2020 Plant Performance & Plant Optimization Symposium

Setting Effective Goals, KPIs and Metrics for Your PdM Program





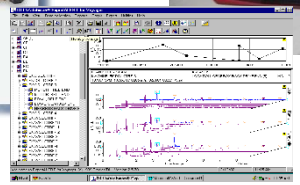
A little background….
What is Predictive Maintenance (PdM)?

Techniques designed to determine the condition of in-service assets in order to determine what type & when corrective action(s) should be performed.

Part of a conditioned-based maintenance approach that is more cost-effective than time-based maintenance activities. Corrective actions are performed when warranted based on asset condition, not calendar or hour/run meters.

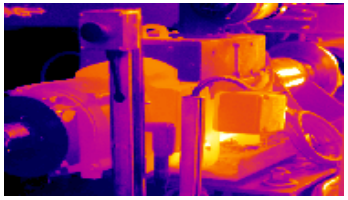
With early detection of impending failures, proper planning, scheduling, and replacement parts/material are in place to reduce maintenance time and avoid unplanned downtime events, thus driving productivity gains.

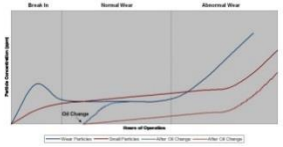
Predictive Maintenance Technologies



Vibration Monitoring

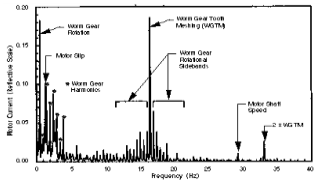
Thermography



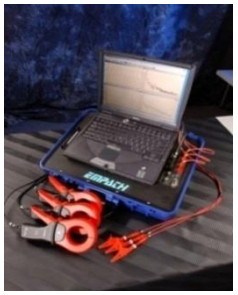


Oil Analysis

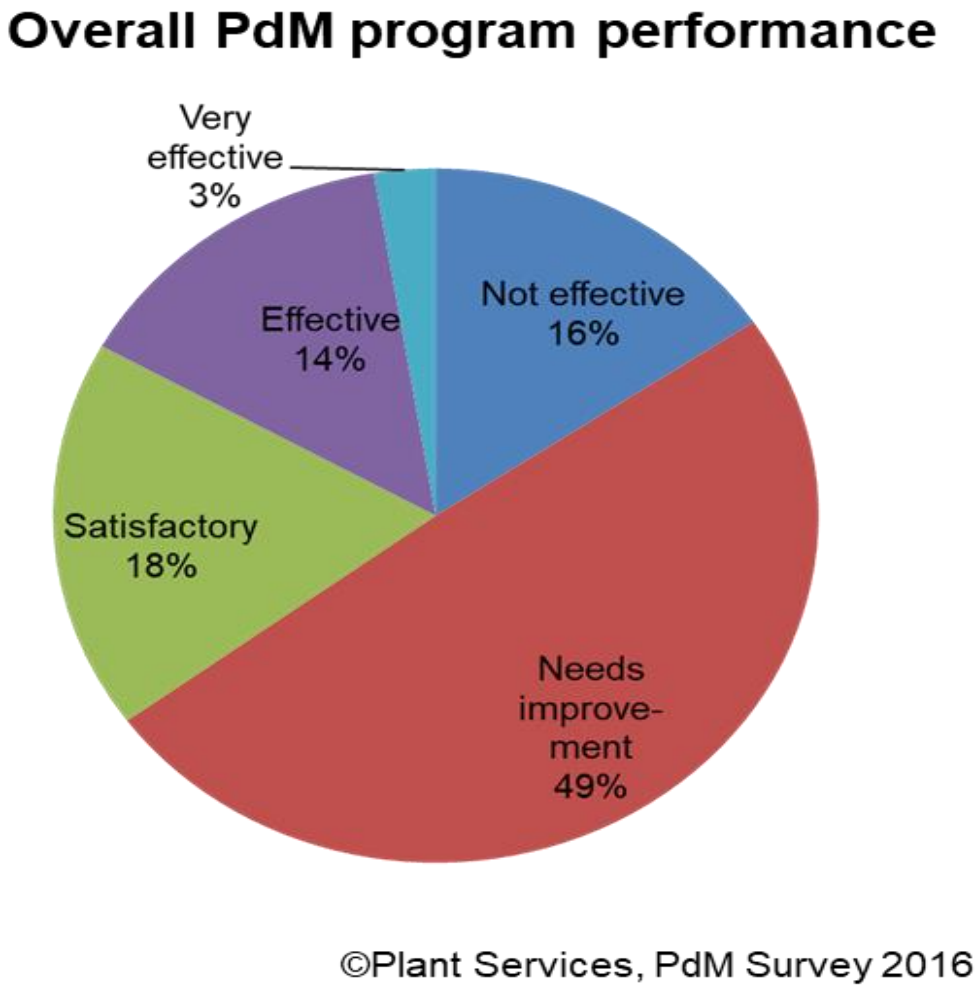
Ultrasound



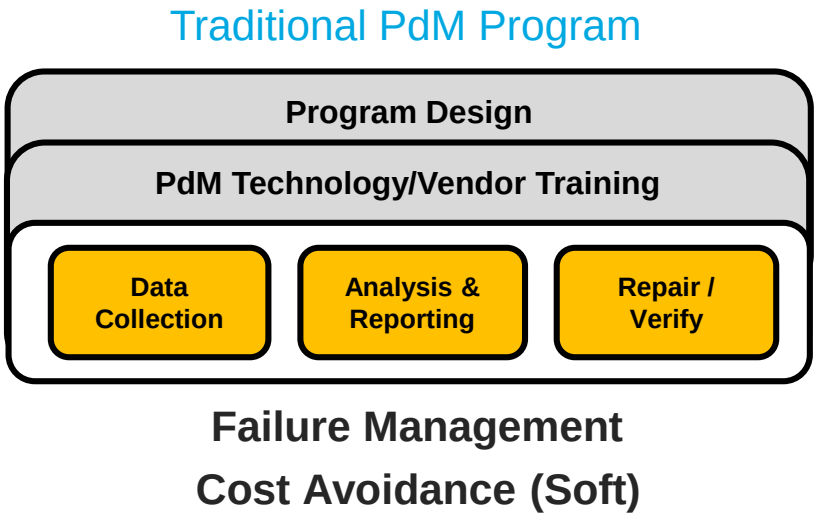
Motor Testing



Are programs achieving the desired results?



Traditional Program Design



Traditional Setup

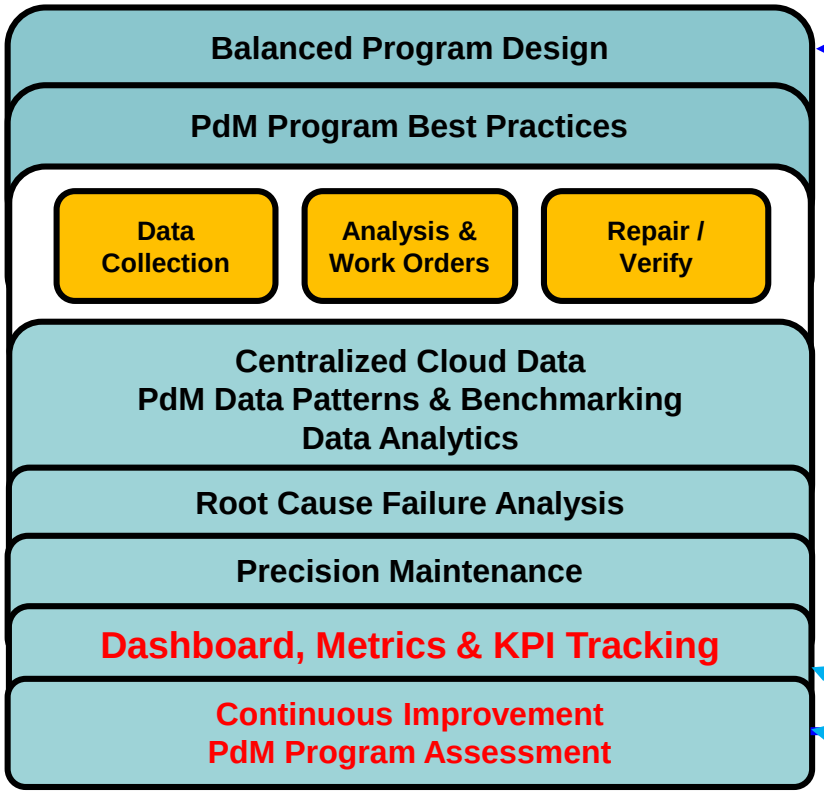
- Included assets are not risk based
- Data collection frequencies assigned globally
- Alarm thresholds assigned globally
- Minimal changes made throughout life of the program
- Typically “one size fits all”

“Manage the Program not the data”

Many PdM programs fail to achieve desired results because the program activities are mainly focused on completing the basic tasks (data collection, analysis & corrective actions) and less on analytics of the reliability and asset data.

