Setting the Standard for Automation™

Analysis of Instrumentation Failure Data

A structured approach

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Current role, Matt is working as a corporate leveraged resource to assist sites in North America in implementing reliability programs for mission critical electrical and instrument equipment.

Agenda

- What is Reliability?
  - Reliability
  - What is a Failure?
  - Mean Time Between Failures
  - Availability
- Using Reliability to eliminate Failures
  - Predictive Maintenance
  - Test and Inspection
  - Calibration Verification

What is Reliability

- Reliability measures the likelihood of failure free operation for a specific time period
- Reliability is always a function of time.
- Reliability calculation assumes no maintenance is performed during the time cycle (t).
- Reliability is related to MTBF but they are not the same

$R(t) = e^{-t/MTBF}$ If MTBF = 365 days and t = 100 days

R(100) = .76 or 76% reliability

What is a Failure?

- Reliability is the key performance indicator for predictive maintenance
- Starts with defining failures
- Failure is a *loss of desired function*
- Failure modes are important
- The definition of a failure is different depending on the organization and application.
  - Loss of function
  - Loss of performance
  - Noise or diagnostic indication of a failure
  - Calibration verification outside of acceptable range.
- Reliability assumes that design/installation meets the required performance

What is a Failure?

- Failure is an *inability to perform a desired function*
  - Specific for the device and application
- ISO 14224:2006 Petroleum, Petrochemical, and Natural Gas Industries
  - Failure definitions and failure codes
  - Standard format and terminology
  - Facilitates the exchange of information between parties
  - Requires every failure to use standard coding (work history)
- For functional safety need additional coding
  - Dangerous or Safe Failures
  - Detected or Undetected Failures

What is a Failure

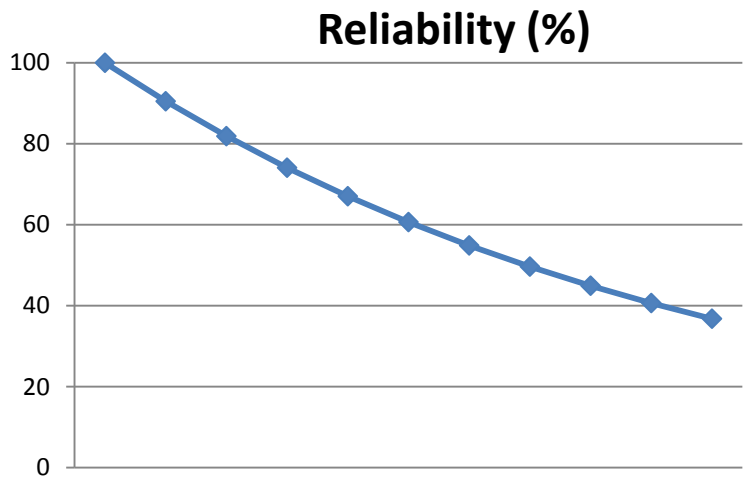
Functional Safety Term	Definition
Failure-Safe (Undetected/Detected)	The failure does not have the potential to put the safety-related system in a hazardous or fail-to-function state.
Failure-Dangerous (Undetected/Detected)	The failure prevents a safety instrumented function from performing its automatic protection function.
Annunciation (Undetected/Detected)	Enter this if the failure prevents automatic diagnostics from detecting or annunciating that a failure has occurred inside the equipment.
Undetected/Detected	*For each failure either detected or undetected must be selected. If detected by automatic diagnostics performed in the safety instrumented system or BPCS, select Detected. If discovered during testing, inspection, troubleshooting, observation, or incidents, select undetected.*

Failures Dangerous-Undetected: Discovered by testing or demand

Reliability

Graph of R(t) from t=0 to t=MTBF

- $R(t) = e^{-t/MTBF}$
- At (t=MTBF) R(t) = 36.8%
- Airplane engine with a 10,000 hour MTBF on a 10 hour flight → R(10) = 99.9%
- If the flight is 20 hours instead, R(20) = 99.8%
- R(∞) = 0%



Originally intended for operation when maintenance is not possible, i.e., space flight or airplane flight

Mean Time Between Failure

- Mean Time Between Failure (MTBF) can be used whether or not maintenance is performed between failures.
- MTBF does not normally include end of life failures

$$MTBF = \frac{(TxP)}{N}$$

Where:

T = Observation Time

P = Population (number of units included in calculation)

N = Number of Failures

Mean Time Between Failure

Equipment Class	# installed	# of Failures in 24 months	MTBF
Pressure Transmitter	**53**	**3**	**35 years (2*53)/3**
Temperature Transmitter	**150**	**5**	**60 years (2*150)/5**
Control Valves	**50**	**4**	**25 years (2*50)/4**

* The table (above) is an example and not intended to describe a particular plant

$$MTBF = \frac{(T*P)}{N}$$

Mean Time to Restore (MTTR)

- Includes time to detect that a failure occurred, time to diagnose problem, and time to make the repair.

Mean Time to Failure (MTTF)

- (MTBF – MTTR)

Mean Time Between Failure

Availability – The probability that a device is successful at time *t* when needed and operated within specified limits

Typically, availability is calculated as an average over a long time interval. This is referred to as “steady state” availability.

