Maintenance and Reliability – Theory

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WGA3-06 Tutorial

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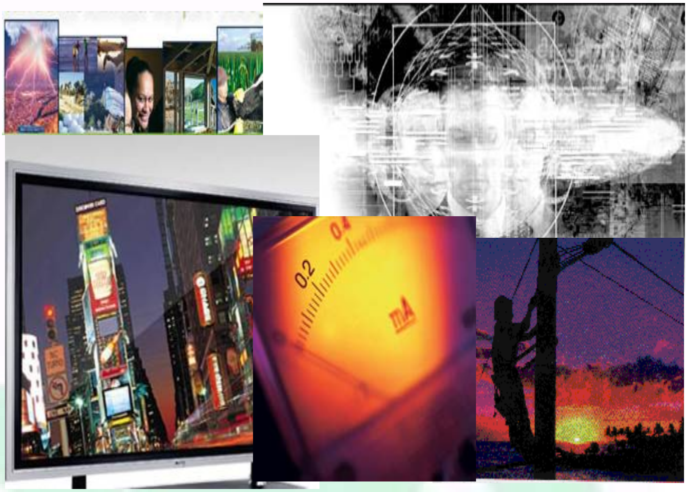
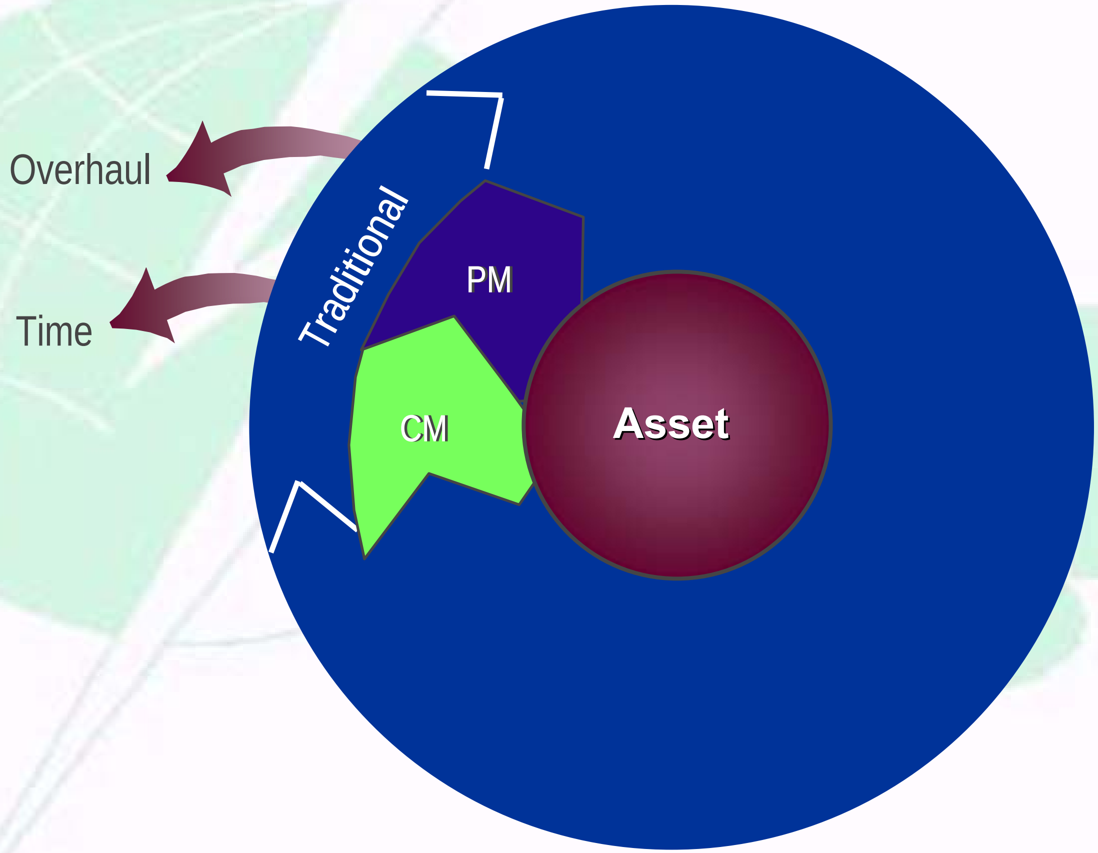
MAINTENANCE & TEST ENGINEERING, LLC

Today's Agenda

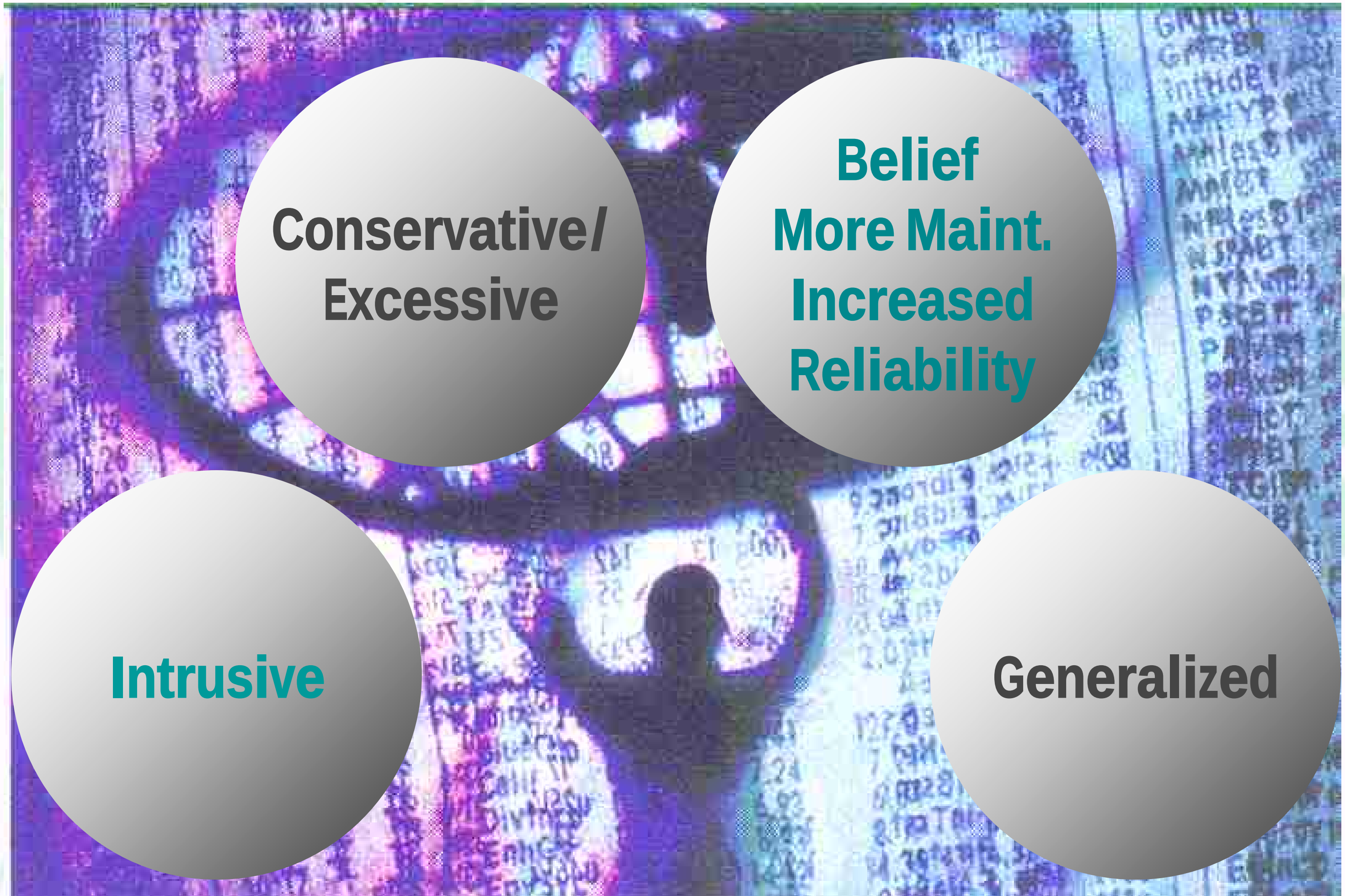
- Evolution of Maintenance and Driving Theory
  - Traditional Bimodal Maintenance
  - Reliability Centered Maintenance
  - Condition Based Maintenance
  - Performance Focused
- Three Case Studies
  - Cables
  - SF_6 Breakers
  - Transformer On-line Monitoring



Maintenance Evolution – Traditional



Characteristics of Traditional Maintenance



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Traditional Maintenance

Benefits	Drawbacks
Periodic inspection servicing is necessary	Time is poor predictor of wear
Acknowledgement that full equipment operating life is only possible if worn parts are replaced.	Overhauls create more problems than they solve
	High cost
	Manufacturers did not understand the operating environment
	Reliability and availability were not being met

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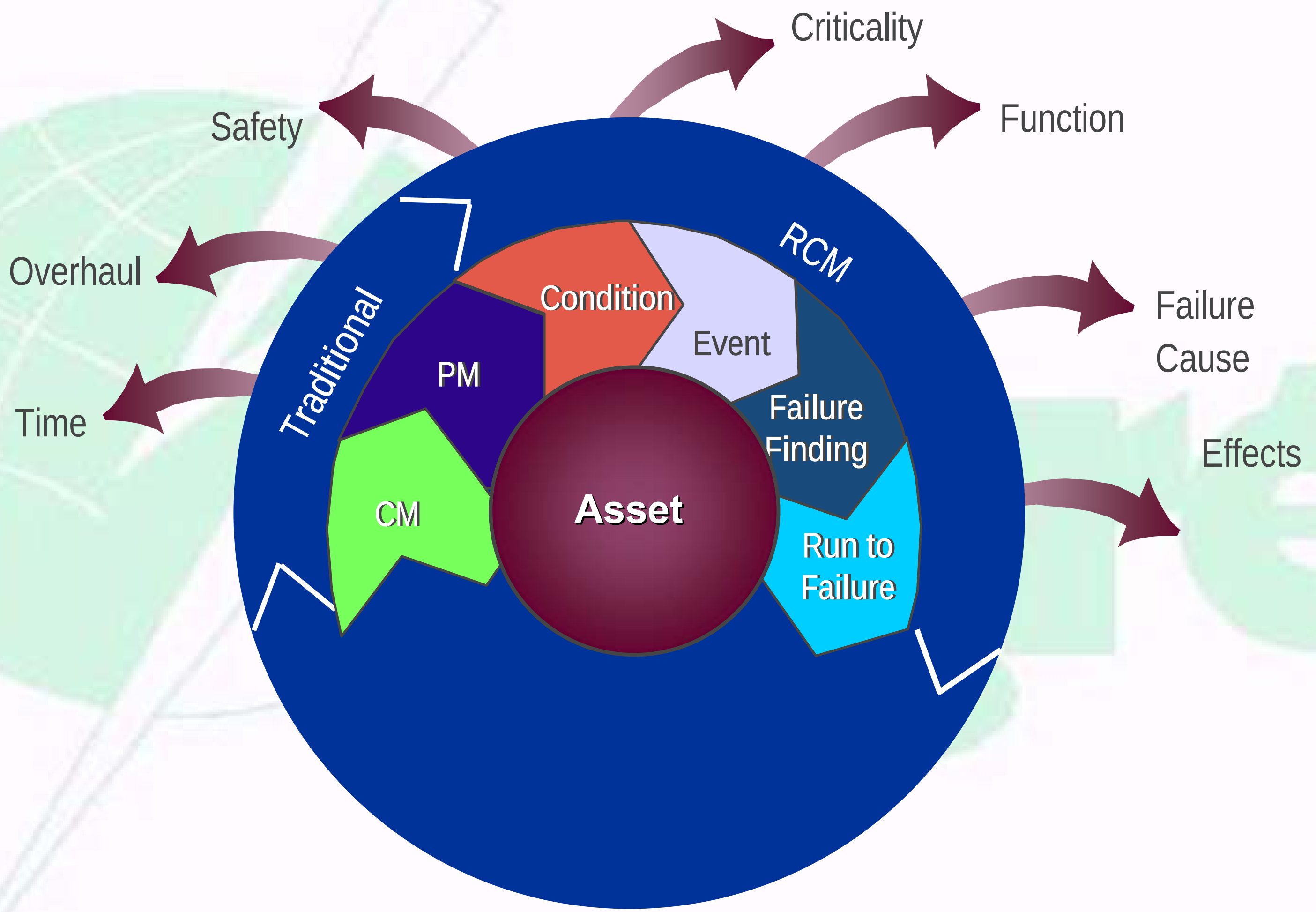
Maintenance Evolution – RCM