Although these tasks are important, adding or enhancing program analytics should be a key for stakeholders who are responsible for improving maintenance and overall reliable operations.

Advanced PdM (aPdM) Design



Failure/Loss Elimination

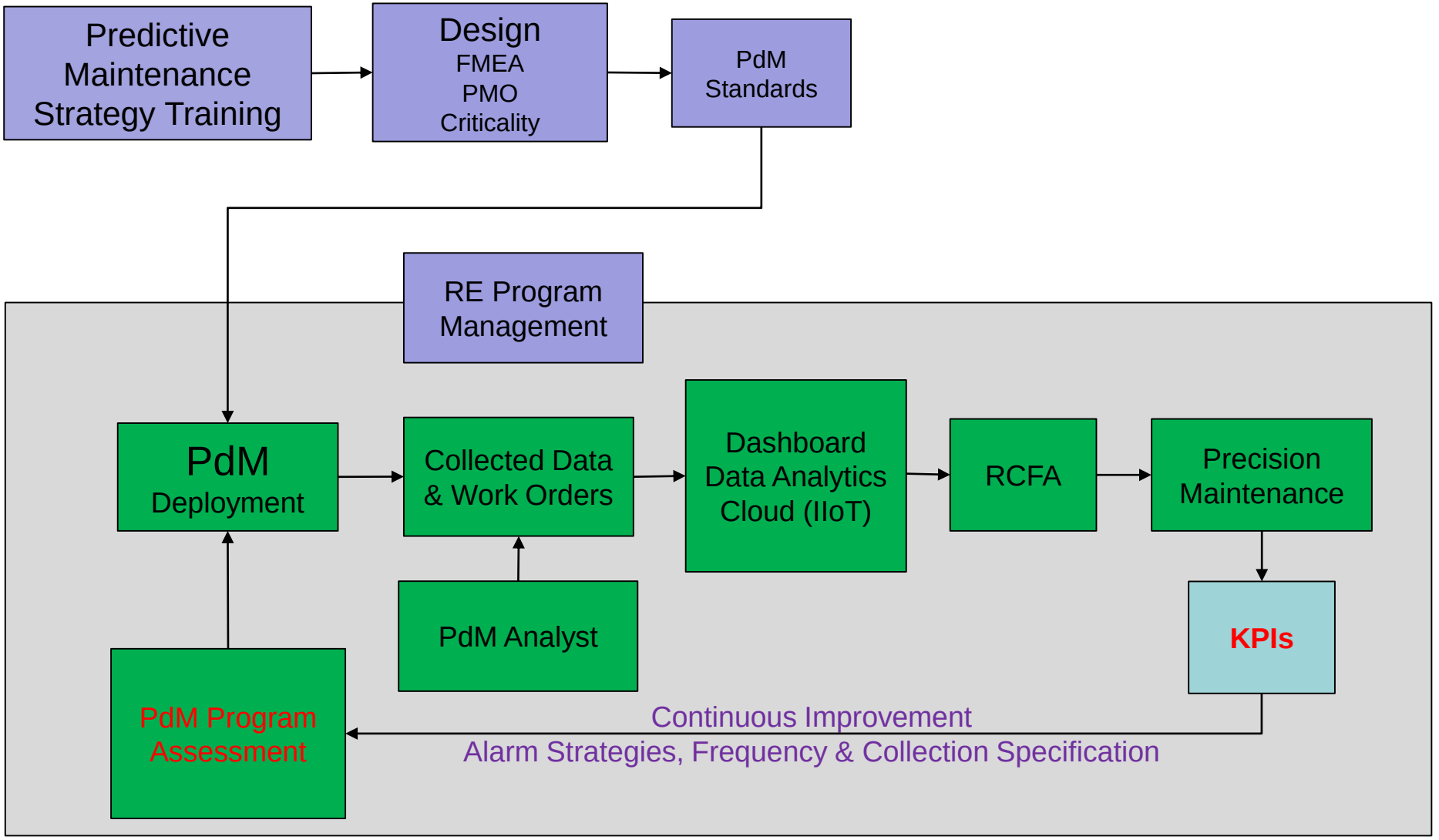
Cost Savings (Hard)

Balanced Design Criteria

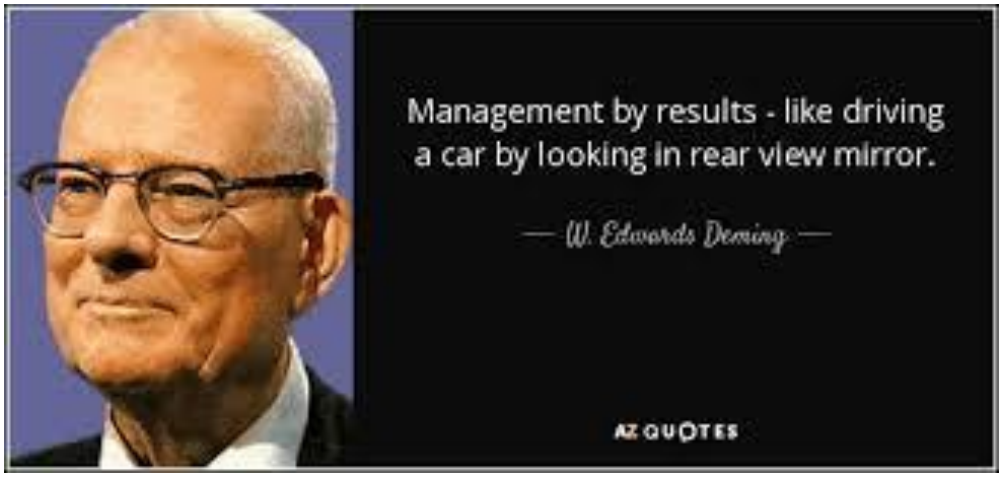
- Asset Criticality Analysis
- Failure Mode Mitigation
- PdM Discipline Assignment
- Frequency Decision
- **Cost Justification**

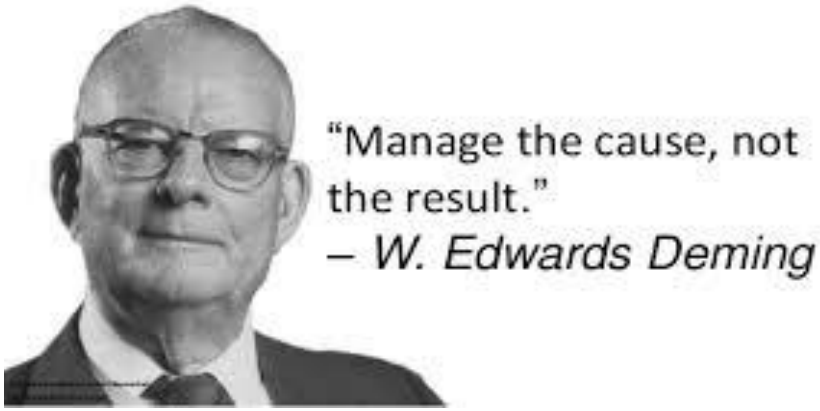
Our focus today!

PdM Program Integration Model



How do we manage a successful PdM program?

