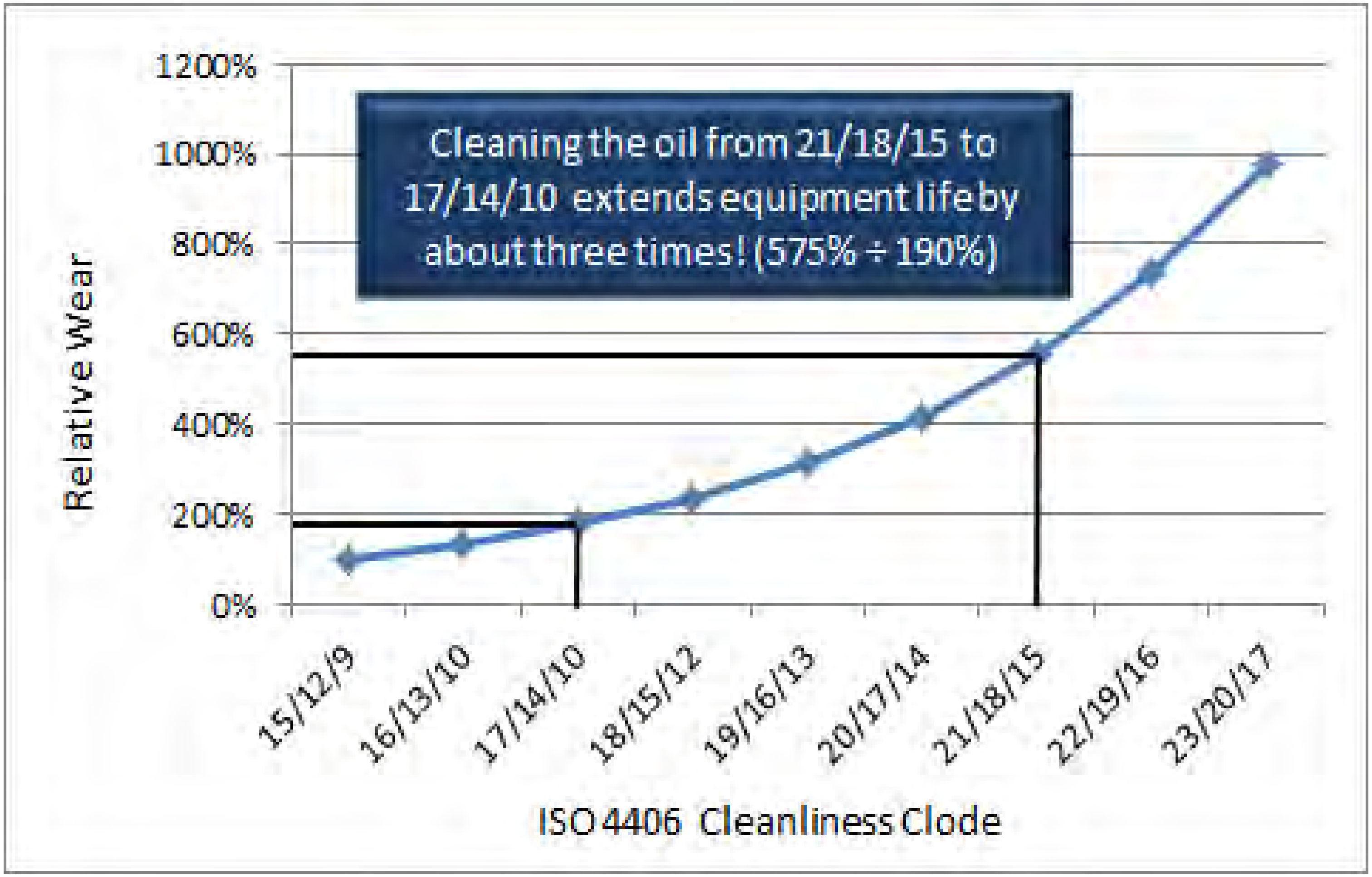
Increasing Component Life With Particle Contamination Control



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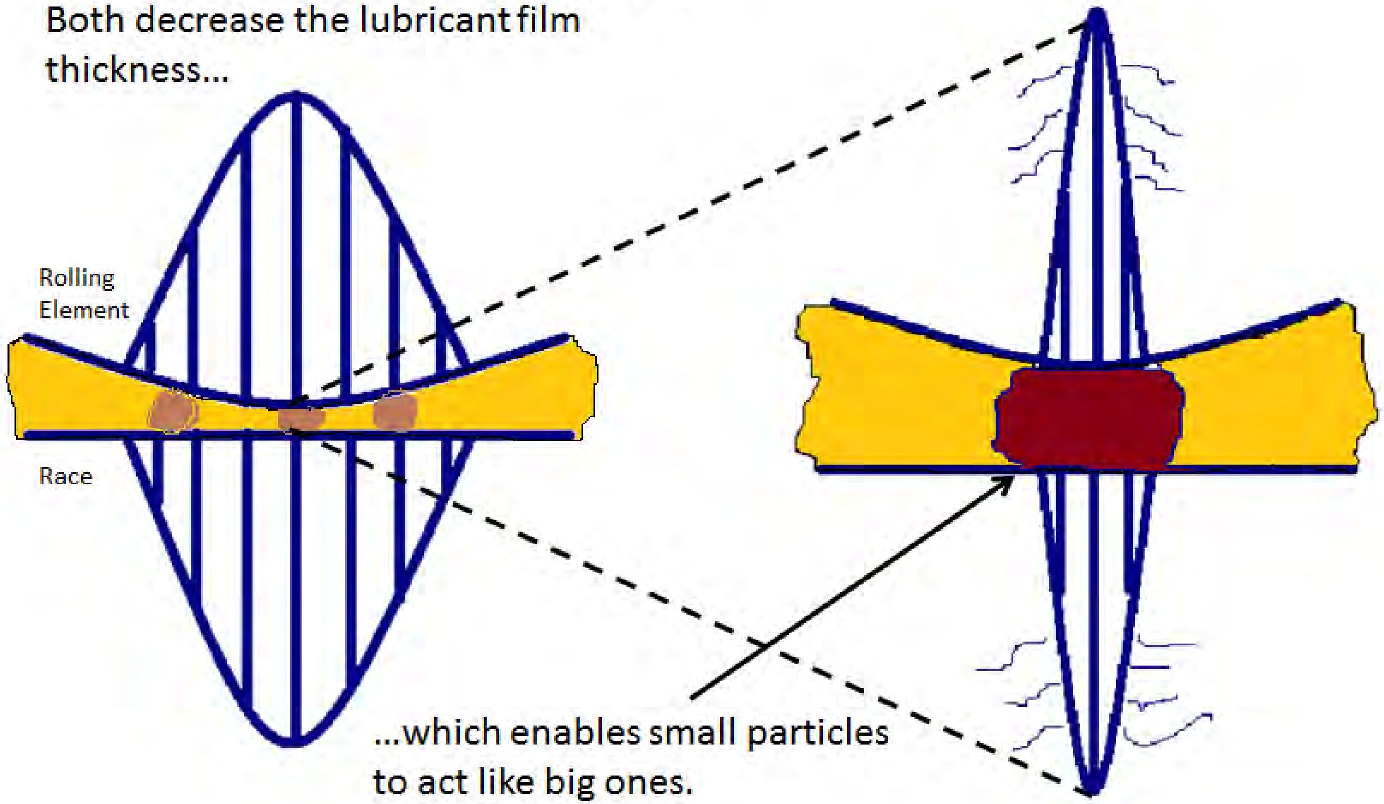
How the Combined Effect of FLAB Causes Wear and Failure

Unbalance, misalignment, looseness increase load. Water contamination and wrong viscosity decrease film strength. Both decrease the lubricant film thickness...