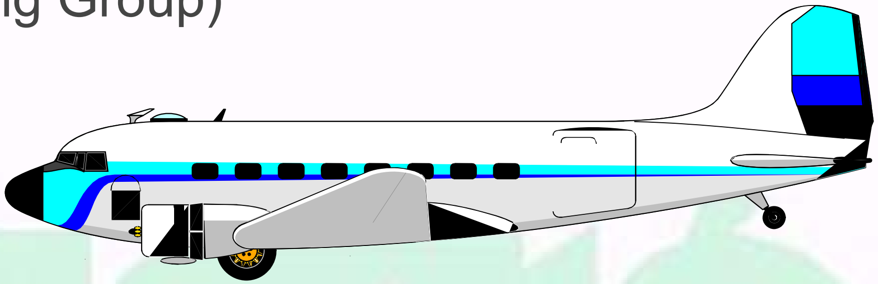


RCM

"A structured process that identifies the effects of failures and defines the appropriate maintenance path for managing their impacts. <u>RCM identifies both the most technically and economic effective approach to maintenance</u> ."

RCM History

- Airlines
  - 1965 MSG-1 (Maint. Steering Group)
  - 1970 MSG-2
  - Experience
  - DC 8
    - 339 Scheduled Removal Tasks
    - 7 Scheduled Removal Tasks
  - 747
    - 8 Scheduled Removal Tasks



RCM History (cont.)

- Airline Observations:
  - Maintenance needs to focus on system that have significant impact on safety or economics.
  - Hard time overhaul policies were ineffective.
  - Management of maintenance was crucial.

RCM History (cont.)

- US Navy
  - 1978 Contracted United Airlines
- US Electric Utilities - 80’s
  - EPRI Sponsored Nuclear 1985-1987
  - Fossil Fuel Plants
- US Electric Utilities - 90’s
  - Substations 1990
  - T&D
- EDF and Others
  - Nuclear Plants
  - Transmission Substations

RCM Task Selection

"The RCM task selection approach used to ensure that only applicable and cost effective tasks are selected to address the causes of critical equipment failure modes"

RCM Task Categories

- Inspection-Condition Monitoring-Predictive Maintenance
- Periodic
  - Rework-Time Directed
  - Discard-Time Directed
- Failure Finding
- Run to Failure

Simplified Task Selection Logic

Mode & Cause Selected

Review Effects

Is Condition Monitoring Effective?

Safety Conseque...
Task Must Reduce Risk of Failure

...rational ...uences
Task must cost ...ir

Is a periodic task e...

No-Periodic PM

Pr...

No-Failure Finding Task

...the failure be ...

Is the ... nt?

Failed

No-Design Change

Correct... Maintenance

Run to failure

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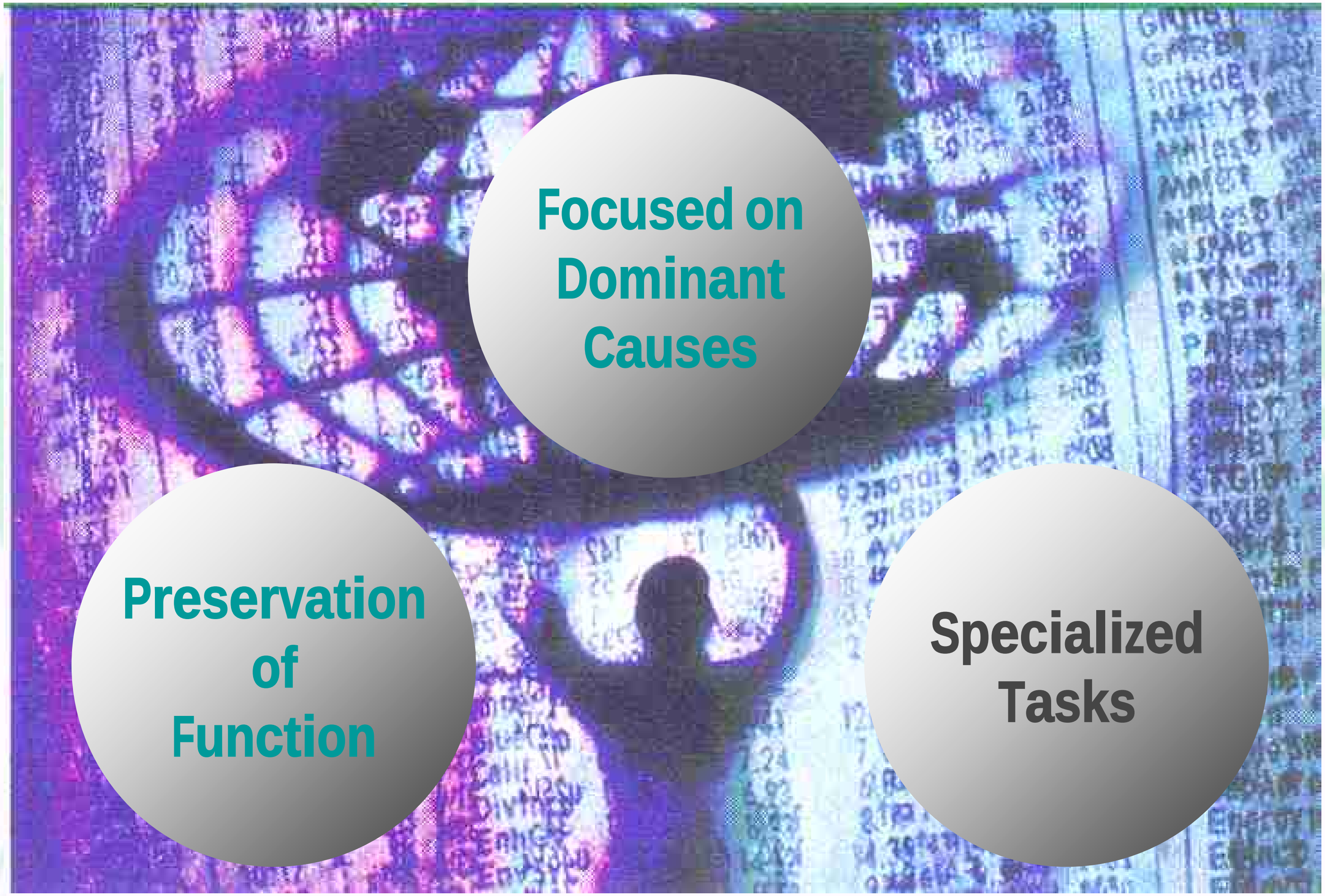
Characteristics of Reliability Centered Maintenance



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Reliability Centered Maintenance

Benefits	Drawbacks
Critical Functions	Viewed as difficult and not applicable to power industry
Equipment and application specific	99.999% (1 hour of outage per year) reliability is difficult to understand
Greater insight into failure process	Living program forgotten
Eliminated ineffective tasks	Did not set maintenance intervals

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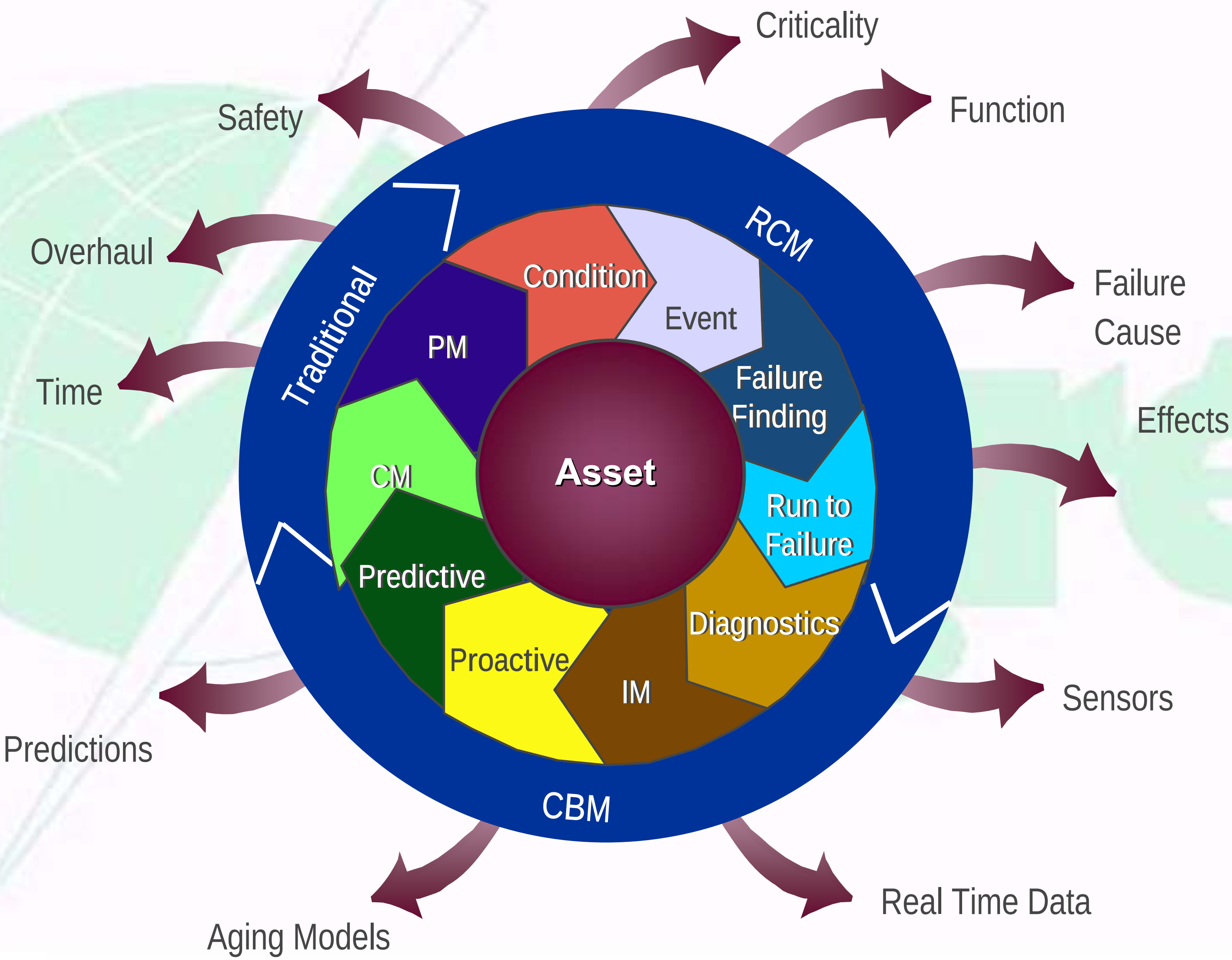
Maintenance Evolution – CBM



Condition Based Maintenance

"Condition Based Maintenance accentuates the value of RCM task selection logic and emphasizes that more intrusive replacement and overhaul tasks only need to take place when measurable wear or aging occurs."