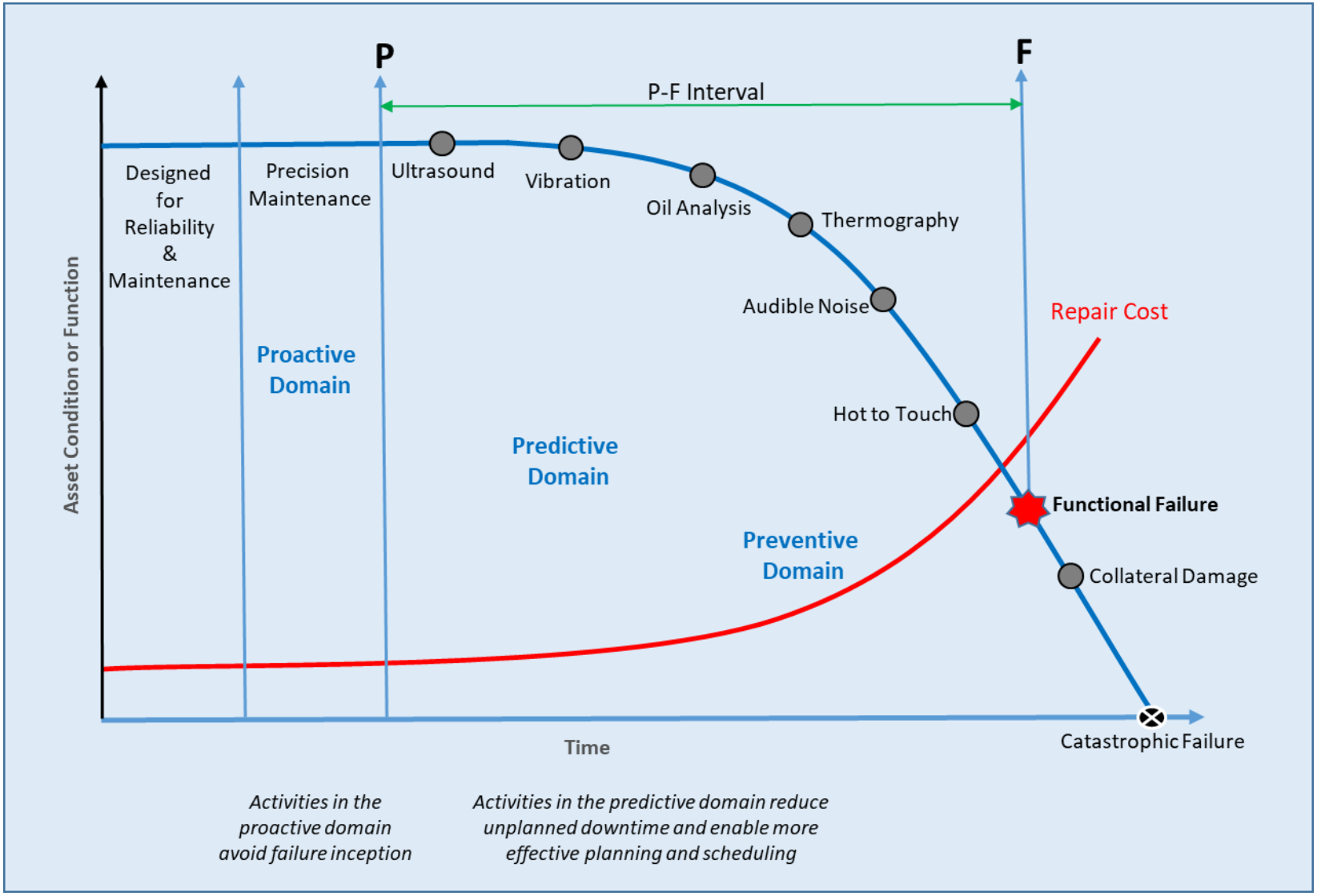




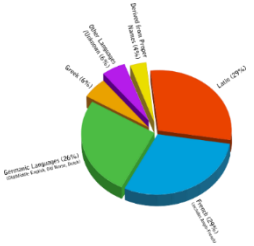
Reliability is the primary goal!

Reliability is - the ability that an apparatus, machine, or system will perform a required function *without failure* under stated conditions for a stated period of time.

PdM – “early warning” or “elimination”?



Key Performance Indicators (KPI) / Metrics



Program Performance Metrics	Program Efficiency Metrics	Asset Performance Metrics	Financial Performance

Program Performance Metrics

Measures findings/data of actions within your PdM program

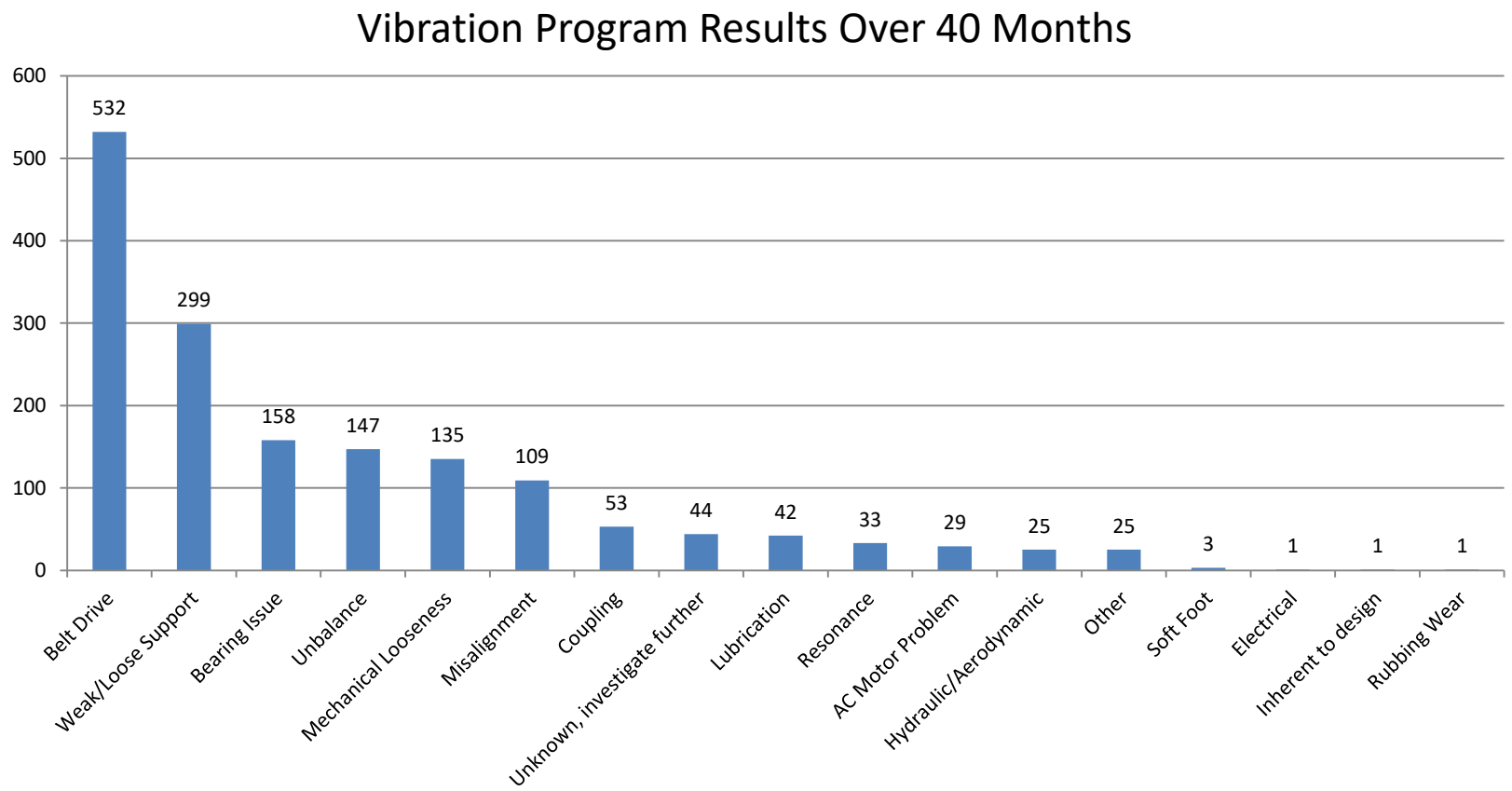
- Monthly number of:
  - Critical / Moderate / Minor faults
  - Normal findings
- CMs issued from a “PdM find”
- PdM Route completion rate
- Number of Assets with PdM applied
- Reoccurring failure tracking (faults found across all assets)
- Emergency work order percent versus planned corrective