Where reliability, R(t) is always a function of time, availability is a function of failure rates and restore rates.

$$A = \frac{MTTF}{(MTTF + MTTR)}$$

Availability is improved by increasing MTTF or decreasing MTTR or both.

Mean Time Between Failure

$$A = \frac{MTTF}{(MTTF + MTTR)}$$

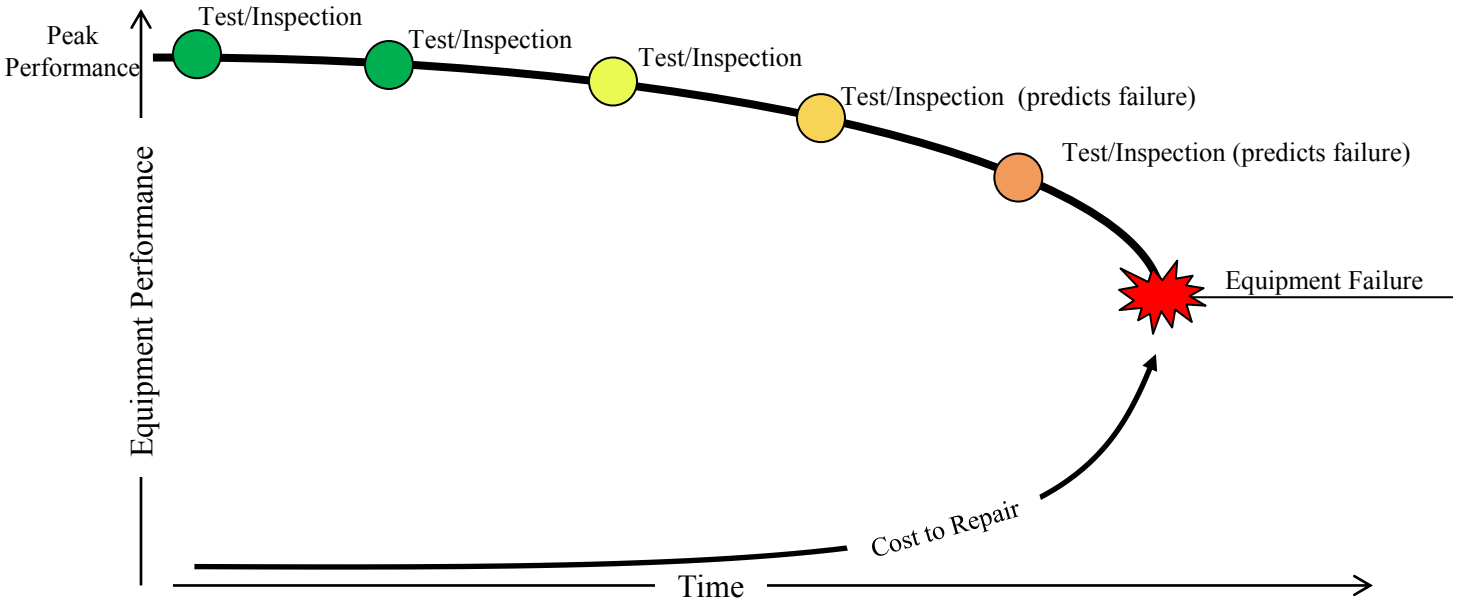
- Availability is improved by increasing MTTF or decreasing MTTR or both.
- Need to keep failure statistics to find opportunities to improve MTTF
- Need to record restore time to improve MTTR
  - Time to diagnose / troubleshoot
  - Time to obtain necessary spare parts and tools
  - Time to perform the repair
  - Time to restore to service
- Redundancy could drive MTTR toward 0 and A toward 100%

Additional Failure Terms

- Wear Out
  - The failure mode of a device that has failed and shows signs of damage directly from use
- Infant Mortality
  - Failure mode of a device that has failed due to manufacturer quality issues, material faults, or poor assembly techniques.
- Random Failures
  - Failure mode where the time to failure is not uniform
- Distribution Analysis
  - A statistical method that describes reliability characteristics (e.g. Average)

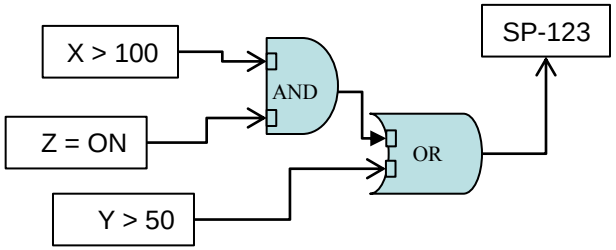
Using Reliability Data to Eliminate Failures