"Condition Directed Tasks are initiated when deterioration has gone beyond a prescribed limit"

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Characteristics of CBM

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Condition Based Maintenance

Benefits	Drawbacks
Increased availability	Data systems were may not be adequate.
Reduced costs	Process management overlooked.
More frequent analysis of asset condition	No methodology for justifying increased monitoring
	Increased back-office analysis

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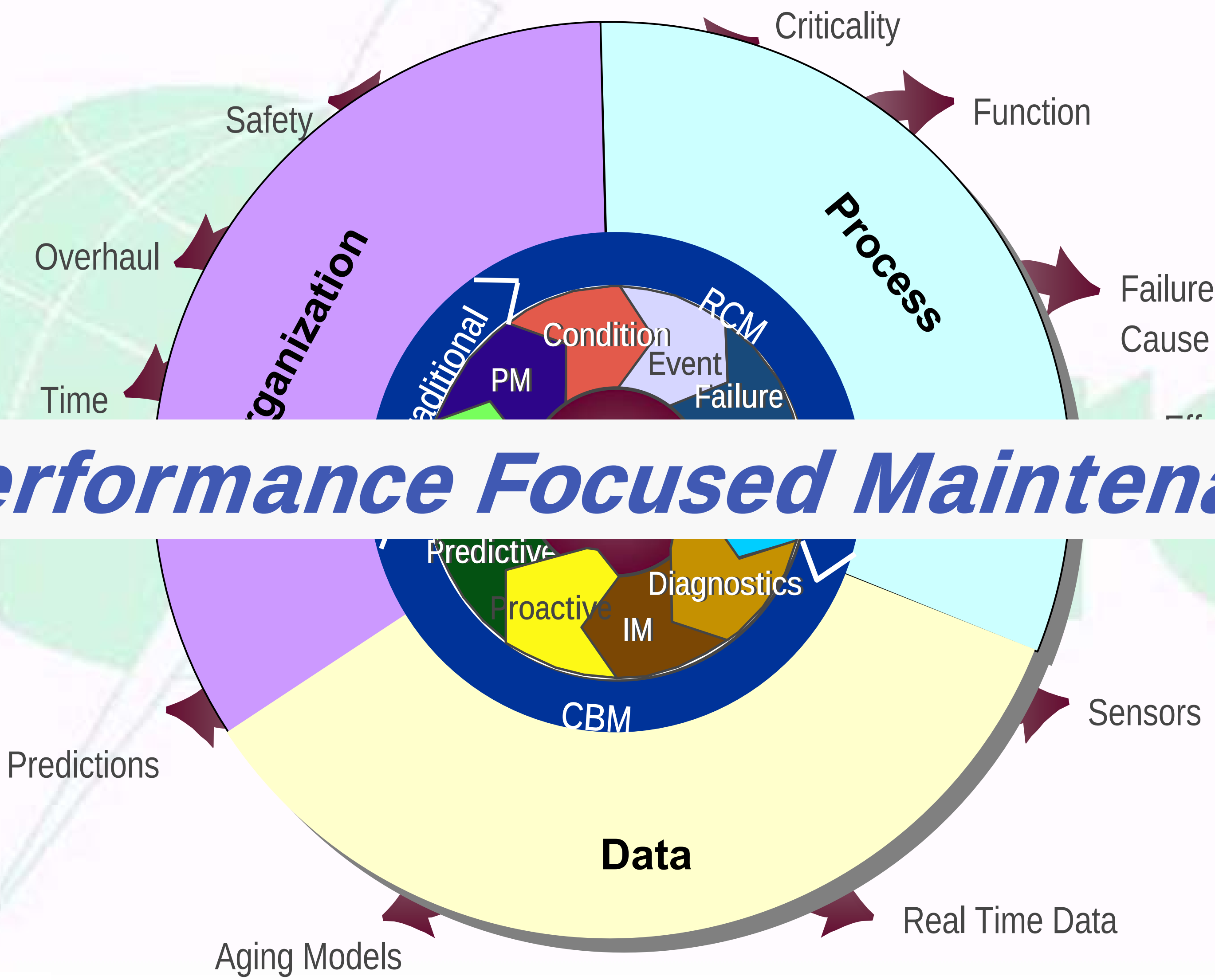
Maintenance Evolution – PFM



Performance Focused Maintenance

What is PFM?

***PFM** is a comprehensive maintenance strategy emphasizing the understanding of Failure Mechanisms, Measurement, Interval Optimization, Task Prioritization, Feedback and the use of Data. PFM recognizes the need for process control*

Mission critical goals and objectives are identified at the executive level. Bottom-up data collection ensures maintenance progress is effectively communicated to all levels of the organization and enterprise information requirements are satisfied.

What Maintenance is Included in PFM?

Maintenance **includes all activities associated with preserving or restoring critical <u>functions</u>. Typical maintenance activities include:**

- Preventive Maintenance
- Condition Monitoring/Inspections
- Diagnostic Testing
- Integrated Monitoring
- Predictive Activities
- Hidden Failure Finding Tasks
- Condition Directed Corrective and Renewal Tasks
- Corrective Maintenance
- Pre-Emptive Replacement

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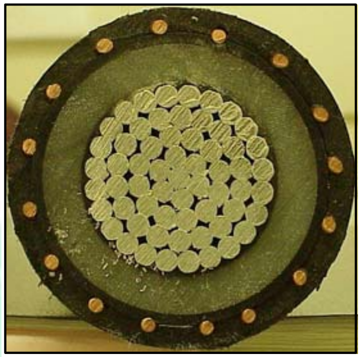
PFM 12 Step Methodology

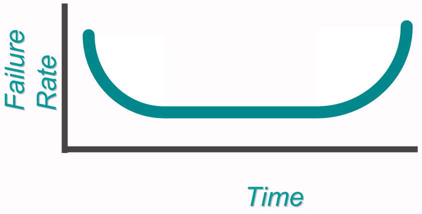


Identify System Boundaries and Critical Functions

Steps 1-2

Perform Failure Mode and Effect Analysis (FMEA)

Steps 3-5



Aging Mechanisms

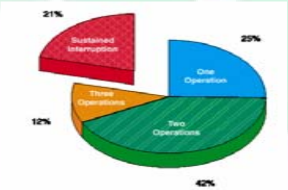
Step 6

Task Selection and Interval Optimization

Step 7

Reconciliation and Program Development

Step 8-9



Measures, Metrics &KPIs

Step 10

Implementation Documentation

Step 11- 12

Bridging Business Issues and Technical Requirements

Understanding:

The Aging Process

Failure Initiation Mechanisms

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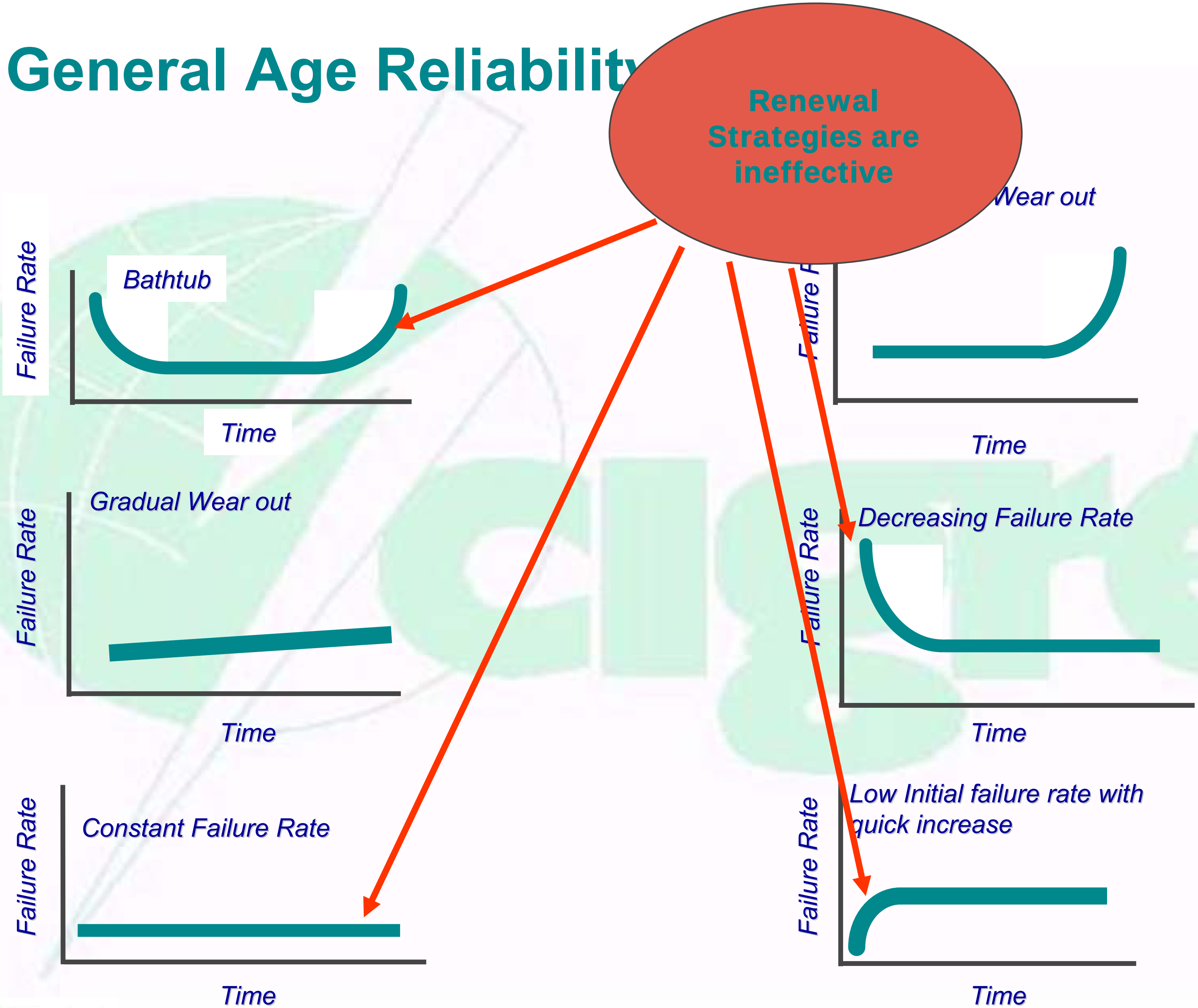
General Age Reliabilit