...which enables small particles to act like big ones.

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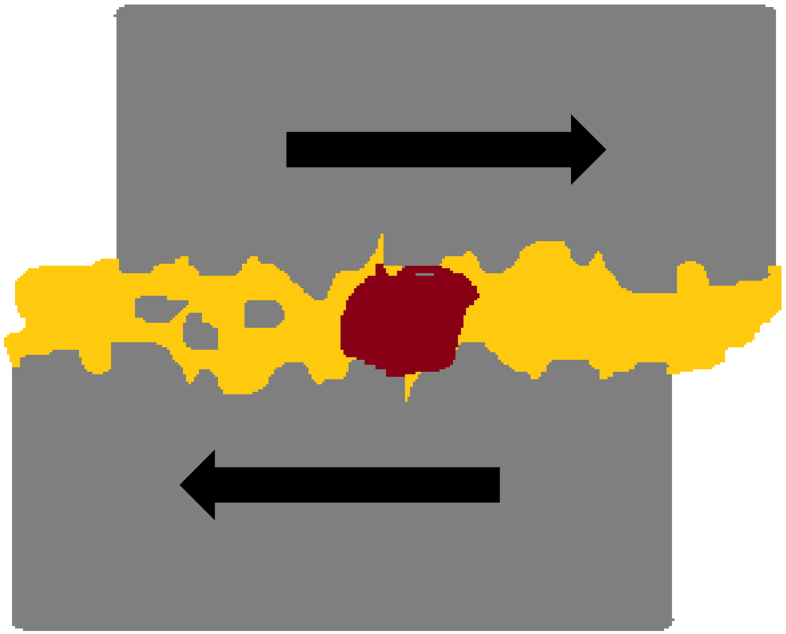
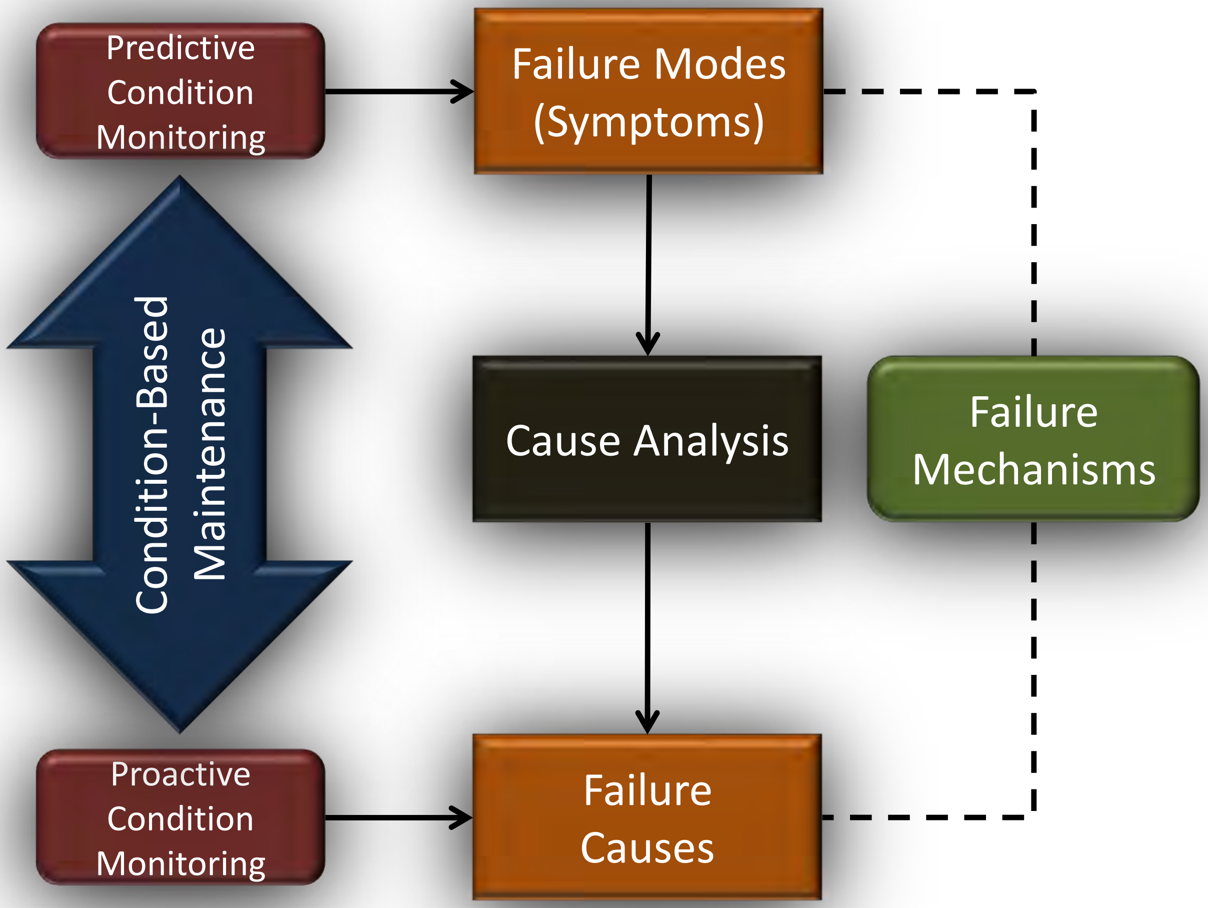
The Same Physics of Failure Apply in Sliding Contacts

We've used rolling element bearings and rolling contacts in our example, but the same forcing functions cause wear and failure in sliding contacts to produce abrasive (cutting) and adhesive wear.



Why Learn About the Physics of Failure Modes and Mechanisms?



To effectively connect failure symptoms to failure causes, we must understand the mechanism(s), or "forcing functions" driving the relationship. Otherwise, our cause analysis is simply guesswork.