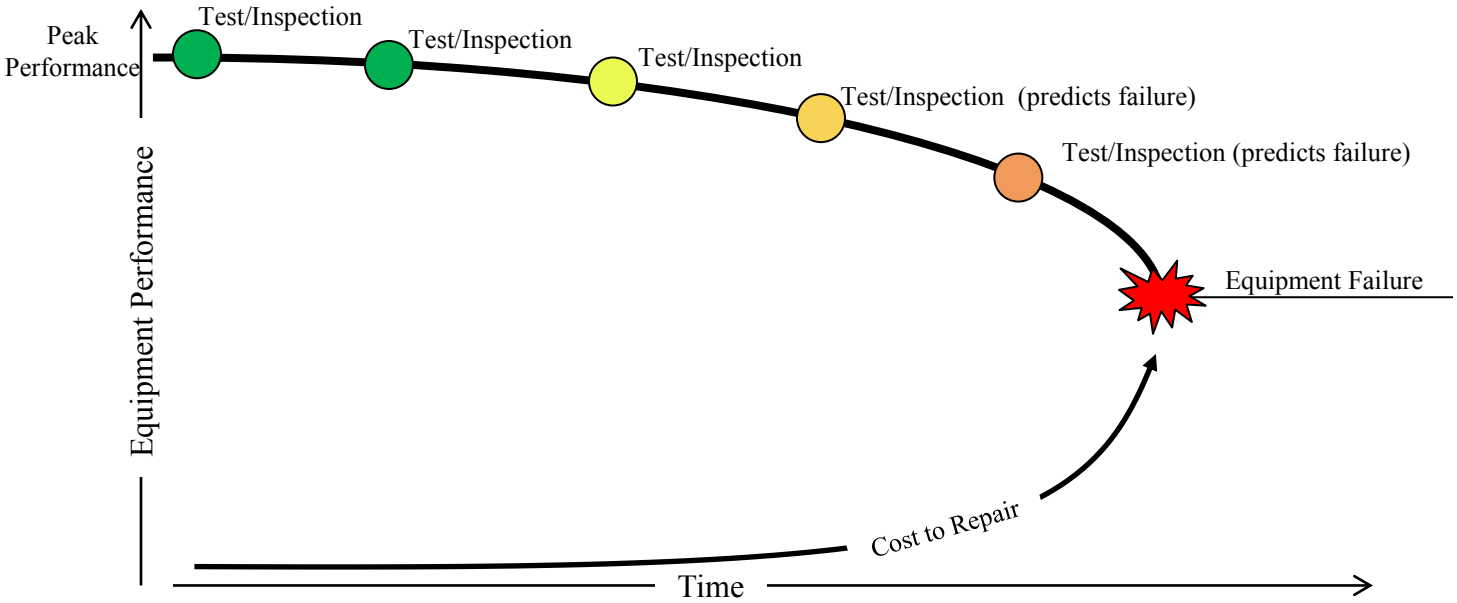
- Predictive Maintenance
  - Requires the ability to detect that equipment is deteriorating
  - Requires sufficient time between detection of deteriorating and failure to allow failure
  - Acute failures are not candidates for predictive maintenance.
  - Improves availability by minimizing MTTR and extending MTTF
  - Need to collect and analyze data



Using Reliability Data to Eliminate Failures

- Predictive Maintenance
  - Trend
    - ❖ Three consecutive data points in the same direction
  - Statistically significant change (not data noise)
  - Conditions with Logic





Using Reliability Data to Eliminate Failures

- Set-up the Computerized Maintenance Management System (CMMS)
  - Use Class information to manage population (P)
  - Use ISO 14224 to log failures (N)
  - Capture all test, inspections, calibrations, (including OK), failures, etc.
  - Use Maintenance Plans to manage test schedules (T)
    - ❖ If condition based, the time could vary
  - Manage work flow, authorizations, permits, and test equipment.

Class	Tech ID Number	Manufacturer	Model Number
IA0004 - Analyzer/Sensor, Conductivity	11110X	COMML	3444
IMF009 - Flowmeter, Mutivariable	11112FT	ROSEMONT	1151DP
ICE002 - Valve, Control Linear Motion	11112FV	VALTEK	MARK ONE
ICE005 - Valve, Power Actuated Block	11112FV2	MAXON-CP	CC5000CP
ICE005 - Valve, Power Actuated Block	11112FV3	MAXON-CP	STOAS
ICE005 - Valve, Power Actuated Block	11112FV4	MAXON-CP	CC5000CP
ICE005 - Valve, Power Actuated Block	11112FV5	MAXON-CP	5000S
ICE005 - Valve, Power Actuated Block	11112FV6	PARK-MFG	12F2306
ICE005 - Valve, Power Actuated Block	11112FV7	MAXON-CP	5000S
IMPR05 - Pressure Switch	11112PS	UNITD-ELE	H105-146
IMPR05 - Pressure Switch	11112PS2	UNITD-ELE	H105-146
IMPR06 - Pressure Transmitter	11112PT	ROSEMONT	1151GP
ICE002 - Valve, Control Linear Motion	11113FV	VALTEK	MARK ONE
ICE005 - Valve, Power Actuated Block	11113FV2	MAXON-CP	8760
ICE005 - Valve, Power Actuated Block	11113FV3	MAXON-CP	8760
ICE005 - Valve, Power Actuated Block	11113FV4	APOLLO	7610764
IMPR05 - Pressure Switch	11113PS	UNITD-ELE	H105-S164B
IMPR05 - Pressure Switch	11113PS3	UNITD-ELE	H105K-S164B
IMPR05 - Pressure Switch	11113PS4	UNITD-ELE	H105K-456
IA0005 - Analyzer/Sensor, Dissolved Oxygen	11114XT	ROSEMONT	3000-02
IMF009 - Flowmeter, Mutivariable	11115FT	ROSEMONT	1151DP
IMPR05 - Pressure Switch	11116PS	UNITD-ELE	H105-137
IMPR05 - Pressure Switch	11116PS1	COMML	51204933-001
IMPR06 - Pressure Transmitter	11116PT	ROSEMONT	1151GP