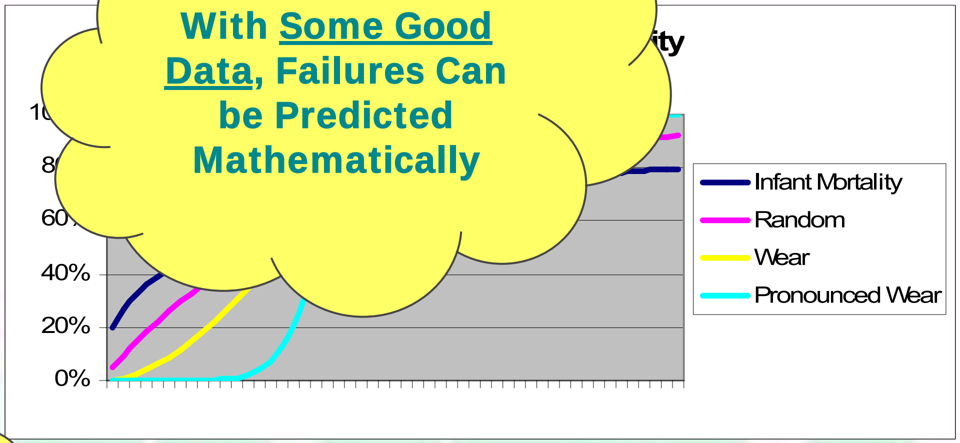


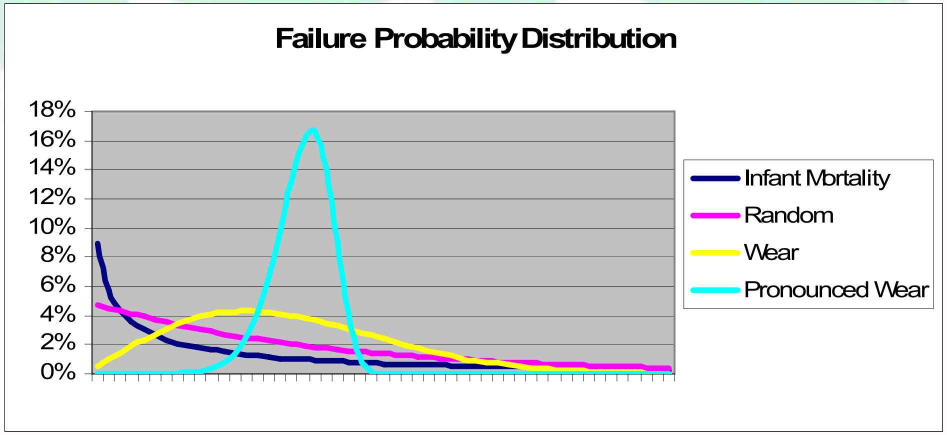
Task Interval Optimization-Weibull Age Modeling

$$F(t) = 1\text{-}e^{-[(t-t_0)/\eta]^{\beta}}$$

- t_0 = Guarantee Period
- η = Characteristic Life .. MTBF
- β = Shape factor

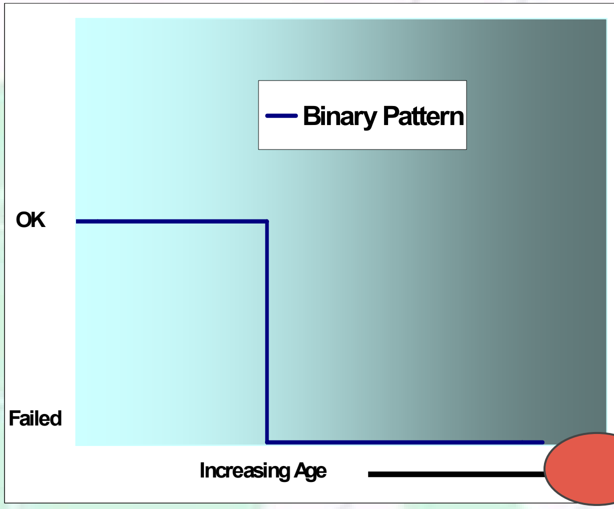
With <u>Some Good Data</u>, Failures Can be Predicted Mathematically

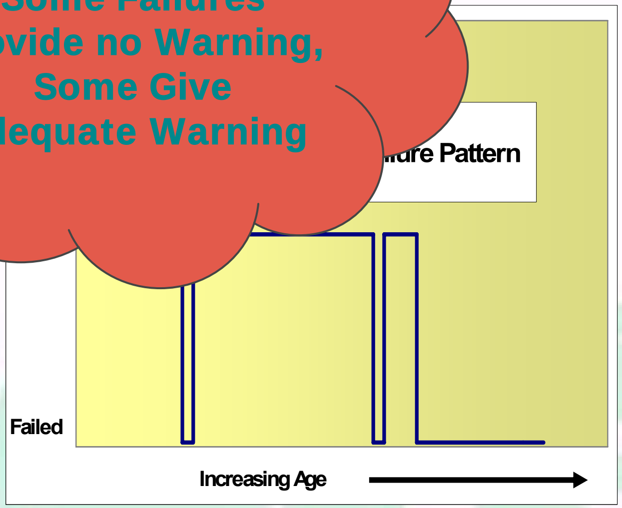


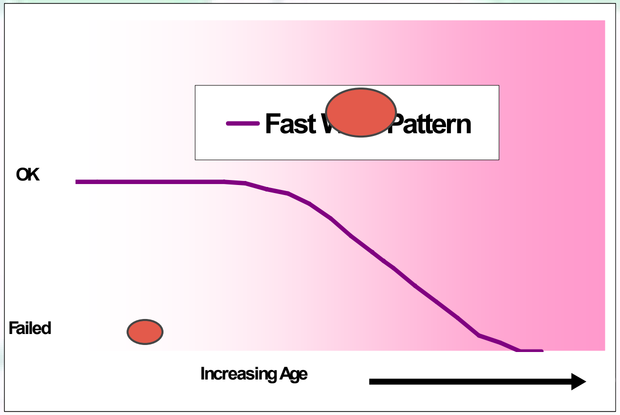


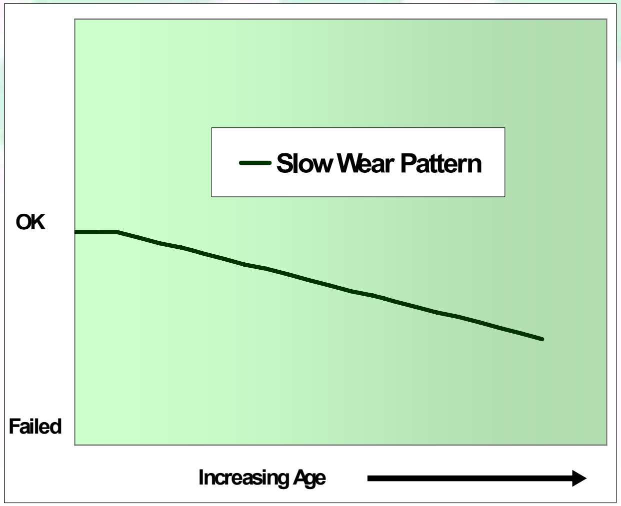
Failure Initiation Patterns

Some Failures Provide no Warning, Some Give Adequate Warning









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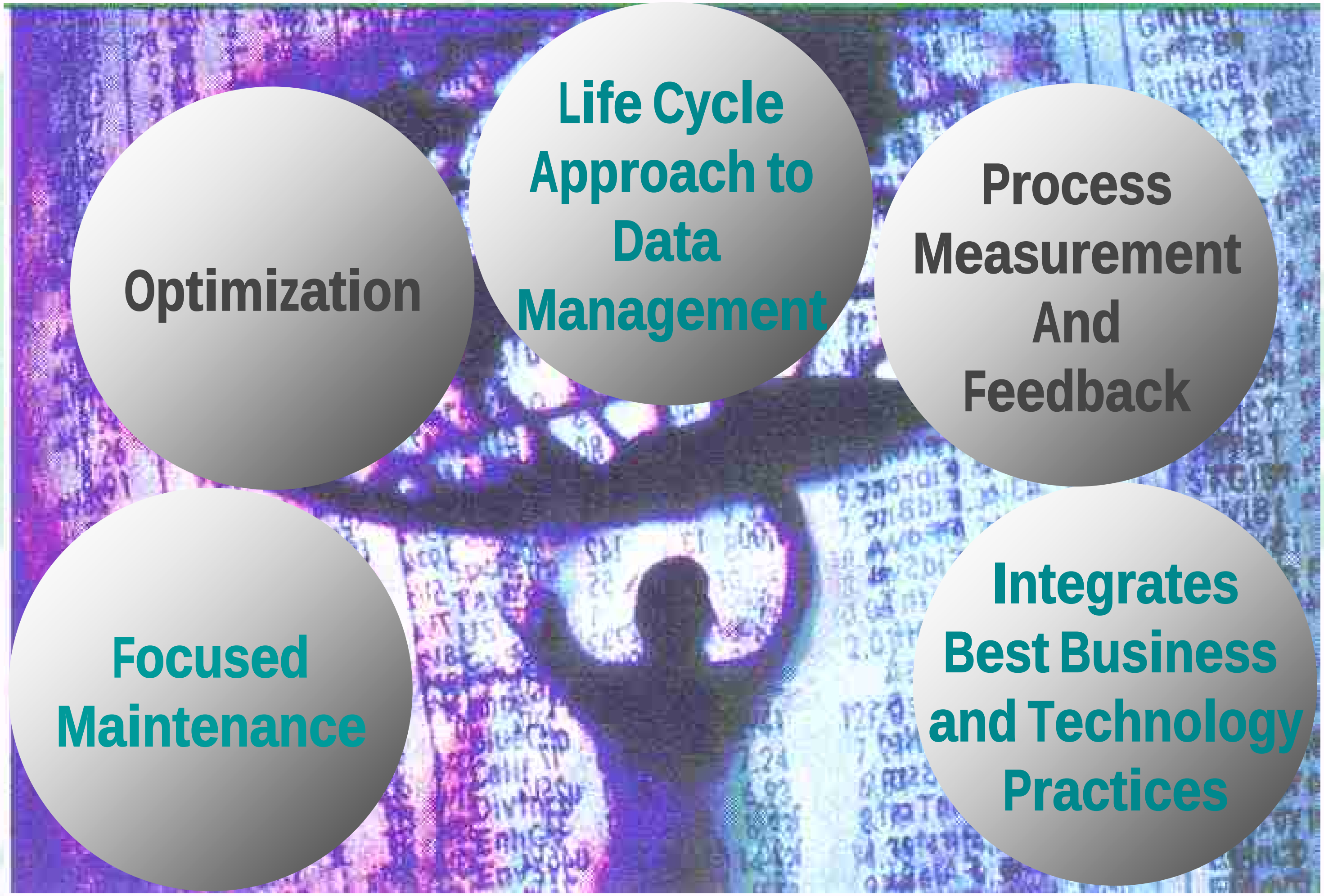
Characteristics of PFM



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Performance Focused Maintenance

Benefits	Drawbacks
Increased availability and reliability	Requires quality data collection and storage processes
Reduced life-cycle costs	Must be understood and supported by the highest management levels
Data collection fundamental part of the process	
Integrated business and technology approach to maintenance	