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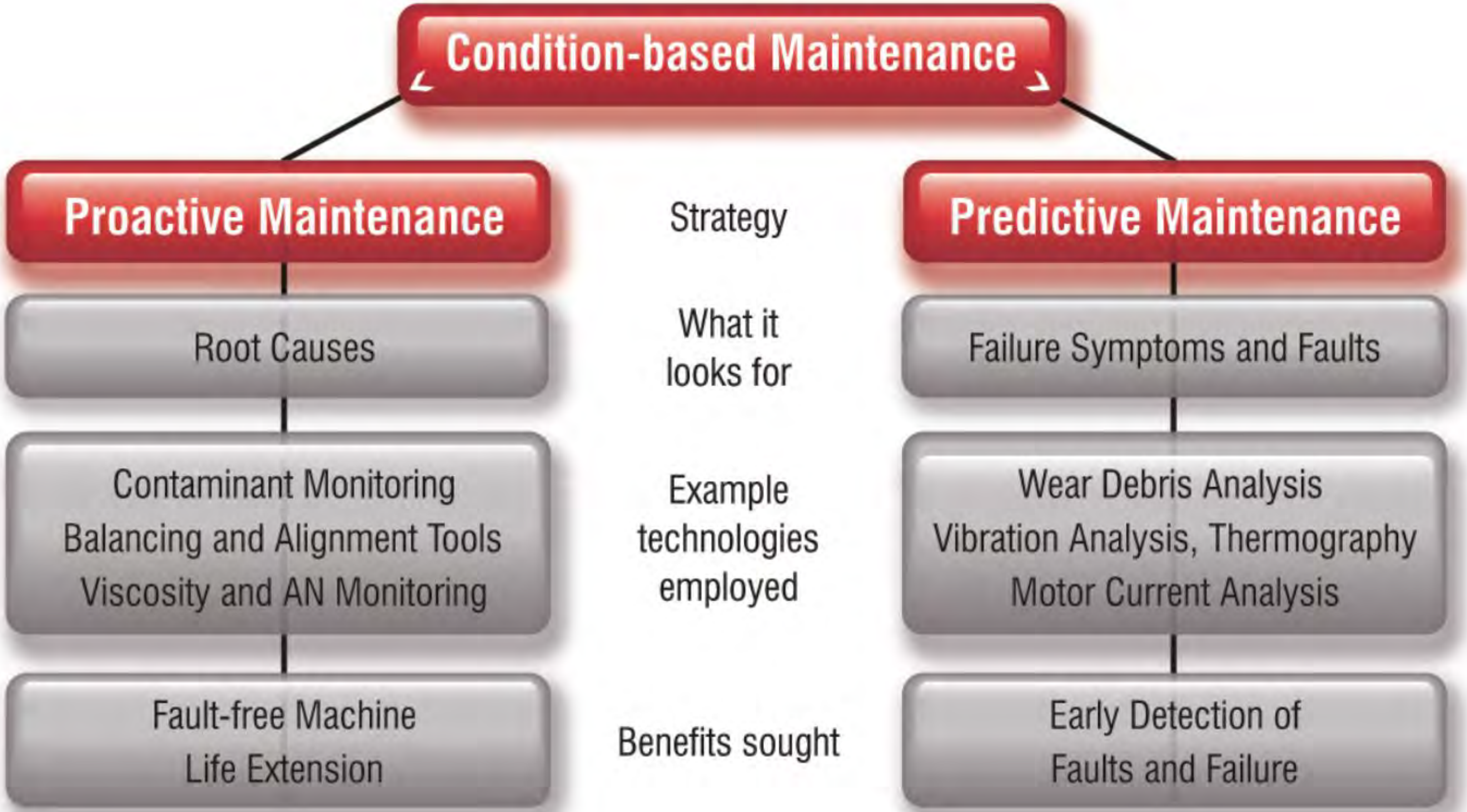
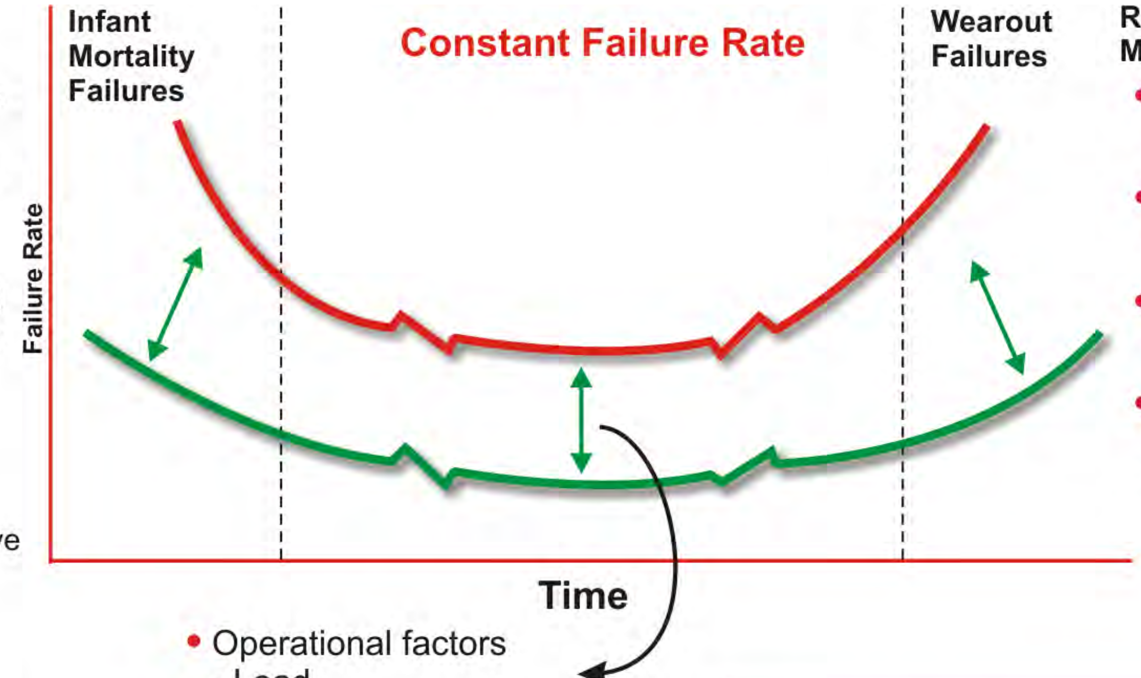
Modern Maintenance Technologies



Keep Your Bathtub Clean

Reduce by Eliminating:
- Design defects
- Manufacturing defects
- Assembly, installation and commissioning defects.
- Operating defects
- Reduce invasive maintenance actions



Reduce by Managing:
- Overload conditions
- Material deterioration
- Fastener looseness
- Equipment/ system design

Reduce rate and extend service life by controlling:
- Operational factors
  - Load
  - Speed
- Environmental factors
  - Lubrication
  - Contamination
  - Vibration
  - Heat
  - Etc.

Bathtub Curve: An equipment failure-rate with an initial sharply declining failure rate, followed by a prolonged constant-average failure rate, after which the failure rate again increases sharply.