Build instrument list by class in the CMMS to track the population

Using Reliability Data to Eliminate Failures

- Enter standard failure codes to document history
  - Recommend using SO 14224 failure codes.
  - Available by equipment class
  - Automatic Valve (example)

	FAILURE CODES
DOP	Delayed operation
ELP	External leakage - process
ELU	External leakage - utility
FTC	Fail to close on demand
FTO	Fail to open on demand
FTR	Fail to regulate
LCP	Leakage in closed position
PLU	Plugged / Choked

	DAMAGE CODES
0100	Acceptable / OK
1000	Corroded
1100	Cracked
1300	Damaged
1400	Defective
1500	Detached - disconnected
1700	Eroded
2000	Leaking
2300	Loose
3100	Moisture
3310	Open Circuit
3500	Plugged
4200	Short Circuit
4300	Sticking
4700	Worn
4900	Wrong Material
5100	Wrong Size
5200	Wrong Specification
5400	Wrong Type

Using Reliability Data to Eliminate Failures

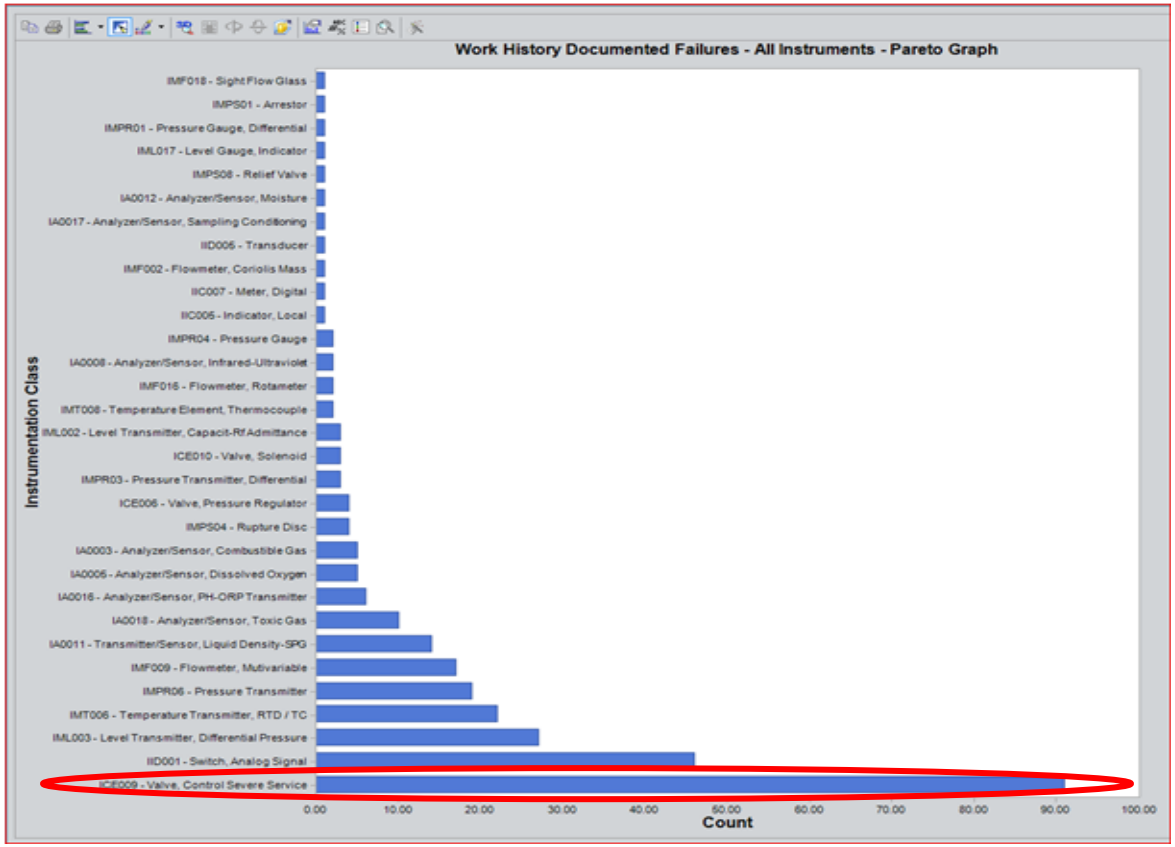
- Enter standard failure codes to document history.
  - Pressure Transmitter (example)
  - Use “Acceptable OK” to document test, inspections where no problems found
    - Improve population validity