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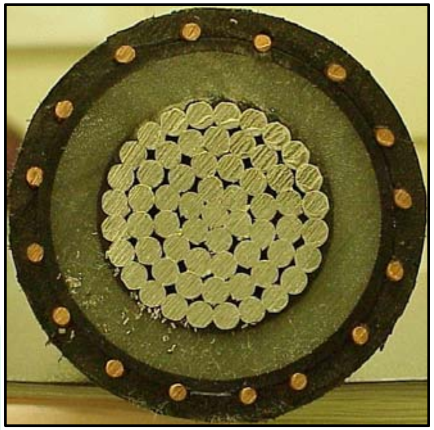
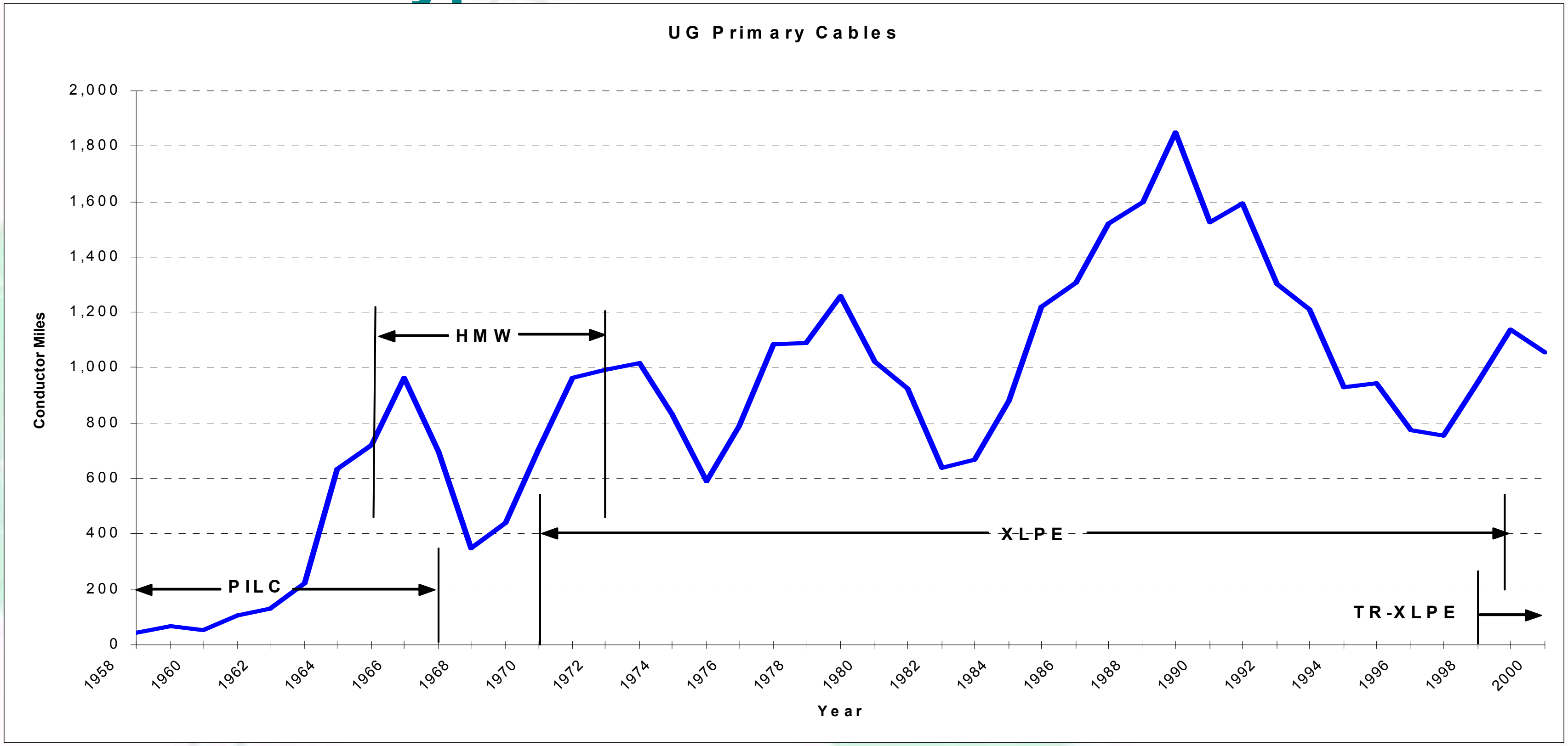
Performance Focused Maintenance Case Studies (3)

Case I-15kV Distribution Cables

- Issues:
  - Aging population-(four insulation systems)
  - Inspection program that did not affect failure rates
  - Complicated and time consuming replacement ranking system
  - Ineffective condition assessment tasks
  - Poor asset data
  - 0.4% replacement rate
- Drivers
  - Performance Based Rates
  - High replacement costs
- Key Considerations
  - Design Improvements
  - Mostly in conduit



Equipment Group: Population by Age and Insulation Type



Type of Insulation	Expected Service Life	Circuit Miles
PILC	45 - 50 years	4,900
HMW-PE	15-20 years	1,500
XLPE	25-30 years	30,200
TR-XLPE	45 years +	2,400

Identify System Boundaries and Critical Functions

Steps 1-2

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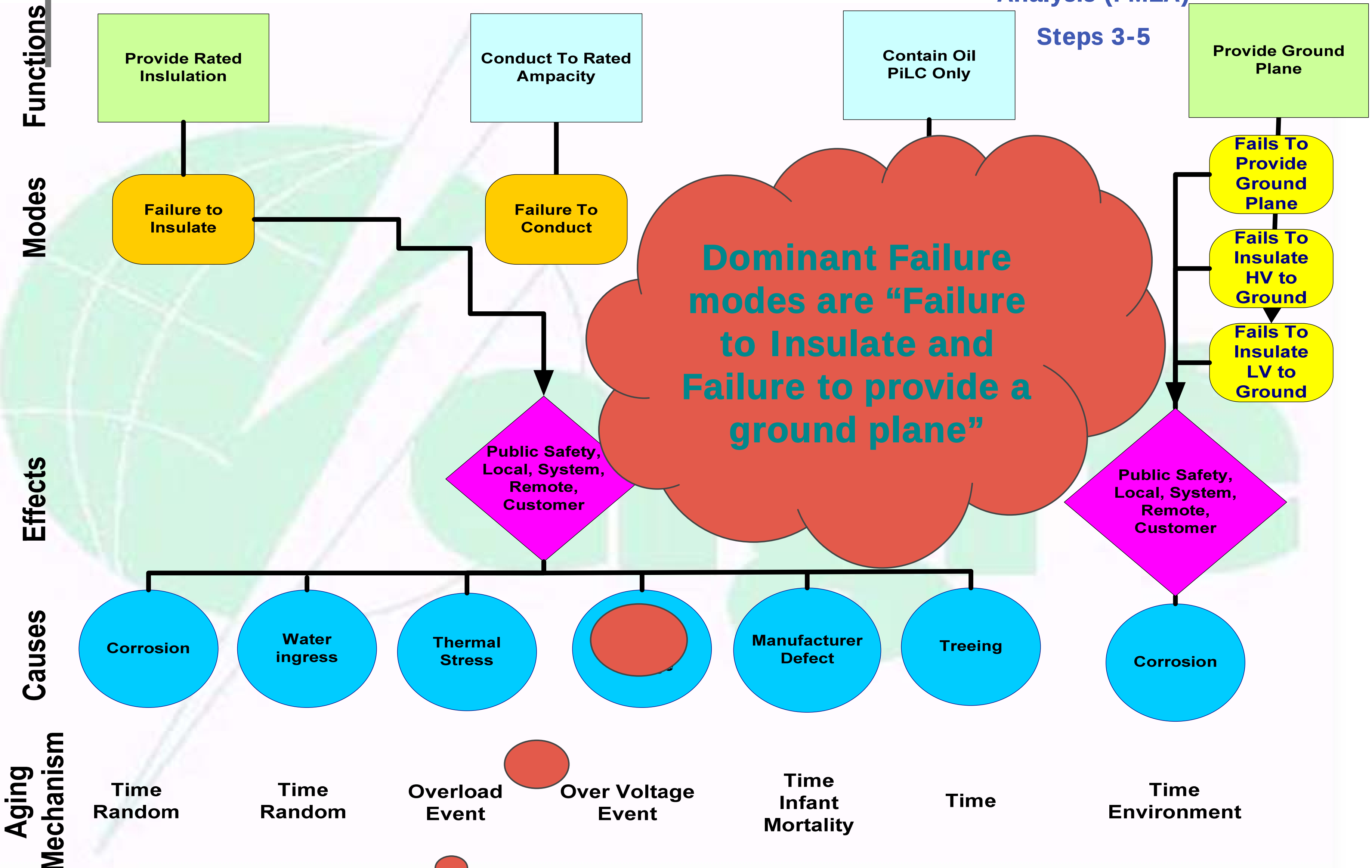
FMEA: Cables

Perform Failure Mode and Affect Analysis (FMEA)

Steps 3-5



* Varies with each type of cable

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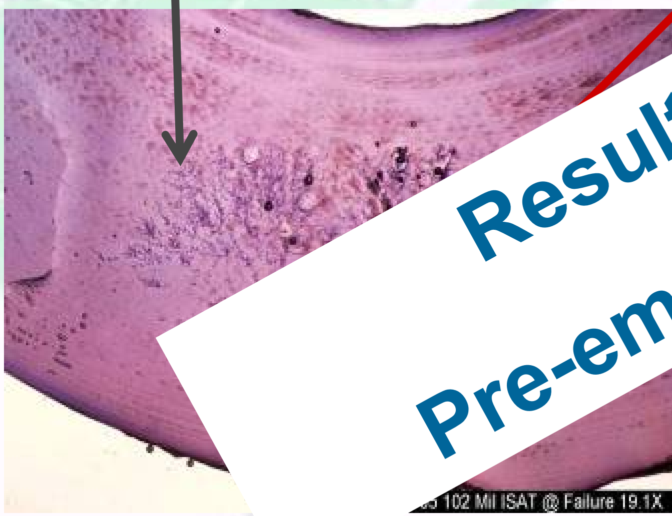
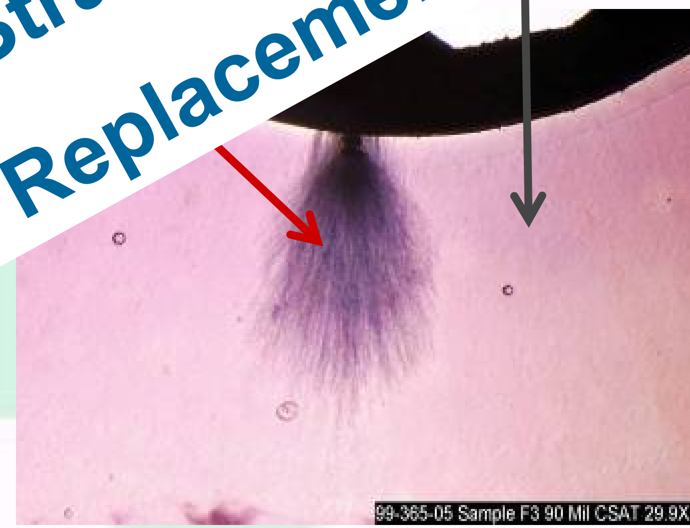
Tree Examples - Failure to Insulate

Cable Insulation

Water Trees





Resultant Strategy:
Pre-emptive Replacement

#2 AWG HMW vintage cable which failed in Ridgecrest. Water treeing more than 50% through the insulation

- #2 AWG XLPE cable from Fullerton. Water treeing more than 40% through the insulation.