Ref: DT, E.C.Fitch

FLAB Optimum Reference States: Fasteners

- We include torque values, fastener lubrication requirements and required fastening sequence in all corrective and preventive maintenance work instructions.
- We employ properly selected and specified (e.g. grade, material, etc.) and sized fasteners and washers for fastener applications and the fastener type, size and material are clearly defined in maintenance work instructions.
- Fasteners are audited at least twice a year and a routine audit of fasteners will reveal no loose, missing, improperly sized or damaged fasteners in the plant.
- Torque wrenches are employed for tightening fasteners in the plant and when a specialized torque wrench is required, it is specified in the maintenance work instructions.
- Foundation mounting bolts are properly selected, sized and grouted, and machines are correctly shimmed when installed to eliminate soft foot.
- Belts on belt-driven equipment are properly tensioned with a spring or vibration tensiometer upon installation, re-tensioned shortly after start-up to adjust for relaxation or belt seating and required tension values and tensioning instructions are explicitly included in corrective and preventive maintenance work instructions.
- Belts are inspected visually (or with a stroboscope) at least once a month and checked for tension at least once a year.
- Ultrasonic analysis is routinely employed for finding, tagging and correcting air and other pressurized gas leaks. Leaks are fixed as found and recorded where possible.

FLAB Optimum Reference States: Fasteners (cont.)

- Machines are routinely inspected for liquid leaks. Leaks are found, tagged, and corrected. Where required, fluorescent dye is employed to identify the location of leaks. Leaks are fixed and found and recorded where possible.
- All mechanical crafts people are properly trained and qualified on the theory and practice of applicable forms of fasteners, belt installation and tensioning, and leak detection and management. Where appropriate, specialized monitoring is contracted out to qualified experts.
- Mechanical looseness is routinely monitored utilizing vibration analysis where appropriate.
- Looseness or soft foot issues revealed by vibration analysis or other inspection technique are attended to with a high priority, before damage to bearings, gears and other components can occur.
- Electrical connections, including circuit breakers, fuses, contactors, overloads, disconnects, lug connections, etc., are routinely tested with thermography, motor analysis or other inspection techniques.
- All electrical craft persons are properly trained and qualified on electrical fastener theory and practice, to include monitoring and inspection techniques. Where appropriate, specialized monitoring is contracted to qualified experts.
- Electrical fastener and circuit problems revealed by thermography, motor circuit analysis or other techniques, are corrected promptly before they can lead to equipment damage and/or functional failure.

FLAB Optimum Reference States: Lubrication

- The required viscosity grade and viscosity index has been analyzed for each application. The analysis considers the operating temperature and range. Viscosity and base oil type requirements are written into material specification standards for greases and oils.
- The required additive system has been evaluated relative to the performance requirements of the application. Additive requirements, along with associated performance property requirements, are written into material specification standards for greases and oils.
- The appropriate grease thickener has been selected for grease lubricated applications and measures have been taken to minimize cross contamination of thickeners (e.g. instructions to motor rebuild shops specify the exact grease to use for initial fill).
- The required re-lubrication interval has been technically evaluated for each application to consider component type and size (e.g. bearings), operating speed, vibration, contamination in the area, shaft orientation, operating temperature, leakage rate, etc. The analysis produces ideal re-grease and oil change intervals where condition monitoring is not employed to determine the interval.
- The required re-lubrication volume has been calculated for greased bearings considering the component size and type (e.g. bearing), seal configuration, etc. and precision methods are employed to ensure that the correct volume is applied.
- Oil lubricated machines are equipped with non-intrusive means to check oil level and these levels are monitoring and adjusted as required at least once per week - more often where leakage is common.
- Particle contamination control limits have been set for all oil lubricated machines and proper measures have been taken to exclude and remove particles as required to achieve those targets. Oil analysis is employed as the feedback mechanisms to ensure that targets are achieved.

FLAB Optimum Reference States: Lubrication (cont.)

- Water contamination control limits have been set for all oil lubricated machines and proper measures have been taken to exclude and remove water contamination as required to achieve those targets. Oil analysis is employed as the feedback mechanisms to ensure that targets are achieved.
- Lubricant storage containers, transfer devices, lubrication tools and machines are all fitted with intuitive tagging labels (e.g. shapes and colors) to identify lubricants and to avoid cross contamination.
- Lubrication PMs are clearly written to specify proper methods for carrying out various lubrication tasks and fits, tolerances, quantity and quality details are included in the associated maintenance work instructions.
- Lubricant samples are drawn at the proper interval, from the proper location and using appropriate methods to assure representative oil analysis data and the samples are tested to an appropriate test slate for which action limits and thresholds have been set.
- All crafts persons are properly trained and qualified on the theory and practice of lubrication and oil analysis. Where appropriate, specialized testing and analysis is contracted out to qualified experts.
- Transformer oils are correctly managed, maintained and tested to ensure the necessary dielectric performance and to avoid the accumulation of potentially flammable dissolved gases such as acetylene.
- All crafts persons are properly trained and qualified on the theory and practice of lubrication and oil analysis. Where appropriate, specialized testing and analysis is contracted out to qualified experts.
- Lubrication, contamination or wear issues revealed by oil analysis, vibration analysis or other inspection technique are attended to with a high priority, before damage to bearings, gears and other components can occur.

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FLAB Optimum Reference States: Alignment

- Shaft and sheave alignment maintenance work instructions include allowable misalignment so there is no guesswork for techs at the job site. Tolerances are calculated based on speed and consider shaft length when calculating angular misalignment limits.
- Thermal growth is considered when setting up alignment limits and maintenance work instructions.
- Laser alignment tools are employed for aligning shafts and sheaves.
- Flexible couplings are NOT used as an excuse to employ lazy and imprecise shaft alignment practices.
- Pipework is installed properly to minimize pipe strain. Thermal growth is considered when laying in pipework. Also, piping is properly mounted and secured to reduce movement induced stress on joins and flanges.
- All mechanical craft persons are properly trained and qualified on alignment theory and practice for shaft and sheave alignment jobs. Where appropriate, specialized work, monitoring and testing is contracted out to qualified experts.

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FLAB Optimum Reference States: Alignment (cont.)

- Mechanical misalignment is routinely monitored utilizing vibration analysis where appropriate.
- Mechanical misalignment issues revealed by vibration analysis or other inspection techniques are attended to with a high priority, before damage to bearings, gears and other components can occur.
- Electrical total harmonic distortion (misalignment with sinusoidal power wave) is maintained to below 3% for electric motor applications.
- The presence of stray voltage is routinely monitored in equipment, where appropriate (e.g. motors, generators, panels, etc.). Stray voltage is the accumulation of electrostatic electrical potential. When the accumulation reaches a critical level, the potential is electrokinetically discharged, causing electrical discharge erosion (fluting) and the potential for injury.
- All electrical craft people are properly trained and qualified on theory and practice related to managing total harmonic distortion in electric motors. Where appropriate, specialized monitoring and testing is contracted out to qualified experts.
- Electrical harmonic distortion and stray voltage are routinely monitored utilizing motor analysis and other technologies where appropriate.
- Electrical harmonic distortion and stray voltage issues revealed by motor analysis or other inspection techniques are attended to with a high priority, before damage to motors and MCCs can occur.