Program performance metrics are the leading metrics for asset performance

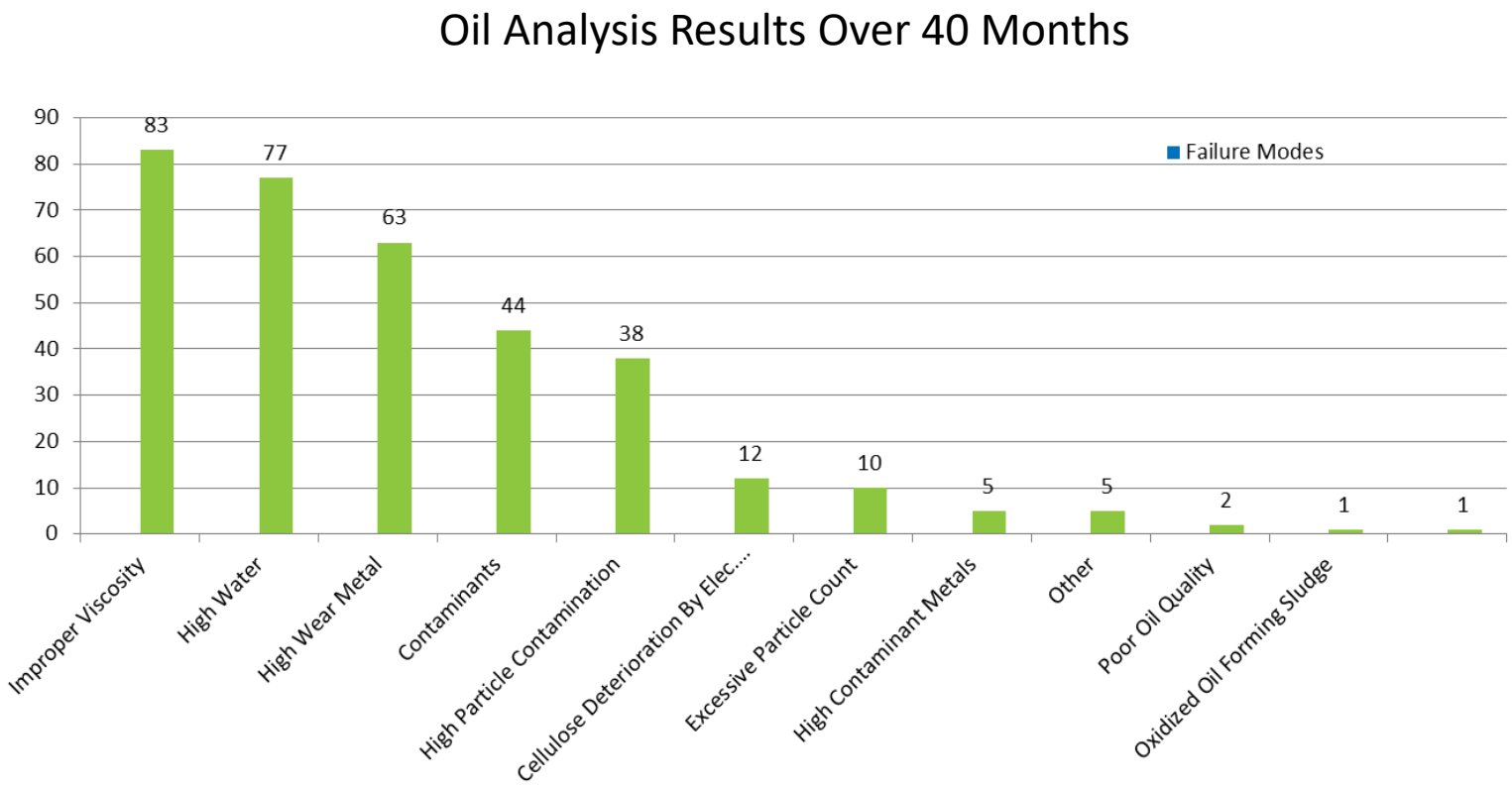
Work Order History

CLM-224786	Oil temp gauge broken	405904DC03C	DECANTER 3C	APPR	5/10/10
CLM-223507	Acturater on valve broke off	405903NV023	DECANTER 2C EVAP CONDENSATE BINARY VALVE	COMP	5/1/10
CLM-210817	Repair pin hole leak on feed inlet nozzle --- top floor	405902DC01C	DECANTER 1C	CLOSE	5/10/10
CLM-210816	feed line has loose bolts on flang---- go through and check all flanges on feed line	405902DC01B	DECANTER 1B	CLOSE	4/26/10
CLM-204141	install 6" blind on drain valve	405901TK02	CENTRATE TANK	CLOSE	3/8/10
CLM-203526	Replace lube oil pump	405902DC01A	DECANTER 1A	CLOSE	4/19/10
CLM-222340	Alarming on low oil flow to bearing	405902DC01A	DECANTER 1A	COMP	4/23/10
CLM-204210	Decanter shut down on lube oil system alarm	405902DC01AD	DECANTER LUBE OIL MOTOR 1A	CLOSE	4/5/10
CLM-208743	Motor turns but conveyor doesn't	4059UL05B	DECANTER 4 - WET FEED CONVEYOR	CLOSE	4/12/10
CLM-215288	City water flush line into feed line blew apart	405902DC01B	DECANTER 1B	COMP	4/21/10
CLM-207958	Feed valve fail opens-solinoid is bad	405903FV011	DECANTER 2B FLOW VALVE	CLOSE	4/5/10
CLM-222339	Decanter feed flange has a bolt missing & is leaking	405903FV011	DECANTER 2B FLOW VALVE	COMP	4/24/10
CLM-207026	Change oil filter	405904DC03B	DECANTER 3B	CLOSE	4/19/10
CLM-215663	Complete PM work	405904DC03A	DECANTER 3A	COMP	3/8/10
CLM-218756	Flush valve alarms closed fail	405904NV003	DECANTER 3A EVAP CONDENSATE BINARY VALVE	COMP	3/30/10
CLM-205438	Keeps shutting down on low oil flow	405905DC04B	DECANTER 4B	CLOSE	4/19/10
CLM-210881	Lube oil pump is running but is not showing pressure	405905DC04C	DECANTER 4C	CLOSE	4/26/10
CLM-205742	Replace the lube oil motor with one that is inverter rated	405904DC03BD	DECANTER LUBE OIL MOTOR 3B	CLOSE	4/5/10
CLM-204654	Change defective lube oil motors on Decanters 1A,	405903DC02CD	DECANTER LUBE OIL MOTOR 2C	CAN	12/30/09
CLM-204653	Change defective lube oil motors on Decanters 1A,	405903DC02CD	DECANTER LUBE OIL MOTOR 2C	CLOSE	3/1/10
CLM-209437	Replace the fuses that were taken from decanter 3A and 3C	405904DC03A	DECANTER 3A	CLOSE	5/10/10
CLM-204655	Change defective lube oil motors on Decanters 1A,	405903DC02BD	DECANTER LUBE OIL MOTOR 2B	CLOSE	3/1/10
CLM-218152	Decanter 2A tripped out on Phase Loss. Wires from the drive to the contactor failed	405903DC02A	DECANTER 2A	APPR	3/26/10
CLM-209193	Troubleshoot the crane in the evap/decant building	4059HO01	DECANTER OVERHEAD CRANE 1	CLOSE	4/19/10
CLM-204652	Change defective lube oil motors on Decanters 1A,	405902DC01AD	DECANTER LUBE OIL MOTOR 1A	CLOSE	3/22/10
CLM-218326	Install LO/TO/TO tags and voltage warning tags on the decanter VFD cabinets.	405902DC01A	DECANTER 1A	COMP	3/30/10