Source: DAE, Improving the performance of underground cable. Sept 14, 2001

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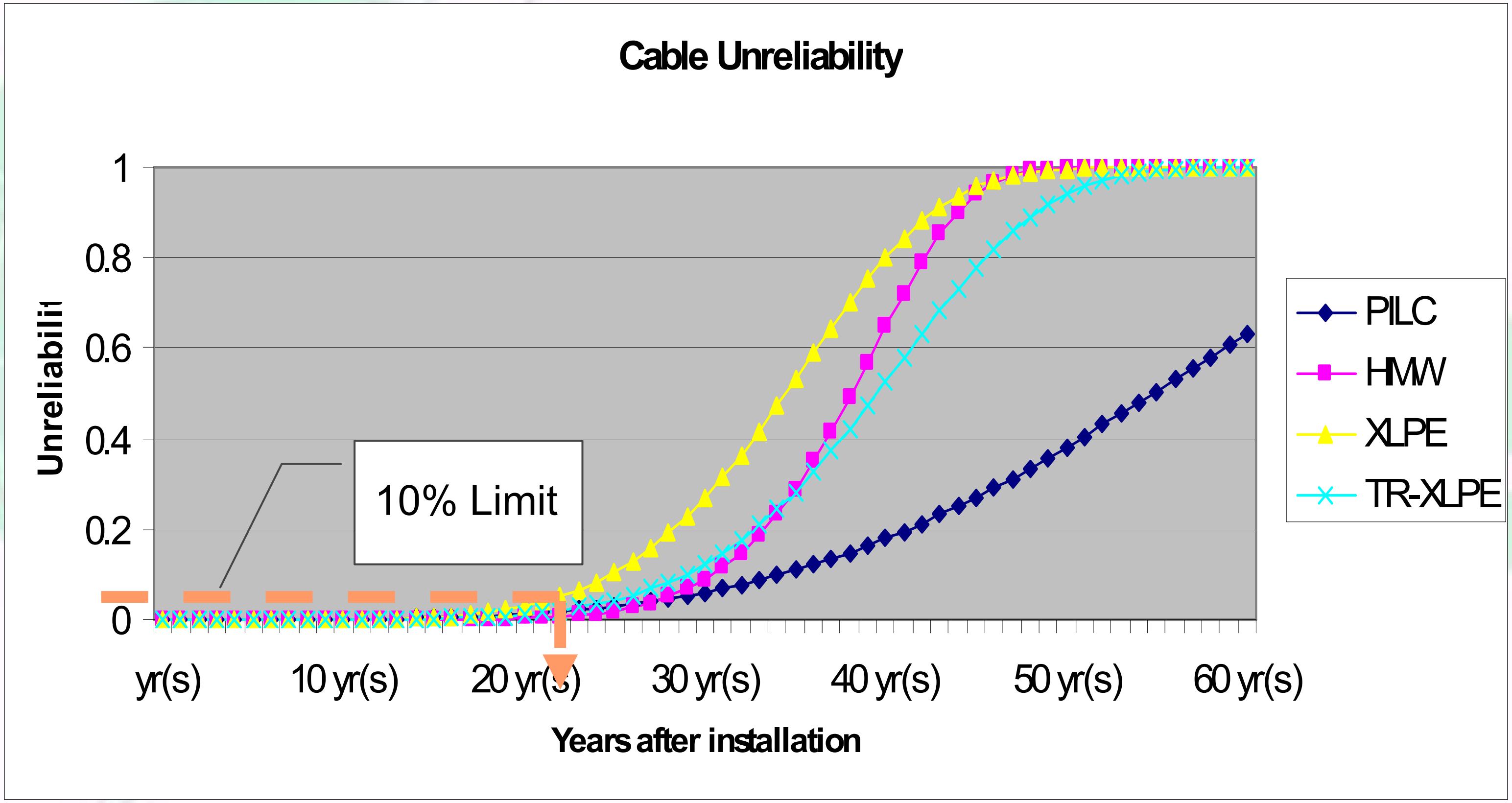
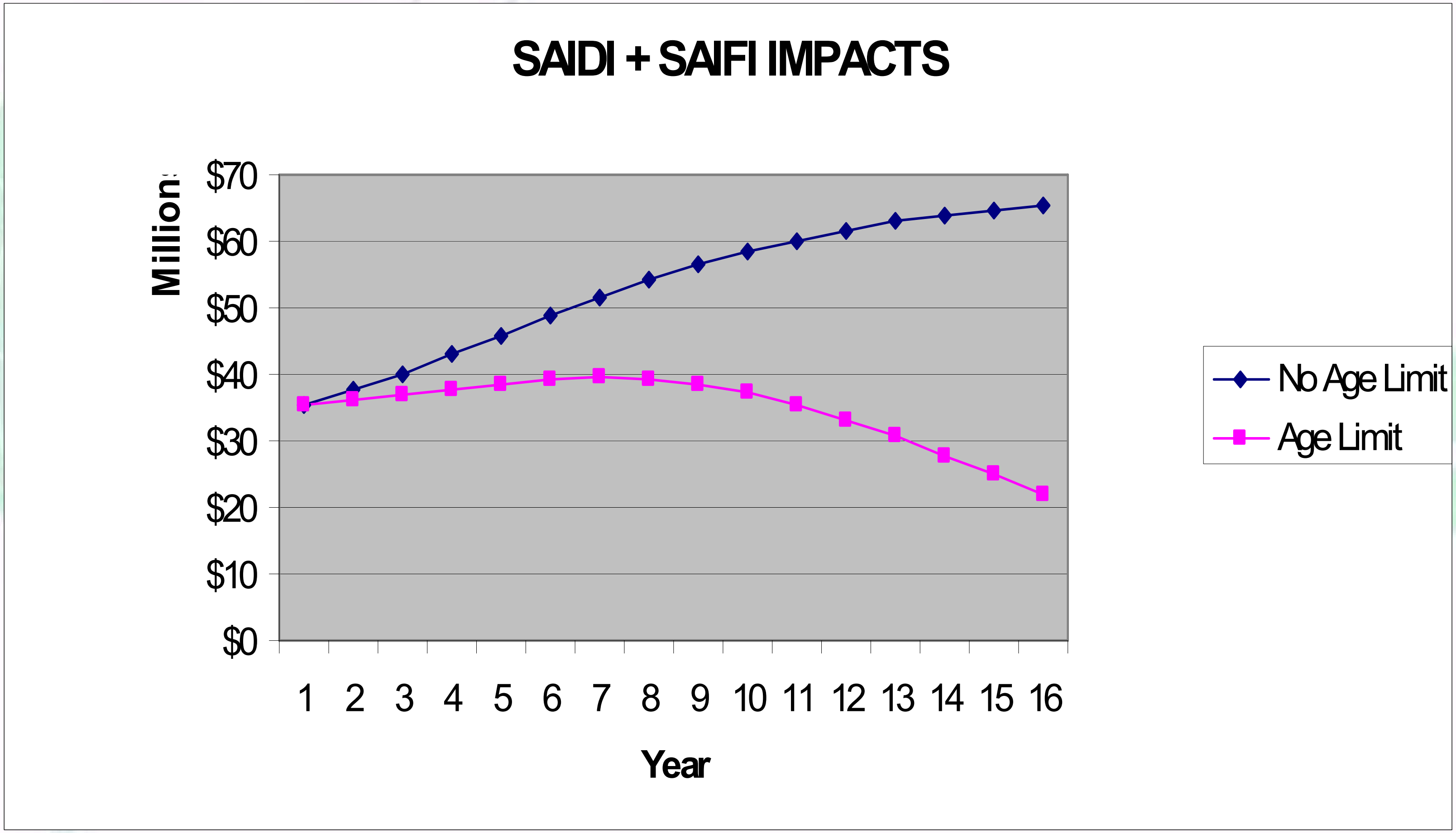
Cable Insulation Failure Model



Pre-emptive Replacement Strategy – Age Limit (10% failure)



Case II – SF_6 Breaker Maintenance

- Issues:
  - Extension of Oil Breaker Maintenance Philosophy
  - Declining Reliability
  - Increasing Maintenance Costs
  - Increased Availability Required
  - No CMMS
  - Maintenance Behind Schedule

10 Year Results

- Effective Knowledge Transfer
- Improve Data Collection
- Extended Maintenance Intervals (double) with Defendable Basis
- Additional PM Triggers-Age Exploration
- Reduction in Rework Activities-Improved PM Effectiveness
- Increased Availability
- Improved Reliability
- Elimination of PM Backlog

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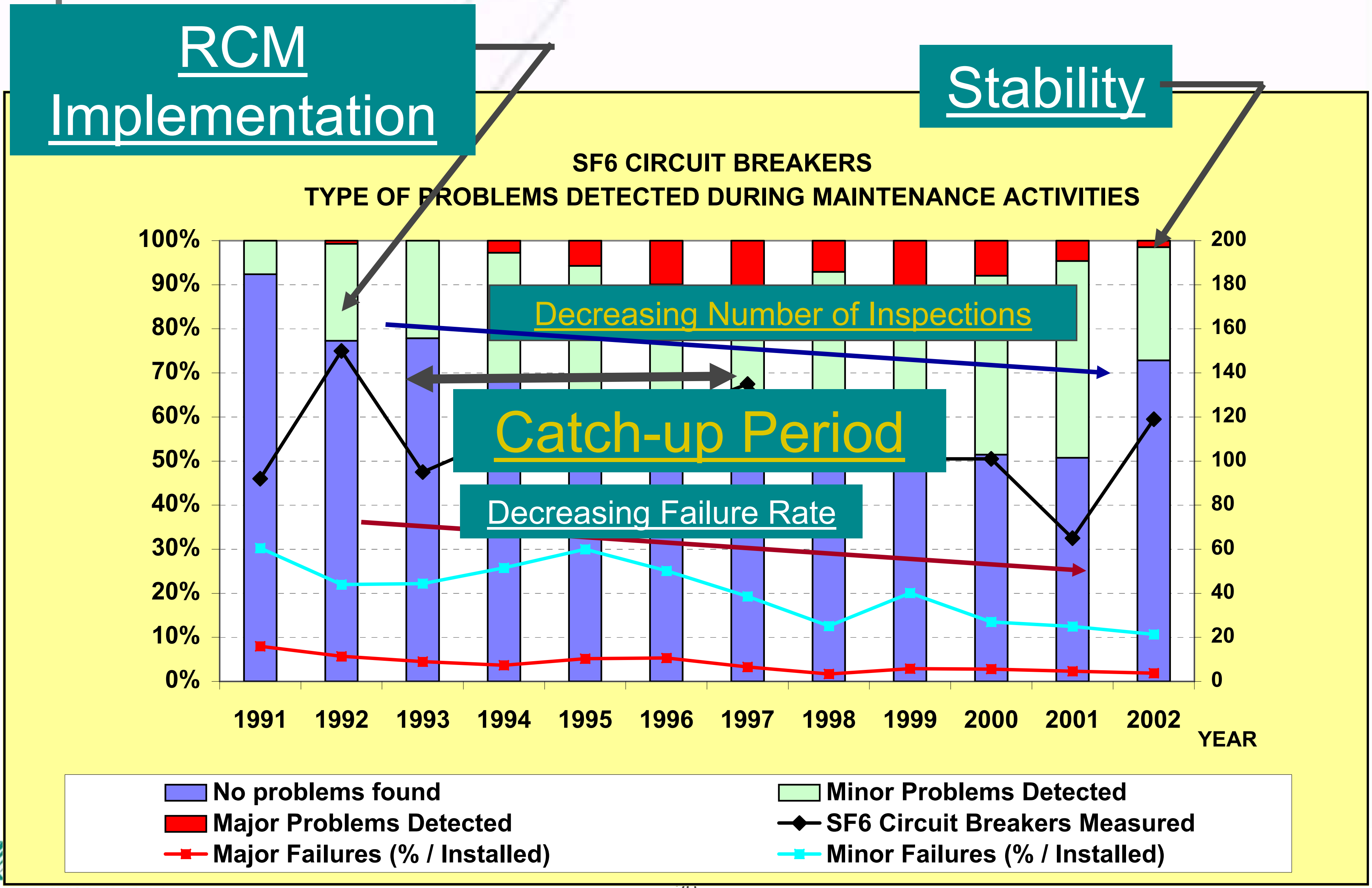
SF_6 PFM Implementation Results