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FLAB Optimum Reference States: Balance

- Where appropriate, pumps, blowers, fans, etc. are shop balanced to appropriate standards prior to being put into service.
- Required balancing precision is included into contracts where equipment is rebuilt offsite (e.g. electric motor rebuild shops). Where required, at-speed (high speed) balance is specified.
- Where appropriate, machines that can be field balanced are when required. Fans and other air handling units are a common example of such equipment.
- When correcting balance problems in the field, care is taken to minimize the risk that the cure won't create other problems. A common example is the wash-down of fan blades introducing water contamination into the bearings.
- All mechanical craft persons are properly trained and qualified on dynamic balance theory and practice and belt installation and tensioning theory and practice. Where appropriate, specialized work and testing is contracted out to qualified experts.
- Mechanical imbalance is routinely monitored utilizing vibration analysis where appropriate.
- Mechanical Imbalance issues revealed by vibration analysis or other inspection technique are attended to with a high priority, before damage to bearings, gears and other components can occur.

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FLAB Optimum Reference States Balance (cont.)

- Phase to phase electrical voltage imbalance is monitored and maintained to acceptable levels to assure maximum motor life. Failure to maintain phase to phase voltage balance results in the generation of heat. Voltage imbalance should be managed to below 2%.
- Electrical current imbalance is monitored and maintained to acceptable levels to assure maximum motor life. Failure to manage current imbalance causes heat generation and can stress electrical circuits. As a rule, current imbalance will be about seven times higher than voltage imbalance. However, current imbalance can be caused by the circuit, even is phase to phase voltage is in balance.
- Phase to phase electrical inductive imbalance caused by poor rotor condition is monitored and maintained to acceptable levels to assure maximum motor life. Inductive imbalance is an indication of wind quality. Limits are 7% for form wound motors and 12% for loose wound motors. The lower the better. This is an acceptance criterion for new or rewound motors.
- Electrical resistive imbalance is monitored and maintained to acceptable levels to assure maximum motor life. Resistive imbalance is a proactive indicator and often a precursor to current imbalance.
- All electrical craft persons are properly trained and qualified on electrical balance theory and practice. Where appropriate, specialized work, monitoring and testing is contracted out to qualified experts.
- Electrical imbalance is routinely monitored utilizing motor analysis (current and circuit) where appropriate.
- Electrical imbalance issues revealed by motor analysis or other condition monitoring or inspection techniques are attended to with a high priority, before motors, MCCs and other components can occur.

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FLAB Optimum Reference States: FLAB Management

- As a matter of policy, proactively managing FLAB with precision maintenance practices is a priority for management and not flippantly disregarded in lieu of fixing broken equipment.
- Organizational roles pertaining to FLAB management and execution have been clearly defined and visible on a responsible, accountable, consulted or informed (RACI) chart. Individual have received adequate FLAB education and training and are properly supported to fulfill their respective roles.
- All preventive and corrective work practices are documented to identify best practice and to specify fits, tolerances, quantity and quality details specific to each machine and application to ensure precision in the maintenance process without depending on "tribal knowledge."
- Inspections and condition monitoring (e.g. vibe analysis, oil analysis, etc.), as opposed to functional failure, drive the work request, planning and scheduling process. And, condition directed work is given a high priority so that work request don't just sit in a backlog until the unit does reach functional failure.
- The organization has a good balance of leading and lagging indicators that drive behaviors. For example, overall lubrication effectiveness (OLE), overall vibration effectiveness (OVE) are leading indicators. Reliability, availability, cost per ton, etc. are lagging indicators.

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FLAB Optimum Reference States: FLAB Management (cont.)

- Rewards are tied to achieving proactive goals (e.g. OLE and OVE), not just production goals or reacting effectively. Remember, rewards can be extrinsic, such as money, or intrinsic, recognition for effort. Historically, we've rewarded reacting to failure with overtime and pats on the back, not proactive behaviors that drive reliability.
- The potential benefits in terms of avoided maintenance cost, increased production availability and utilization, improved safety have been systematically analyzed and quantified in economic terms.
- The organization employs world class work management practices to ensure that proactive FLAB-related PMs and work that is identified and requested gets properly planned, scheduled and executed prior to damage occurring to the equipment.
- Managers and supervisors have been trained and qualified on world-class asset management (e.g. to the five pillars of the body of knowledge set forth by the Society or Maintenance & Reliability Professionals).
- The organization has access to a qualified reliability engineer who is an expert in all aspects of FLAB management, data mining and analysis, maintenance work management and other aspects of reliability engineering and equipment asset management.