Reliability Trends

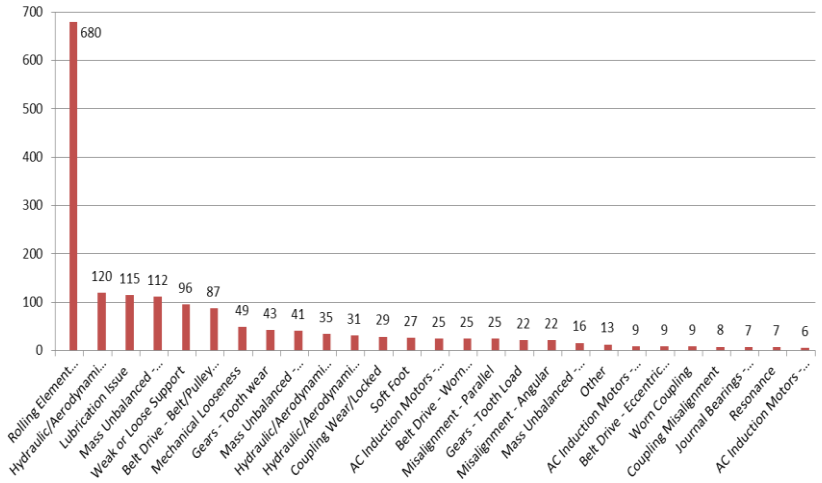


Reliability Trends

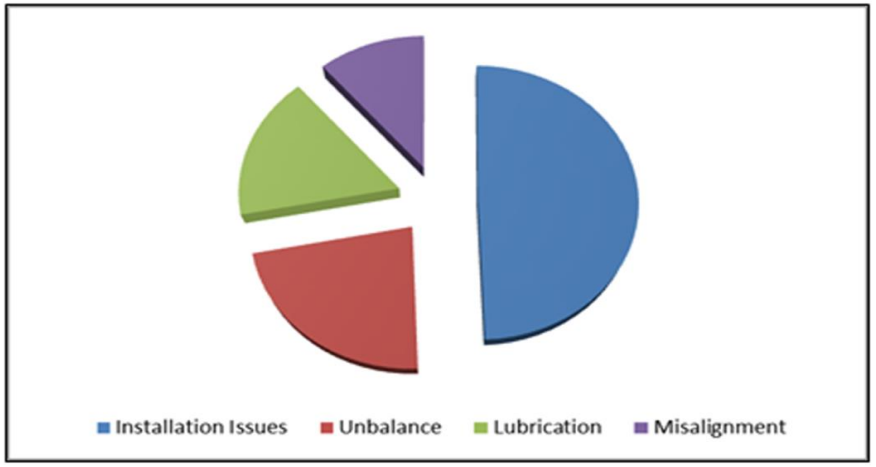


Example - reoccurring failure patterns

Statistical Analysis of Vibration Program's Results over 40 Months



Root Cause Analysis Results of the top reoccurring failure – rolling element bearing faults



Precision Maintenance training for installation issues

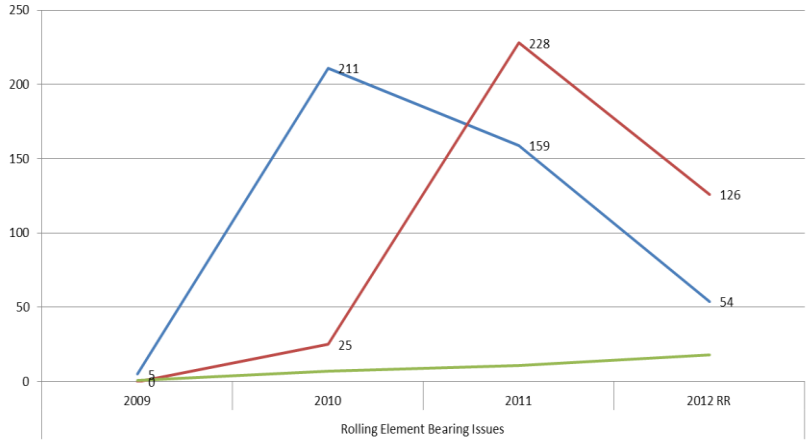
Handling Precautions:

- Store in **clean**, dry area with minimal vibration
- Keep bearing in original packaging until needed
- Hands should be **clean** and dry
- Keep surrounding area **clean**
- Do not wash new bearings
- Keep bearings covered when not in use

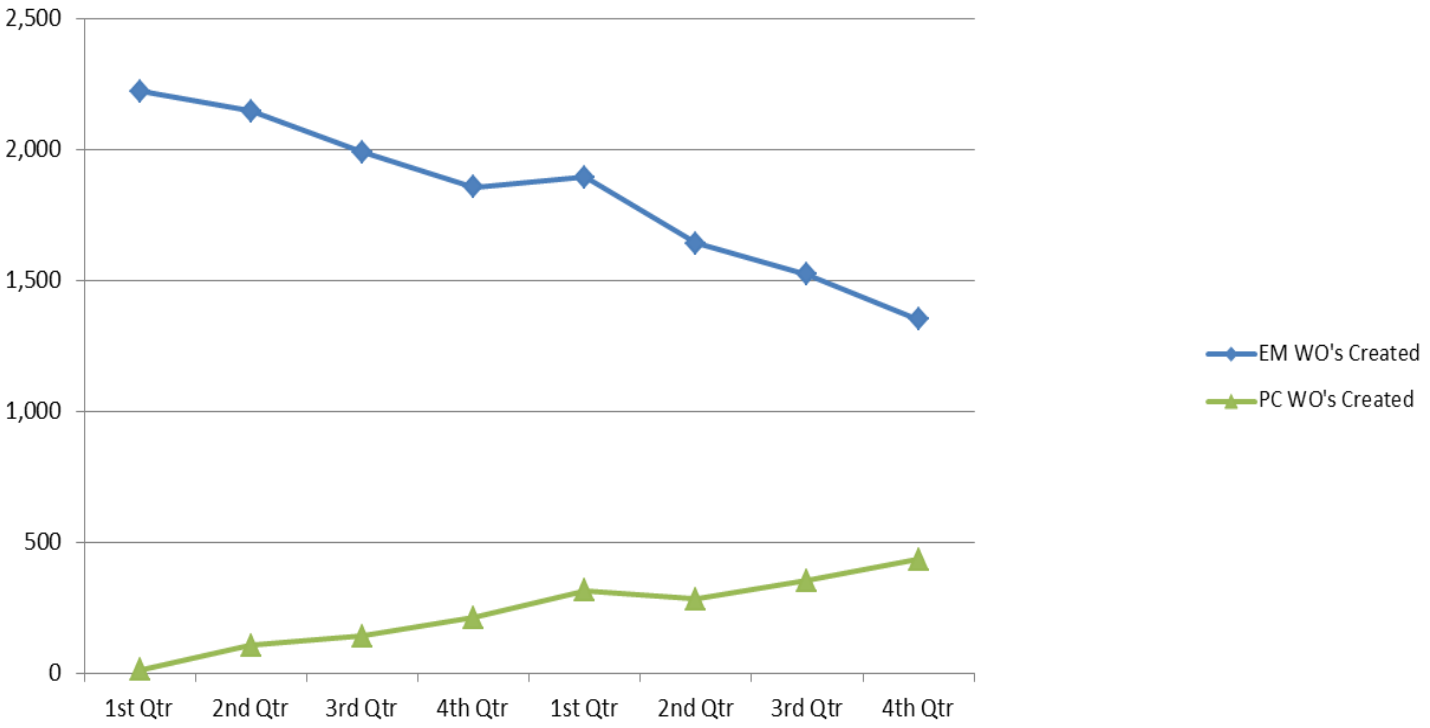
Mounting Considerations:

- Use Proper, Unworn Tools
- Clean Shaft and Housing
- Check Shaft and Housing Dimensions
- Ensure Proper Alignment
- Support Proper Bearing Ring
- Avoid Impacts on Bearing - No Hammers!