SF_6 Breakers
(69% of the total population)

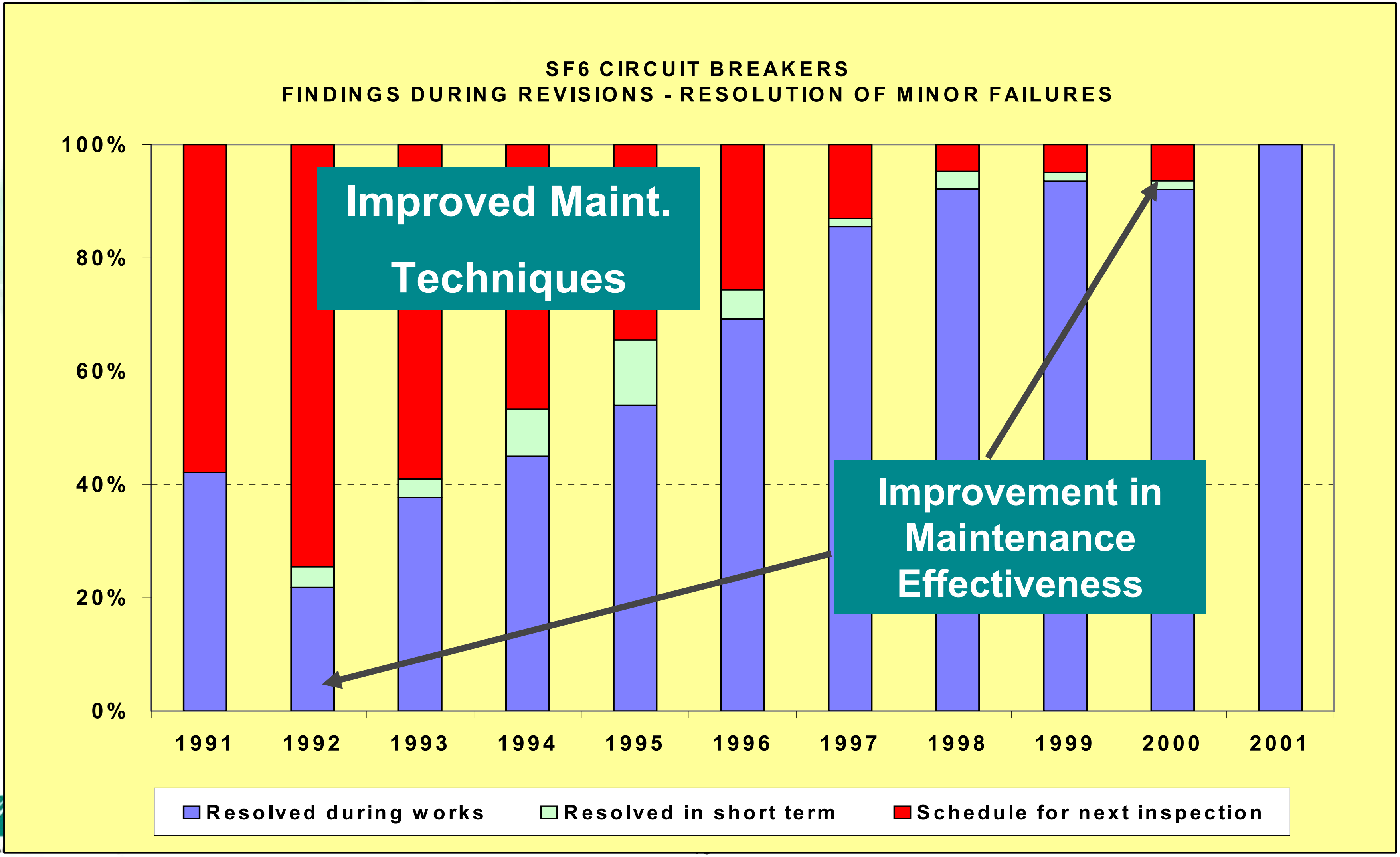
10 Year Analysis Period

More than 10,000 Inspections and Maintenance Tasks

Improved Maintenance Plan Resulted in a Decreased Failure Rate



Improved Effectiveness



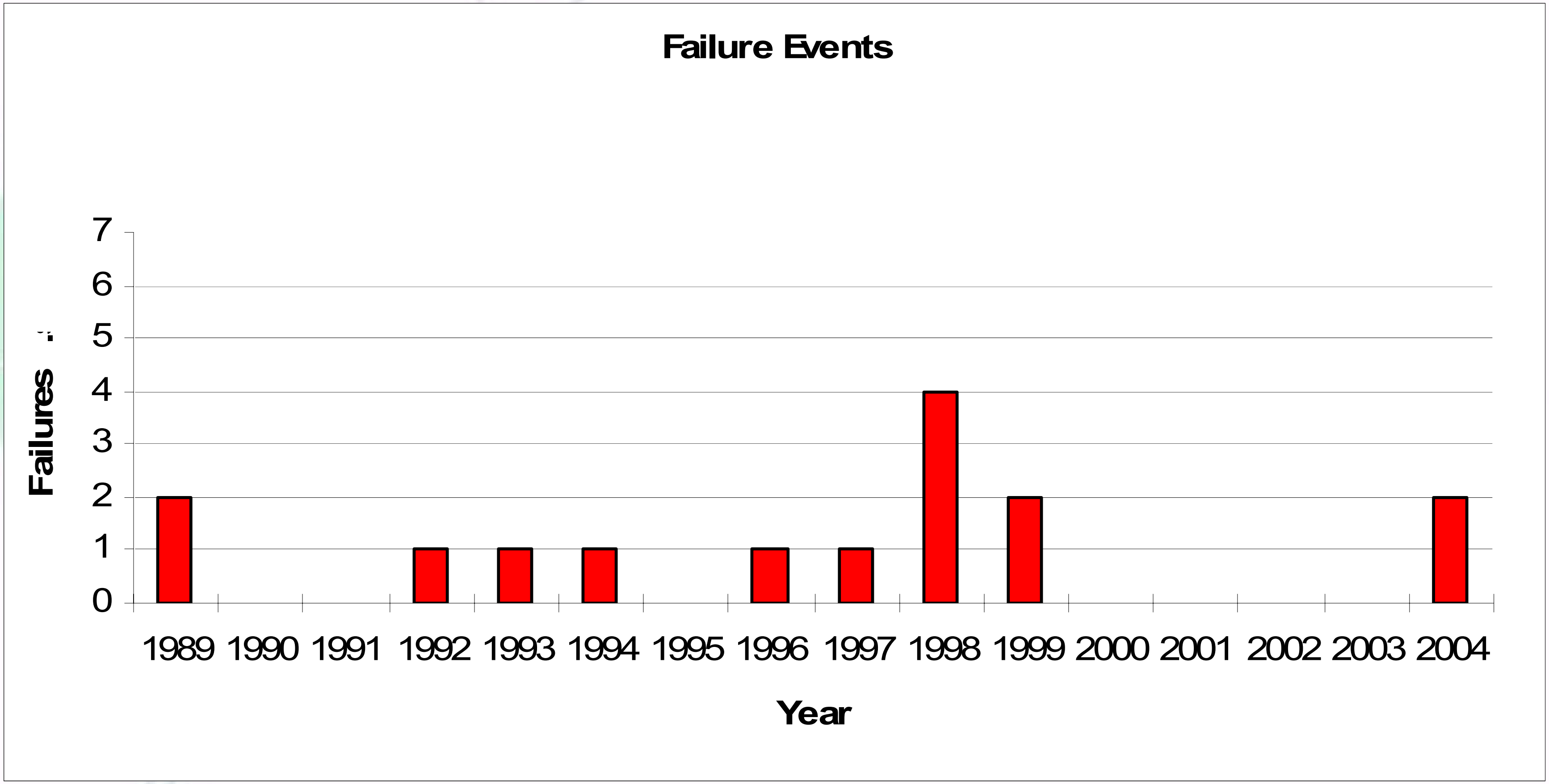
Case III-Application of On-Line Monitors

- Issues:
  - Aging Asset Population
  - Recent Cascading Failure
  - Push to Install New Monitoring Technology
  - Poor Experience with Hydrogen Monitors
  - Increased Insurance Rates

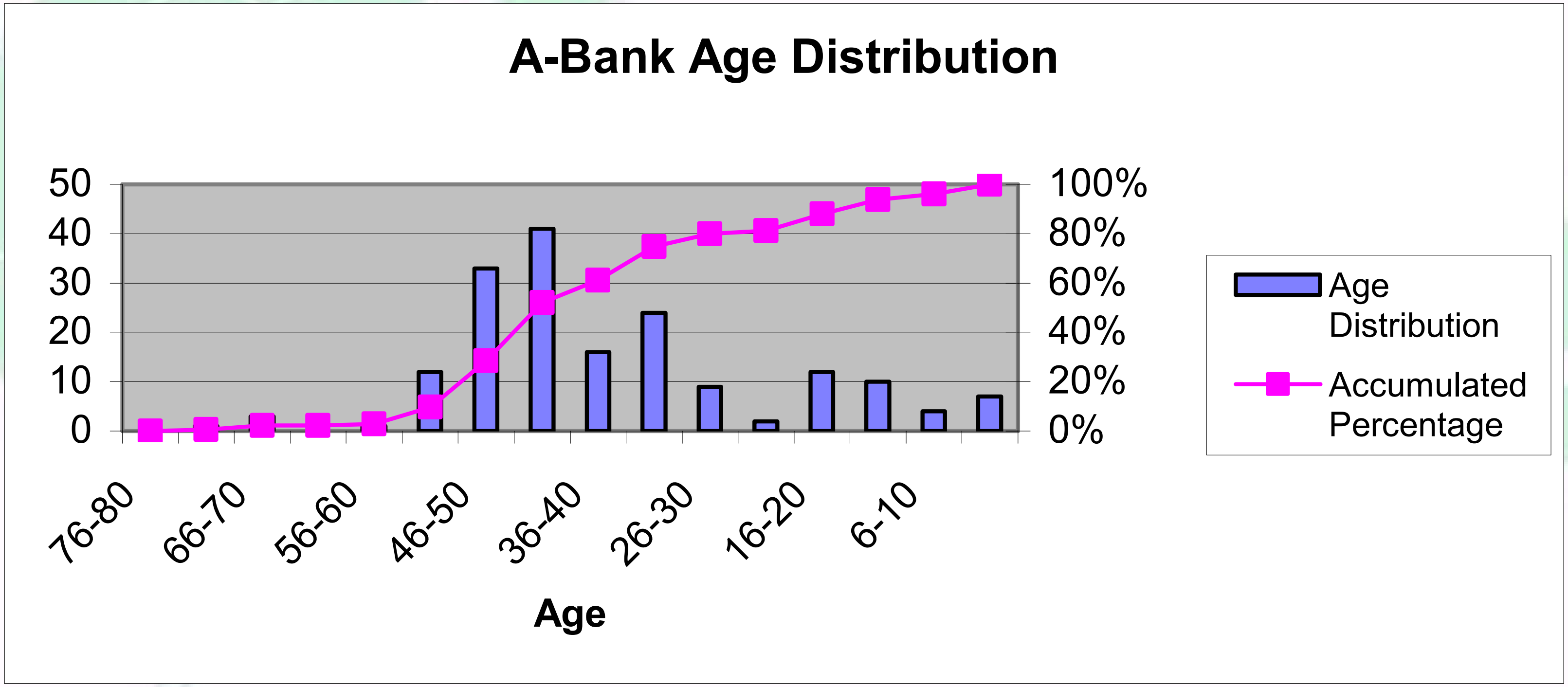
Fleet Characteristics

- “Large” Power Transformers
- 220 KV to 115 or 66KV
- 120 to 280 MVA
- Single and Three Phase
- Average Age = 39 Years
- Max Age = 76 Years
- Replacement Costs $3M to $4M (on the pad)
- Population = 188