AOH	Abnormal output - high
AOL	Abnormal output - low
ELP	External leakage - process
ERO	Erratic output
FCH	Fail to change
FTF	Fail to function on demand

0100	Acceptable / OK
0900	Contaminated - dirty
1000	Corroded
1300	Damaged
1400	Defective
1500	Detached - disconnected
1700	Eroded
1750	Failed on Test
2000	Leaking
2300	Loose
3100	Moisture
3310	Open Circuit
3500	Plugged
4200	Short Circuit
5100	Wrong Size
5200	Wrong Specification
5400	Wrong Type

Using Reliability Data to Eliminate Failures

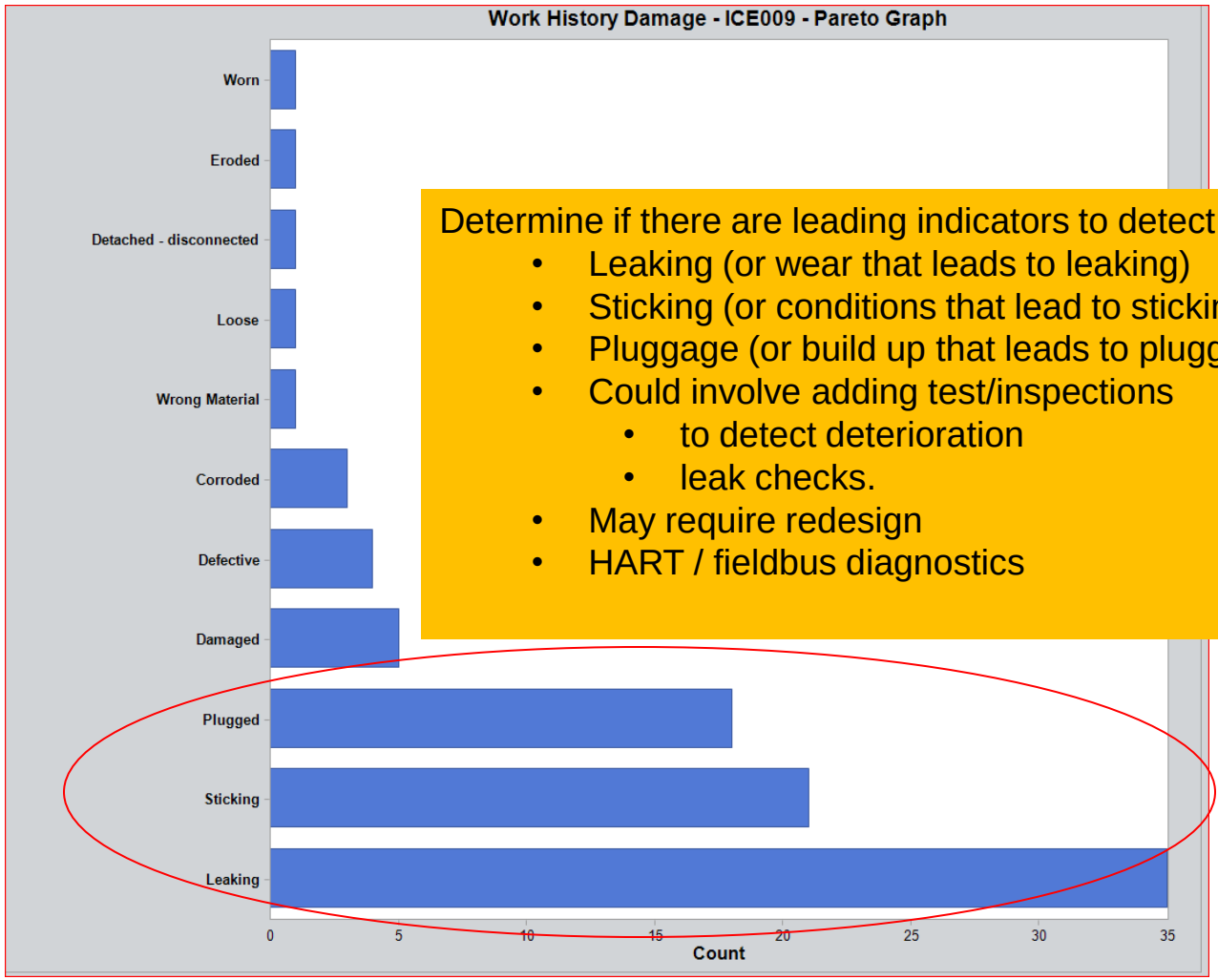
- To improve availability (using data)
  - identify bad actors
  - improve ability to detect deteriorating performance
  - procedures, training and spare parts management to reduce MTTR



In this data set, Severe service valves have twice as many failures as the next class

Using Reliability Data to Eliminate Failures

- Review Failures for this Severe Service valves.