Resulting in a decline in reoccurring failures YOY, eliminating failures



Tracking Problem Severity



Program Efficiency Metrics

Measure of the PdM's execution (in-house or out-sourced)

- Assets/Points per man-hour
- Percent of skipped or missed points
- Ratio between data collection time versus analysis time
- Data collected on scheduled
- Data analyzed/reported on time
- Hours planned versus actual versus budgeted
- Problem found (calls) vs. work performed
- Equipment coverage

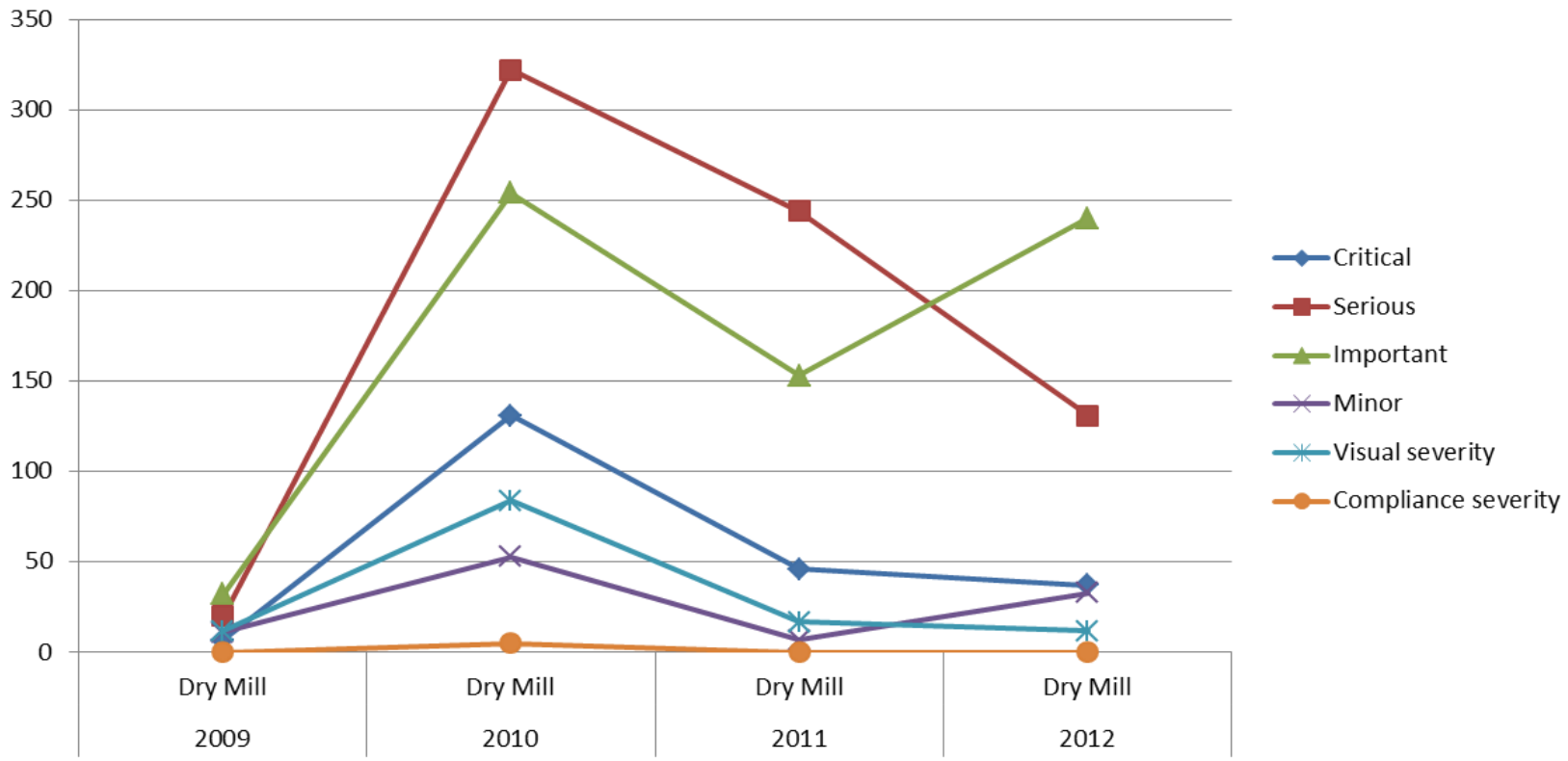
Asset Performance Metrics

Measures how well an asset is able to perform its function as intended

- Mean time between failure (MTBF)
- Uptime
- Unscheduled downtime
- Missed failures from applied PdM
- Mean time to repair (MTTR)
- Bad Actors
- Reliability Index by asset type/class

The PdM program may not be the main influencer of these metrics. Other facility actions may affect these metrics

Tracking Problems by Severity



Tracking Problems by Type & Severity

Infrared Results by Problem Type and Severity

The number of documented Thermal Problems were 198.
The average delta temperature of a Thermal anomaly was 36.83°F

Categories and breakdown of problems:

Item	Quant.	% of Total
Panelboard issues	102	51.51%
Switchboard issues	34	17.17%
MCC Buckets issues	17	8.59%
Fused Disconnect issues	16	8.08%
Contactor issues	15	7.58%
Others	14	7.07%

The criticality of the problems found:

Category	Quant.	% of Total
Critical	26	13.13%
Serious	59	29.80%
Important	65	32.83%
Minor	48	24.24%