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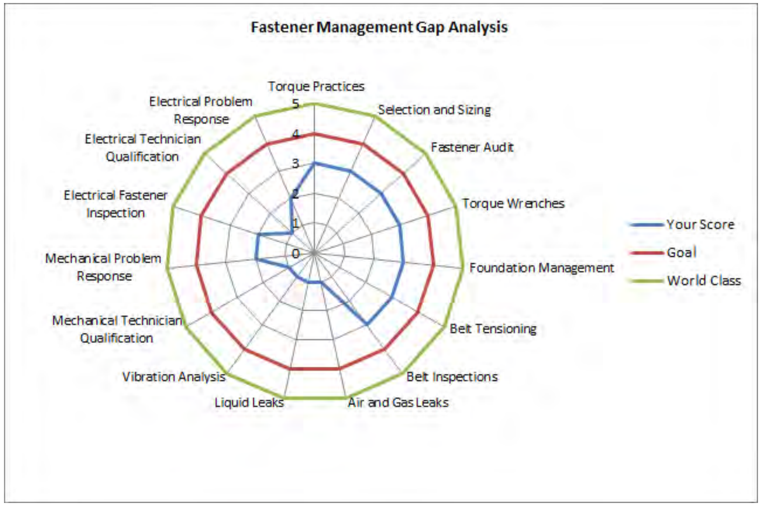
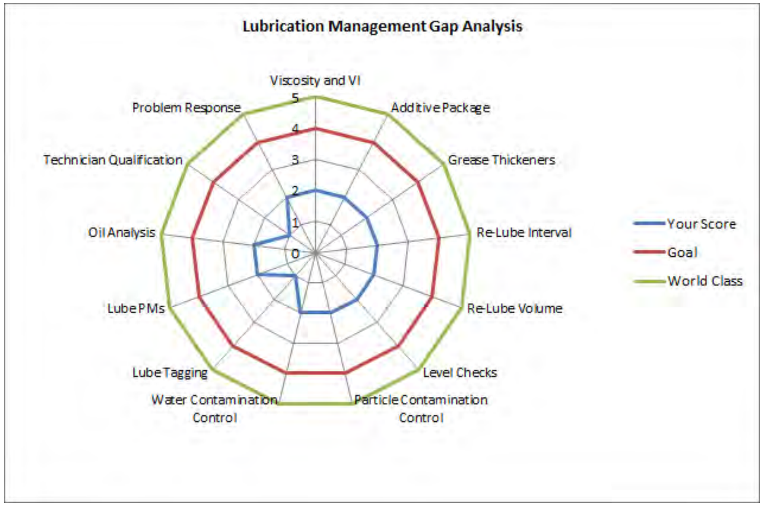
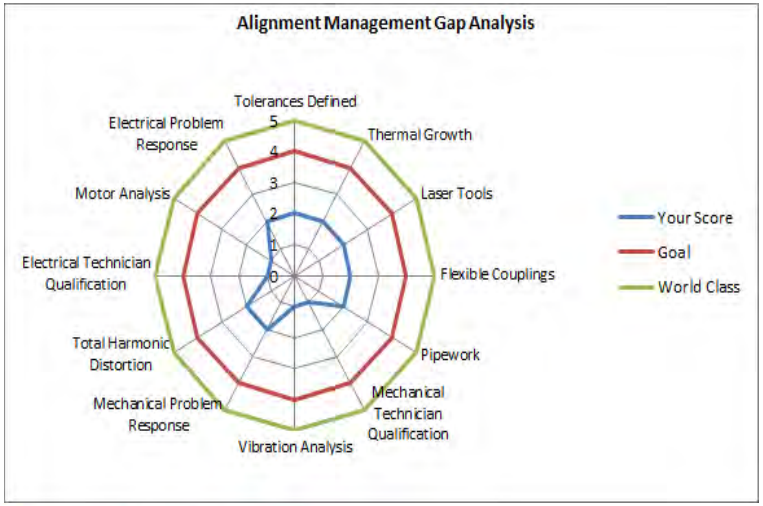
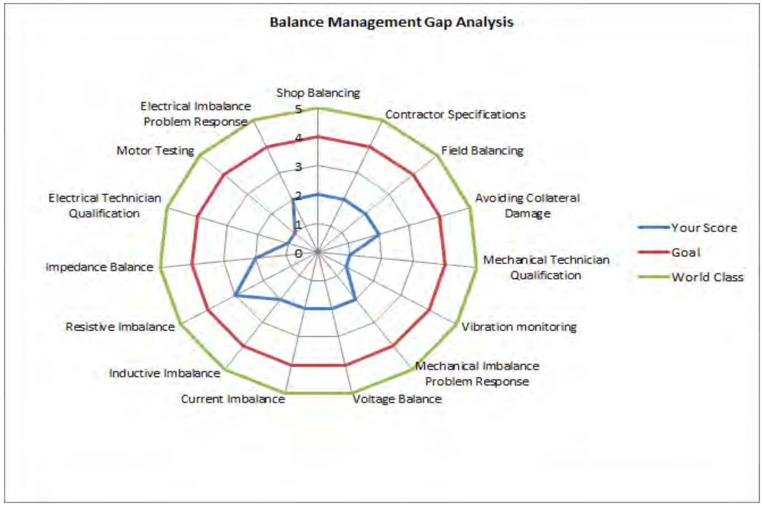
FLAB SWOT Analysis









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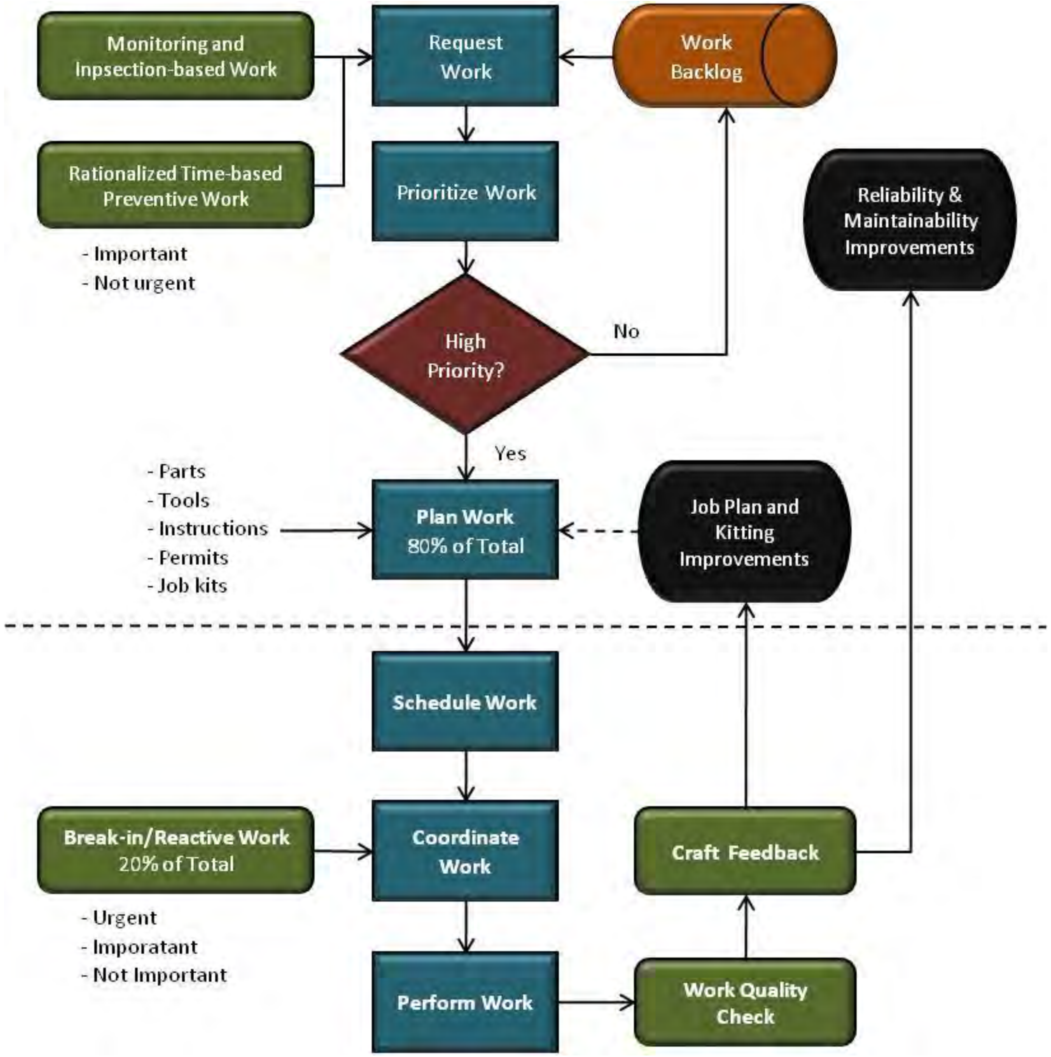
Precision Work Management