Determine if there are leading indicators to detect :

- Leaking (or wear that leads to leaking)
- Sticking (or conditions that lead to sticking)
- Pluggage (or build up that leads to pluggage)
- Could involve adding test/inspections
  - to detect deterioration
  - leak checks.
- May require redesign
- HART / fieldbus diagnostics

Using Reliability Data to Eliminate Failures

- To improve availability (using data)
- Identify where predictions can anticipate failures
  - AMS with HART or other fieldbus (continuous)
  - Test and inspections (test interval)
- Calculate MTBF
  - A large population improves the fidelity of the MTBF
  - Need a long term strategy. MTBF fidelity improves with time.

$$MTBF = \frac{(T*P)}{N}$$

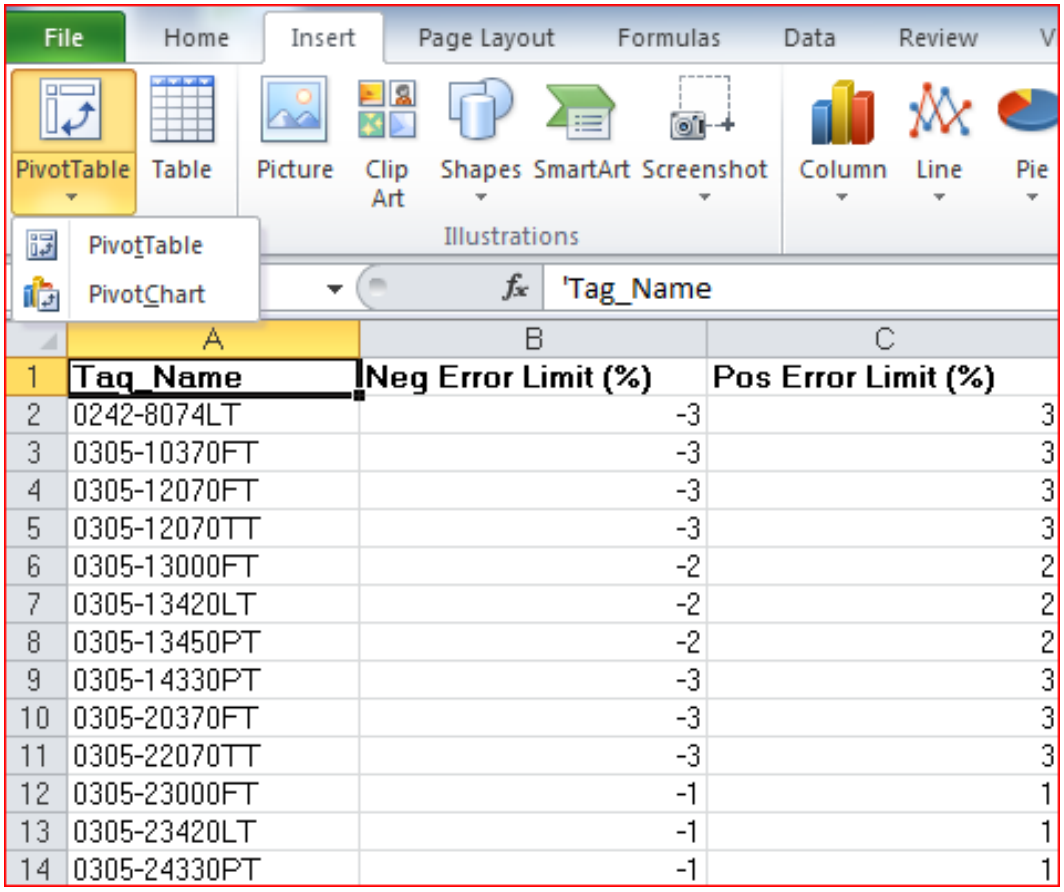
Using Reliability Data to Eliminate Failures

- Review Calibration As Found data

Tag Name	Negative Error Limit	Postitive Error Limit	Event Start Date	Overall AF Error Max	Overall AF Pass/Fail
745-4968-FT	-0.5	0.5	9/26/2013	-0.9687	FAIL
745-4976-PT	-0.5	0.5	9/25/2013	-0.1487	PASS
745-4981-PT	-0.5	0.5	9/25/2013	-0.2479	PASS
745-4982-PT	-0.5	0.5	9/25/2013	0.1083	PASS
745-5007-PT	-1	1	9/19/2013	0.2363	PASS
745-5058-LT	-3	3	3/26/2013	-0.1919	PASS
745-5069-PT	-1	1	9/23/2013	-0.125	PASS
745-5072-PT-2	-0.4	0.4	10/31/2013	-0.3187	PASS
745-5072-PT-3	-3	3	10/31/2013	-1.1125	PASS
745-5140-TT	-1	1	10/1/2013	-0.225	PASS
745-5141-TT	-1	1	8/15/2013	0.575	PASS
745-5191-LT	-0.5	0.5	9/25/2013	0.4586	PASS
745-5252-PT	-1	1	5/10/2013	0	PASS
745-5274-PT	-0.5	0.5	6/4/2013	0.0812	PASS
745-5274-PT-1	-0.55	0.55	6/4/2013	-0.0625	PASS
745-5274-PT-2	-1	1	6/4/2013	0.3292	PASS
745-5277-TT	-1	1	6/4/2013	0.0563	PASS
745-5277-TT-1	-0.5	0.5	6/4/2013	-0.1687	PASS
745-5278-PT	-0.5	0.5	6/4/2013	0.4667	PASS