Tracking Problems by OEM

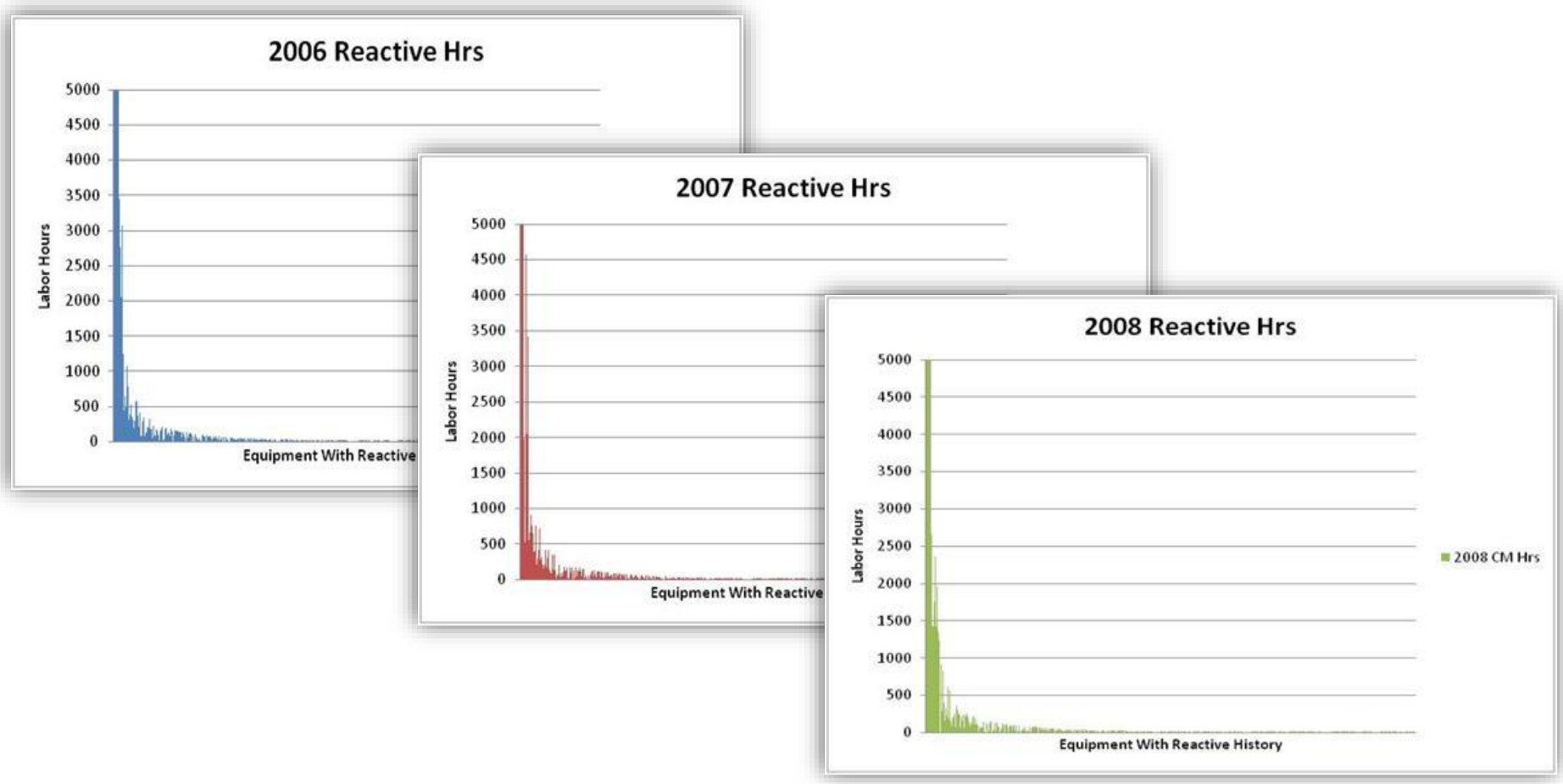
Benchmarking – Infrared Results by OEM

Manufactures listed had 100 or more pieces of equipment surveyed

MANUFACTURER	# of Anomalies	% of Equipment Inspected	% of Problems	% Problem Likelihood
Federal Pacific*:	10	0.79%	5.05%	45.45%
General Electric:	41	11.91%	20.71%	12.31%
ITE:	21	8.05%	10.61%	9.33%
Square D/Topaz:	38	15.31%	19.19%	8.88%
Siemens:	19	9.23	9.60%	7.36%
Westinghouse:	18	12.56%	9.09%	5.13%
Cutler Hammer:	6	6.30%	3.03%	3.41%

***Only 22 pieces inspected**

Bad Actor Identification
Work History Analysis



Financial Performance Metrics

Measure the amount of cost savings and cost avoidance from the PdM Program

- Cost savings (hard)
  - Direct savings (example energy)
  - Eliminating reoccurring failure
- Cost avoidance (soft)
  - Cost of failures avoided per PdM “find”

Financial Performance Metrics

Value per PdM “Find”

- Determine what the cost ***would have been*** if PdM wasn’t used on this asset
  - Account for the probability of identifying the failure before it was catastrophic
  - Account for the percentage of time the asset is in “production” operation
- Specific to the failure mode of the specific asset

Financial Performance Metrics

(Cost Avoidance) = (Projected Failure Cost) - (Actual Cost of Repair)

Projected Failure Cost =

- Avoided lost production cost +
- Avoided labor costs +
- Avoided parts/material costs

Actual Cost of Repair =

- Actual lost production (scheduled) cost +
- Actual labor costs +
- Actual parts/material costs

Financial Performance Metrics

How do I calculate avoided lost production?

- Would equipment failure have eventually led to unscheduled downtime?
  - If Yes, then estimate % of time the asset is directly supporting production
  - Estimate cost of downtime ($/hr)
- What is the probability of identifying failure before it was catastrophic?
  - Based on equipment location, failure mode, notifications, alarms, other maintenance activities (%)
- Were probable parts needed in-stock?
  - If No, determine time to expedite parts (hours)
  - If Yes, determine the length of repair (hours)

-OR-

- Projected Failure Cost – determine a standard to use for consistency (3x model)

Financial Performance Metrics

Actual Repair Cost - Nov/02/2007:	
Labor:	$90.00
Rate:	$90.00
Hours:	1 hrs
Materials:	$55.00
Misc. Costs:	$15.00
Total Repair Costs:	**$160.00**

Failure Cost:	
Labor:	$180.00
Rate:	$90.00
Hours:	2 hrs
Materials:	$55.00
Misc. Costs:	$0.00
Total Failure Costs:	**$235.00**

Lost Production Impact:	
Plant Annual Revenue:	$40,000,000.00
Est. Failure Downtime:	6 hrs
Revenue Impact:	15.00%
Total Lost Production Impact:	**$4,120.88**

Energy Savings:	
Temperature Δ:	17.00 °F
Cost/KWh:	$0.09
Operating Hours:	168 hrs/wk
Total Energy Savings:	**$287.37**

Financial Performance Metrics
Energy savings examples

Quantifying Compressed Air Loss and Savings From a Survey

The going estimate in the field is that about 30% of all compressed air is wasted through leaks.

Here's a simple formula that can be used to estimate the loss/savings of your compressed air survey.
$S=(L/4.2)(0.746)(T)(C) \div 0.90$

S = Annual Savings, $
L= Air loss, cfm
4.2 = average number of cfm/bhp. This is based on manufacturers' equipment data*
0.746 = average power requirement in kW/bhp to generate one bhp
T = hours of operation
C = Cost per kWh
0.90 = motor efficiency factor

Example: 100-hp air compressor produces 450 cfm of air
Electrical cost of $0.08/kWh
Air leaks amount to 25%.

25%(leaks) of 450 cfm = 112.5 cfm (this is L)

112.5/4.2 cfm/bhp = 26.8 bhp

26.8bhp x 0.746kW/bhp = 19.9928 (kW)

19.9928kW x 8760 hrs (24 hrs/day, 365days/year) = 175136.9 kWh

175136.9 x $0.08/kWh = $14010.95

$14010.95 ÷ .90 = $15,567.72

Estimating steam loss example:

Assume: 3/8-inch-diameter orifice steam trap, 50% blocked, 60 psia saturated steam system, steam system energized 4,380 h/yr (50% of year), boiler efficiency 75%.
For 3/8 inch orifice and 60 psia steam, steam loss = 2,500 million Btu/yr
Assuming trap is 50% blocked, annual steam loss estimate = 1,250 million Btu/yr
Assuming steam system is energized 50% of the year, energy loss = 625 million Btu/yr
Annual fuel loss including boiler losses = [(625 million Btu/yr)/(75% efficiency)] = 833 million Btu/yr

Financial Performance Metrics
Energy savings examples

Energy Savings Formula

$$kW = \frac{volts \times amps}{1000} \times PF \times 1.732$$

- **kW** – kilowatt
- **Volts** – voltage used in the application
- **Amps** – difference in amperage (before – after repair)
- **1000** – takes the total watts and by dividing makes it kilowatts
- **PF** – Power factor
- **1.732** – the square root of three for 3 phase power

Once the kW is determined a second formula is required to determine the annual savings:

$$\text{Annual Savings} = hrs \times kW \times \$ / kW$$

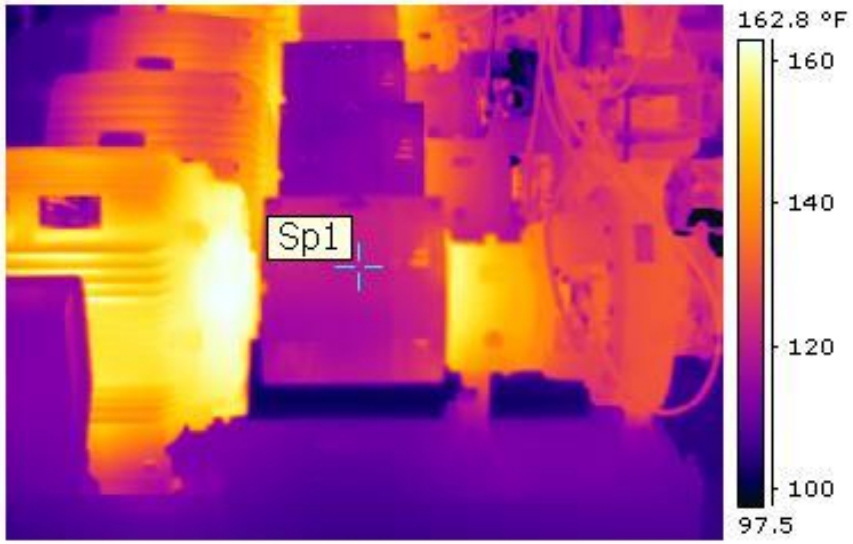
Breaker With Temperature Anomaly

- 171 ^{o}F Anomaly
- 73 ^{o}F Ambient
- 480 Volts
- Rated 100 amps
- Measured 38 amps
- Two other legs average 35.5
- Loose connection
- Calculations:
  - 38 - 35.5 = 2.5
  - 480 x 2.5 x .87 x 1.732 / 1000 = 1.808 kW
  - 8760 x 1.808 x $.08/kW
  - **$1,267 annual savings**