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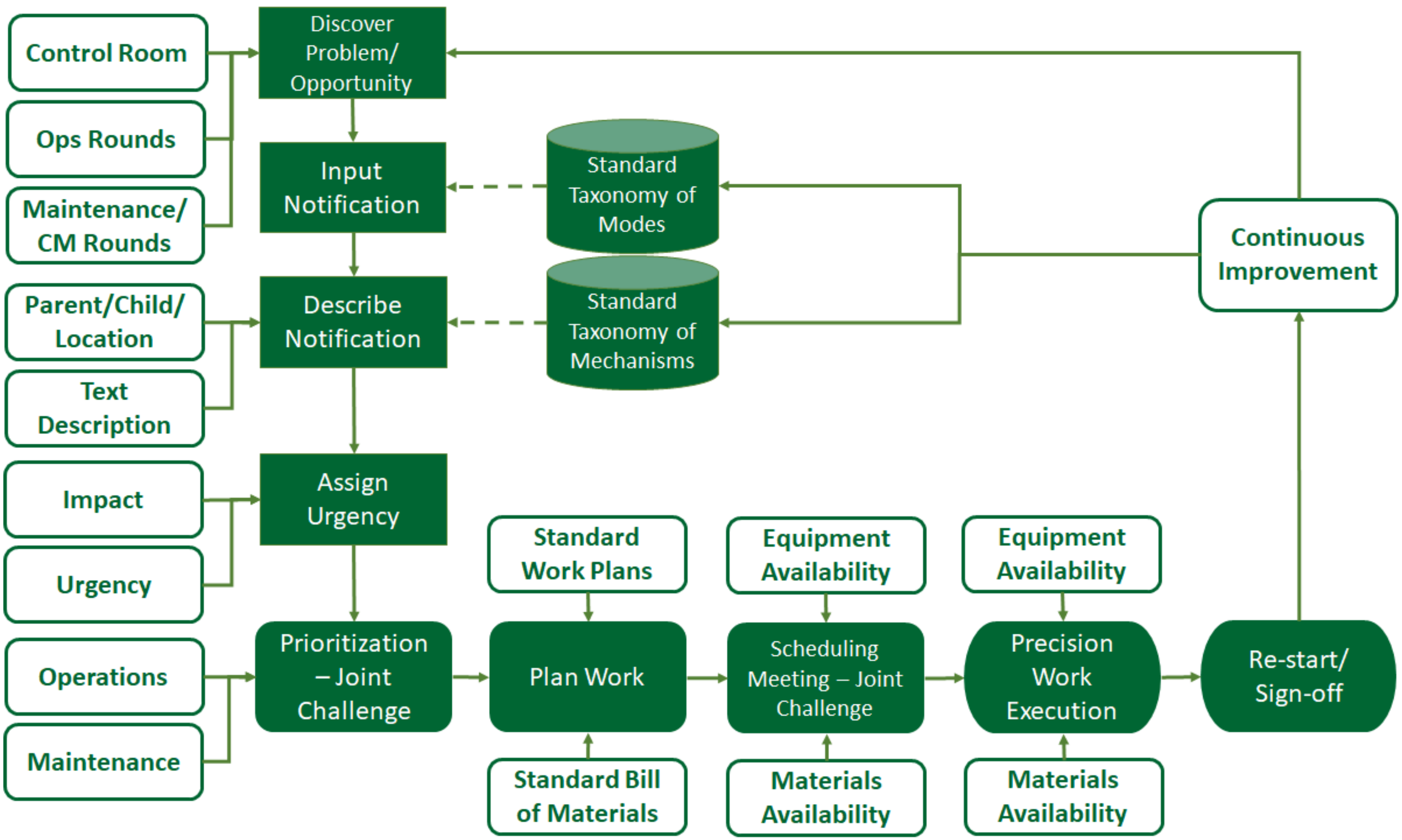
Standardizing Maintenance Work



Ref: DT

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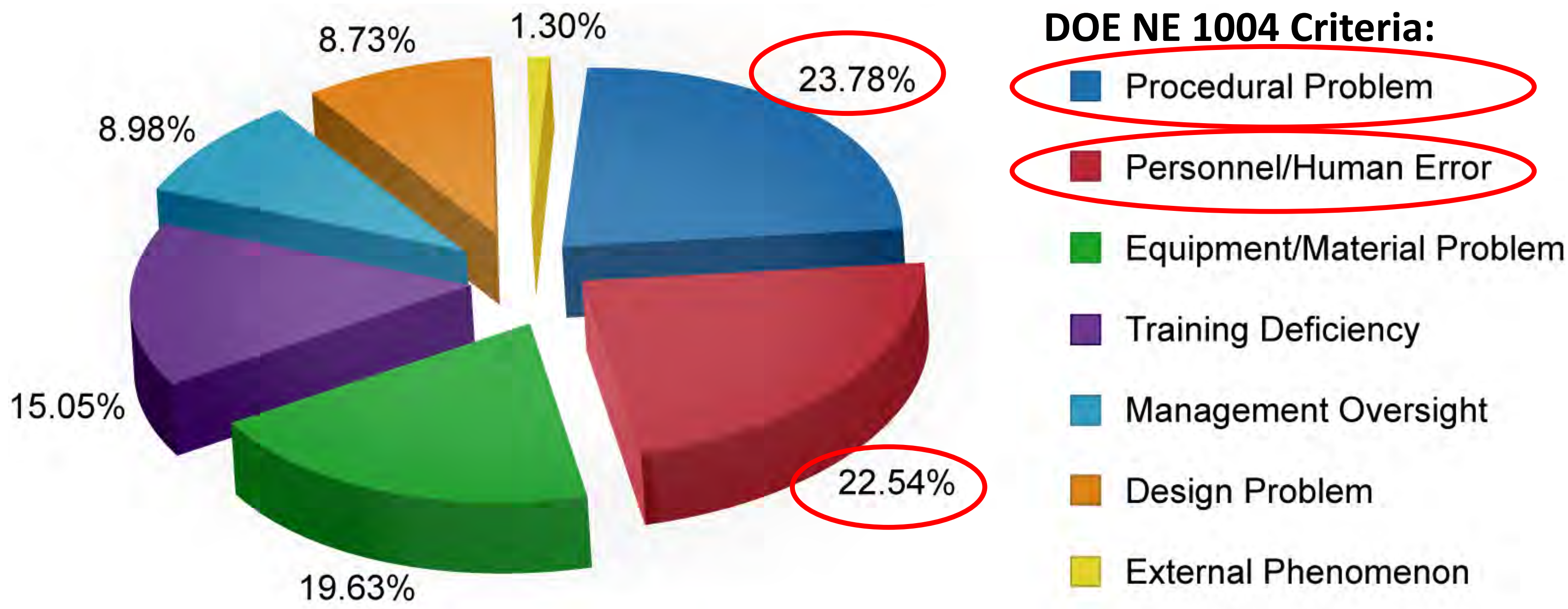
What Goes Wrong in the Plant



Source: D.Troyer, CRE – ReliablePlant Magazine

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FLAB Goal: "Do the Right Work Right!"