Using Reliability Data to Eliminate Failures

- Build a pivot table using the calibration data



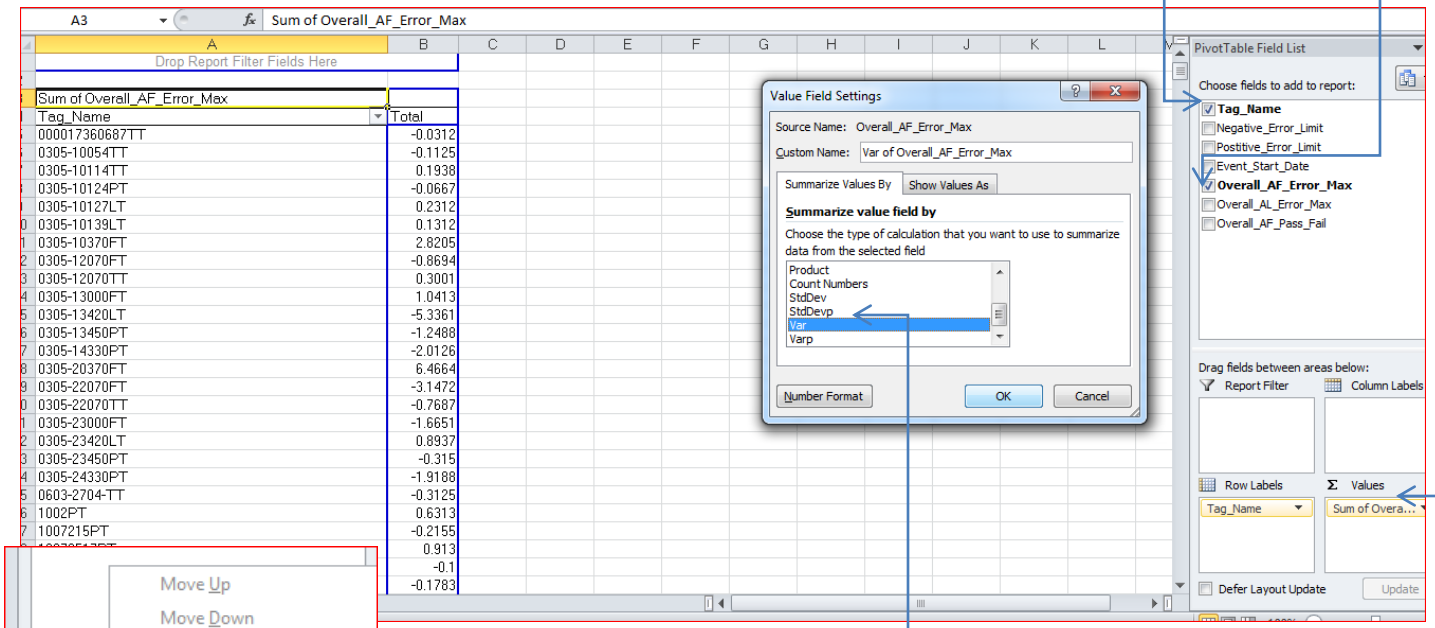
	A	B	C
1	Tag_Name	Neg Error Limit (%)	Pos Error Limit (%)
2	0242-8074LT	-3	3
3	0305-10370FT	-3	3
4	0305-12070FT	-3	3
5	0305-12070TT	-3	3
6	0305-13000FT	-2	2
7	0305-13420LT	-2	2
8	0305-13450PT	-2	2
9	0305-14330PT	-3	3
10	0305-20370FT	-3	3
11	0305-22070TT	-3	3
12	0305-23000FT	-1	1
13	0305-23420LT	-1	1
14	0305-24330PT	-1	1

Using Reliability Data to Eliminate Failures

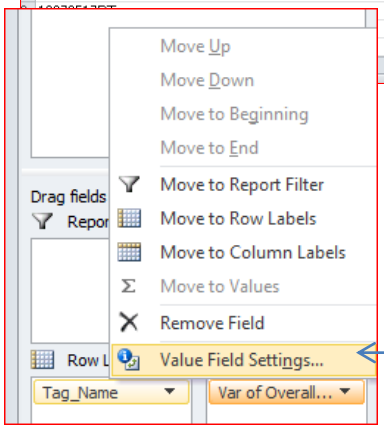
- From the **Pivot Table Field List**

a. Choose **Tag Name**

b. Choose **Overall_AF_Error_Max**



C. below values, left click to get the pop up and select **Value Field Settings**



d. Select **Var** to calculate variability.

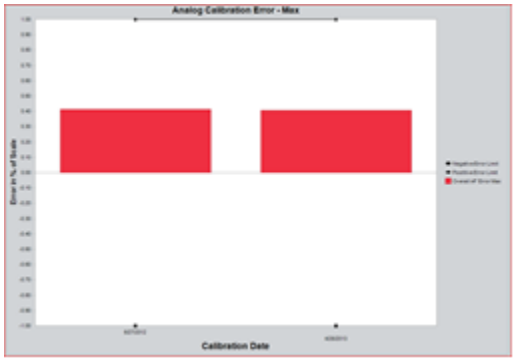
Left click on the **Value Field Settings**

Using Reliability Data to Eliminate Failures

- If the variability approaches 0, the calibration results are similar for the included calibrations.