Rule of Thumb:
70% of electrical problems are caused by loose connections

Hot Motor – Amperage Differential

- 480 volt 100 hp motor and pump running 50 degrees hotter than others - 100% loaded
- 93 Degrees hotter on one of the legs
- The hot leg is drawing 45 amps and the others are at 30 amps each.
- Loose connection
- **This 15 amp differential is wasting $7,174 annually**

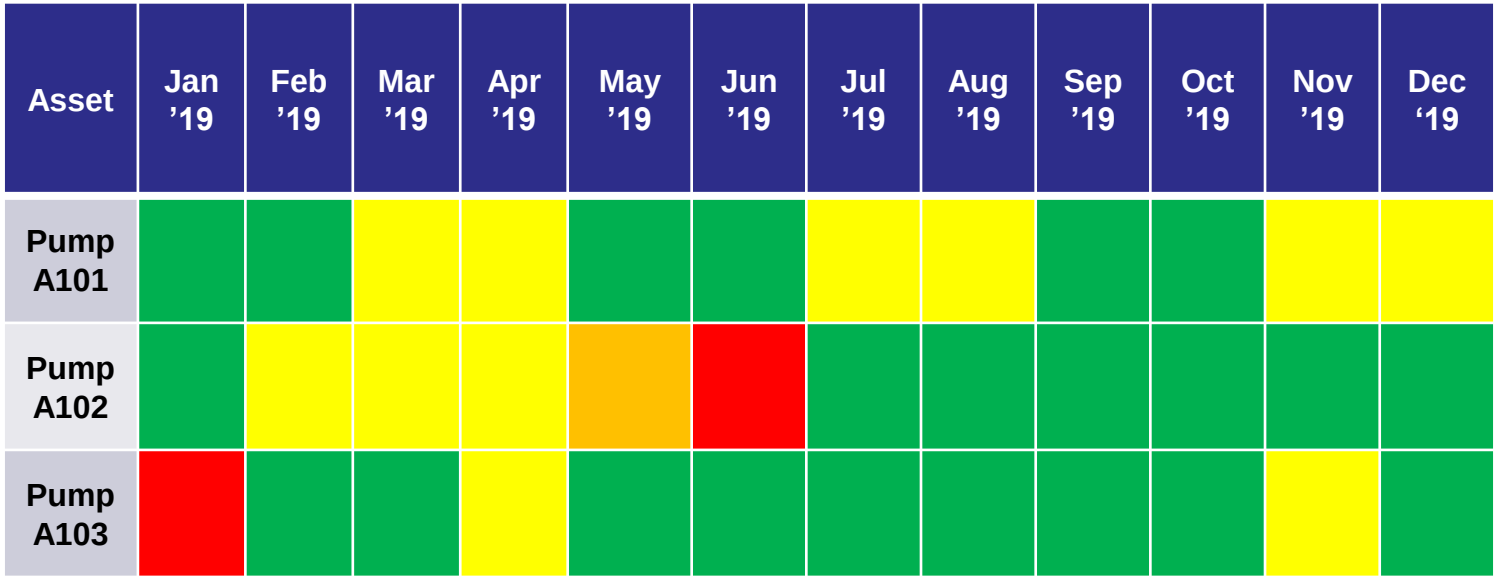


Communicating Results

- Communicating PdM program status and results is extremely important!
  - Reliability and cost avoidance can be a blind-spot to upper management and the site
  - It's our responsibility (and best interest!) to share our findings
- Metrics from previous slides, energy savings, and cost avoidance logs should be communicated regularly

Dashboard Reporting

Utilize visual reporting style for critical assets



Asset	Jan ’19	Feb ’19	Mar ’19	Apr ’19	May ’19	Jun ’19	Jul ’19	Aug ’19	Sep ’19	Oct ’19	Nov ’19	Dec ‘19
Pump A101												
Pump A102												
Pump A103												

Chart Legend:
Red – Critical **Orange** – Moderate **Yellow** – Minor **Green** – Normal

PdM Program Assessment

Assessment Results Dashboard

Program Management	Awareness & Site Support	Sharing Results (Communicating)	Continuous Improvement	Audit & Review	Resourcing
Measuring & Acting on Results	KPIs	Program Performance Metrics	Financial Perfromance Metrics	RCA Reducing Failures	Corrective Actions
Technology Application	Vibration	Ultrasound	Thermography	Oil Analysis	Other Technologies
Applying your Program	Data Collection	Analysis	Route Management	Non-Route Applications	Contractor Management
Setting up Program	Methodology for Choosing Equipment	Roles & Responsibilities / Stakeholders	Defined Goals & Processes	Training/Skills	Systems/CMMS Setup

2.0 Excellence
- Meets Best-of-Class Standards and is universally applied

1.5 Proactive
- Meets Best-of-Class Standards, but is not universally applied

1.0 Emerging
- Approaches Best-of-Class Standards, but is not universally applied

0.50 Needs Improvement
- Processes and Methods are lacking throughout the program

0.00 Not True
- No indication that process or procedure exists within the program

PdM Program Self-assessment tool

Predictive Maintenance Program Self Assessment

1	What method was used to determine the assets covered in the PdM Program?		0
2	Do you have a PdM strategy/charter and defined PdM program procedures in place?		0
3	Do you have documented minimum training standards and minimum experience requirements for PdM data resources?		0
4	Do you have documented objectives and goals for your PdM program?		0
5	Do you have defined roles and responsibilities for the PdM program?		0
6	Do you have a PdM program champion who promotes the program within the company management & leadership team?		0
7	Is the primary reason for your PdM program		0
8	How often are multiple technologies used to confirm a PdM find?		0
9	Does your program trend machine conditions over time to maximize maintenance effectiveness?		0
10	Are your PdM tools used for troubleshooting problems ad hoc?		0

KPI / Metric descriptions and sources

Program Metrics	CMMS	Include at startup	Possible 6 – 12 Months
Number of PdM related problems found and corrected per month. This metric is a count and resulting status of work orders created from the analysis/recommendations associated directly to the reliability program at the end of each month. This is work that comes directly as a result of the PdM report identifying problems found from inspection associated with current PdM technologies. This tracking requires the ability to associate a work order as generated as a result of the PdM program.	X	X	
Number of PdM related problems/work orders open at the end of the month. This metric is a count of "open" status work orders created from the analysis/recommendations associated directly to the reliability program at the end of each month. This is work that comes directly as a result of the PdM report identifying problems found from inspection associated with current PdM technologies. This tracking requires the ability to associate a work order as generated as a result of the PdM program.	X	X	
Number of PdM related jobs over 30, 60, and 90 days old. This metric is a count of aged open work orders created from the analysis/recommendations associated directly to the reliability program at the end of each month. This is work that comes directly as a result of the PdM report identifying problems found from inspection associated with current PdM technologies. This tracking requires the ability to associate a work order as generated as a result of the PdM program.	X	X	
Number of spare parts eliminated from inventory as the result of the PdM Program. This metric is a count of spare parts removed from inventory (either removed or reduced on hand count minimums) as a result of analysis/condition associated directly to the reliability program at the end of each month. Spare part reduction can be directly related to having better, timelier information regarding maintenance needs and the ability to order parts just in time.	X		X
Number of overdue Preventive Maintenance jobs at the end of the month. The total number of deferred PM actions should increase as PdM Program matures. This metric is a count of deferred hours/costs associated with scheduled preventive maintenance (PM) work orders not performed as a result of analysis/condition associated directly to the reliability program at the end of each month.	X		X
Mean Time Between Failures (MTBF) This metric is a calculation applied to PdM program equipment that measures and tracks/trends the time between equipment failures. For the purpose of this metric, the term failure would need to be defined.	X	X	
Mean Time To Repair (MTTR) This metric is a calculation applied to PdM program equipment that measures and tracks/trends the time between equipment repairs.	X	X	

Adobe Acrobat Document

Thank You - Questions

John Pucillo
Reliability and Condition Monitoring SME
jjpucillo@msn.com
513-507-5846

www.johnpucillo.com