- **Find Work**
  - Inspections and monitoring
  - Standardized work requests
- **Manage Work**
  - Systematic prioritization
  - Focus on leading metrics
- **Prepare for Work**
  - Standard work plans/procedures
  - Fit/ tolerance/ quantity/ quality details
  - Materials and tools
- **Execute Work**
  - Skills and training
  - Work quality assurance

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Precision FLAB Management – The Devils in the Details

Wrong	Right
Check oil pressure.	Confirm that oil pressure is between [X_1] and [X_2] psi.
Check temperature of DE bearing.	Confirm that temperature of DE bearing is below [X°] F.
Grease electric motor.	Using [Y] grease, apply [X_1] grams to the DE and [X_2] grams to the NDE bearings of the electric motor.
Tension belt.	Tension belt to [X] lbf, verifying with [Y] tensiometer. Recheck after [Z] operating hours and adjust if required.

Lack of definition in the variable aspects of maintenance – the Xs, Ys and Zs – is killing us. We depend upon "Tribal Knowledge," which lacks precision.

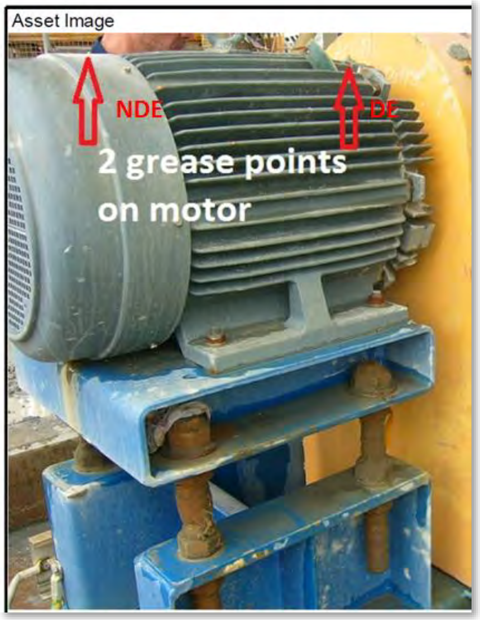
T.A. Cook

Example PM Procedure Elements

Instructions:

1. Remove the dust cap(s) from the grease fitting(s) on the bearing housing(s).
2. Carefully clean the grease fitting(s) with a clean lint-free cloth.
3. Inspect the grease fitting(s) for damage – replace if necessary.
4. Apply 6.7 ml/6.0 gm/6.0 shots of Mobilith SHC 100 grease to the Drive End (DE) bearing.
5. Apply 3.3 ml/3.0 gm/3.0 shots of Mobilith SHC 100 to the Non Drive End (NDE) bearing.
6. Apply grease at a rate of three (03) seconds per stroke cycle.
7. If back pressure exceeds 500 psi, slow greasing stroke.
8. If back pressure can't be held below 500 psi, discontinue greasing and report that bearing couldn't be greased due to excessive back pressure.
9. Reattach dust cap(s), replacing if missing or damaged.

Visual Aids



Mobilith SHC 100

With a very simple work instruction, the maintenance tech is equipped with the information necessary to carry out a precision lubrication task – no guesswork!

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Re: M. Williamson, KEWbic

Driving Precision Behavior with Leading Metrics

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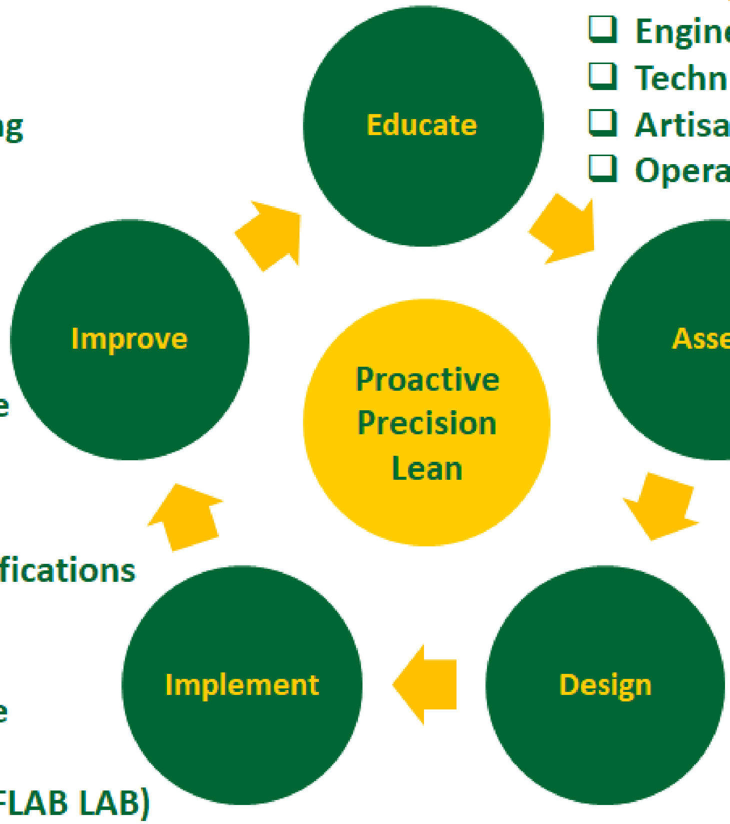
FLAB Management Implementation

FLAB Management Road Map



Educate
- ❑ Executives
- ❑ Managers
- ❑ Engineers
- ❑ Technicians
- ❑ Artisans
- ❑ Operators

FOCUS ON FLAB
Fasteners
Lubrication
Alignment
Balance

Assess
- ❑ Strengths
- ❑ Weaknesses
- ❑ Opportunities
- ❑ Threats
- ❑ Business Case
- ❑ Go/No-go Decision
- ❑ Strategic Plan

Design
- ❑ Equipment Modifications
- ❑ FLAB PM Work Plans
- ❑ FLAB Inspections
- ❑ FLAB Corrective Plans
- ❑ Operate 4 FLAB Reliability
- ❑ FLAB in MRO
- ❑ Metrics and KPIs

Implement
- ❑ Machine Modifications
- ❑ Coaching
- ❑ Mentoring
- ❑ Culture Change Management
- ❑ Task Training (FLAB LAB)
- ❑ Create a “New Business as Usual”

Improve
- ❑ Performance Monitoring
- ❑ FRACAS
- ❑ FLAB Czars and Gurus
- ❑ Optimization
- ❑ Continuous Improvement
- ❑ Management of Change
- ❑ Sustainability

T.A. Cook

Final Words

- Proactive and precision FLAB practices are “actionable reliability” – it’s where asset management hits the plant floor.
- The goal for FLAB management is to extend the life of the equipment by managing the root causes of wear and degradation.
- Precision work is dependent upon effective planning, scheduling and coordination of maintenance work.
- Stockouts, shelf degradation and other poor warehouse management practices compromise the objectives for precision maintenance.
- You’ll likely need some new tools to execute FLAB and in some cases, machines will require some minor modifications for FLAB maintainability.
- Precision maintenance demands clear work instruction with a focus on fit, tolerance, quantity and quality details.
- Culture change will be the biggest challenge – manage it effectively by rewarding proactive and precision behaviors that drive reliability,

T.A. Cook

Drew D. Troyer, CRE, CMRP

d.troyer@tacook.com

+1-918-691-1794

T.A. Cook