Var of Overall_AF_Error_Max

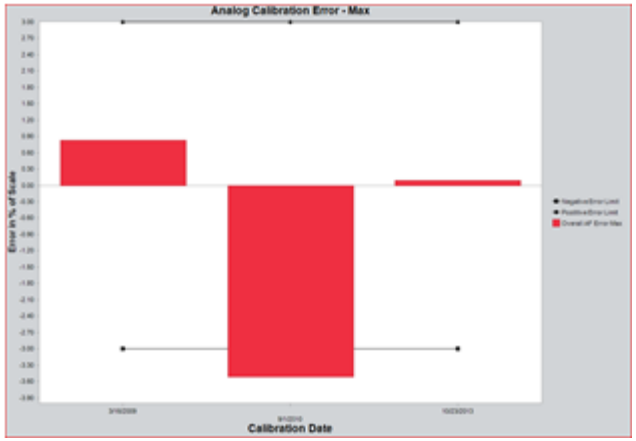
Tag_Name	Total
745-6652-PT	0.0000
745-6104-PT	0.0000
745-4944-PT	0.0000
9398PT	0.0001
9236PT	0.0001
9445TT2	0.0001
77PT1B	0.0001
745-6698-FT	0.0002
616TT1	0.0002
392TT1	0.0002
214TT1	0.0002
444TT1	0.0002
9475FT	0.0003
745-6954-PT	0.0003
752TT1	0.0003
0305-14330PT	0.0003
268PT1	0.0005



- As variability increases, the results are changing each time

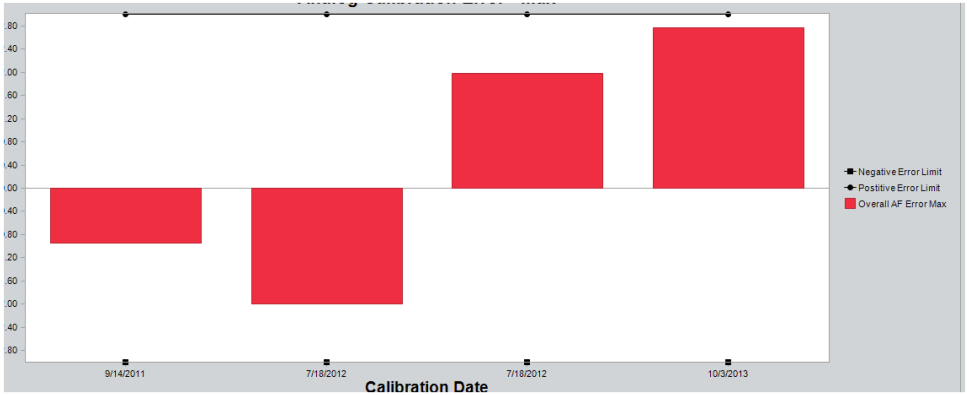
Var of Overall_AF_Error_Max

Tag_Name	Total
7842FT	5.2378074
1163-1370-TT	5.5904992
15424530FT	6.1642627
TT-1000-01	7.5010938
7845FT	7.7483482
507PT	8.1083645
3393LT - 3393LT	8.495442
421FT	9.2768474
523LT	9.4269162
745-9408-FT	11.872577
28LT	11.876026
4007PT2	22.943294
19318408FT	28.529192

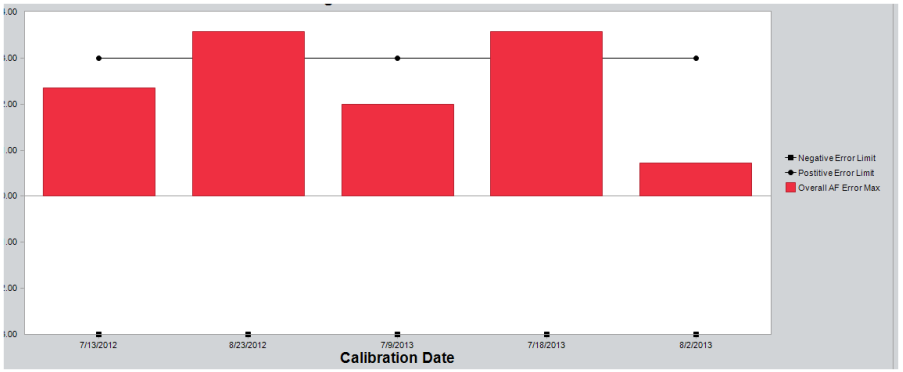


Using Reliability Data to Eliminate Failures

- Failure can be predicted and prevented.



- Failure could not be predicted at this test interval. Consider a shorter test interval



Summary

- Reliability
- Failures
- Mean Time Between Failures
- Predictive Maintenance
- Analyzing Data