Failure History (population = 188)



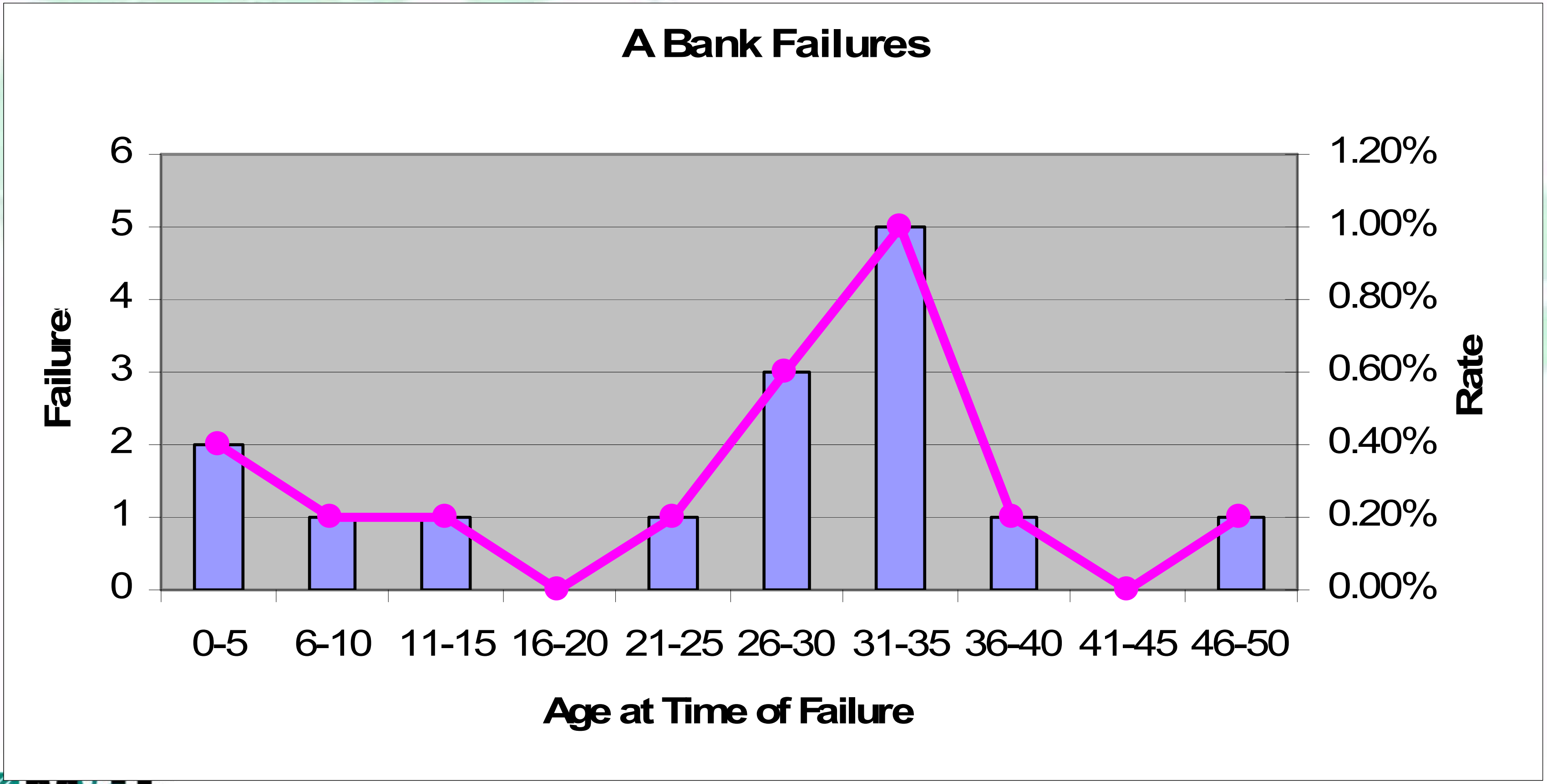
Age Distribution



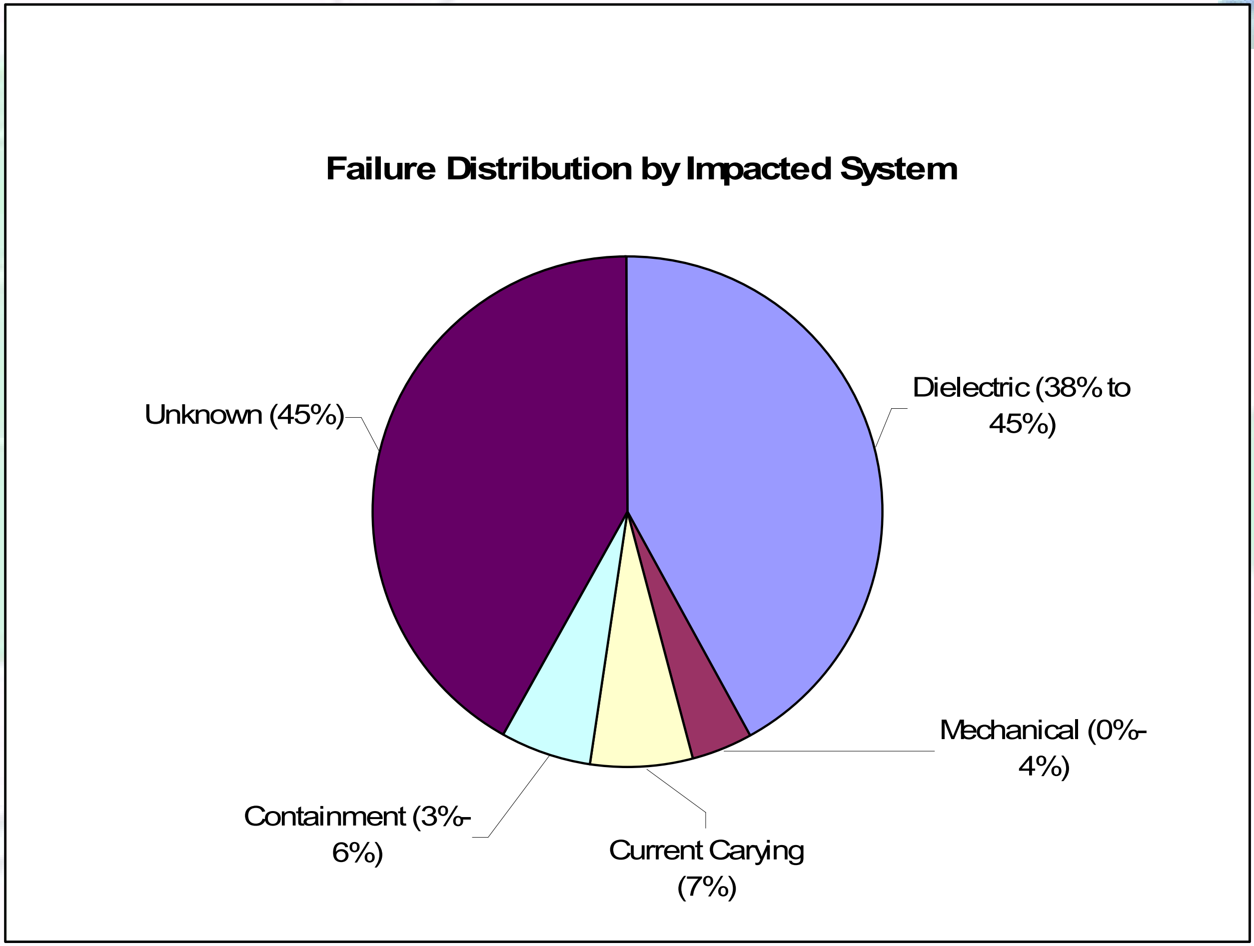
Median Age

44 years

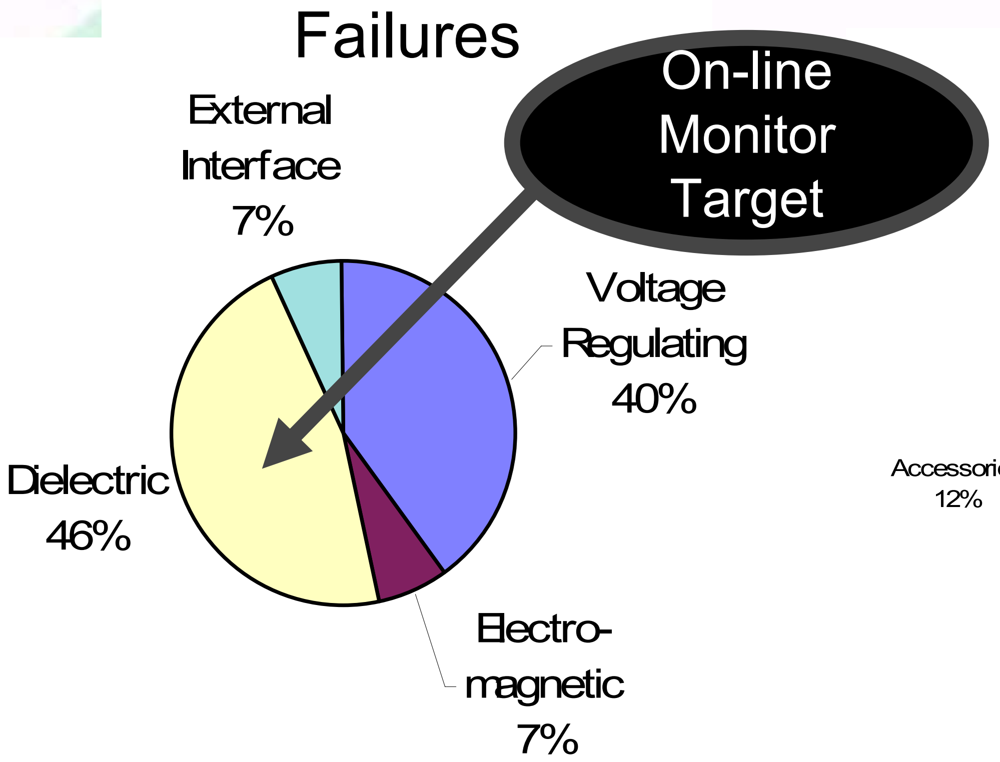
Failures as a Function of Age

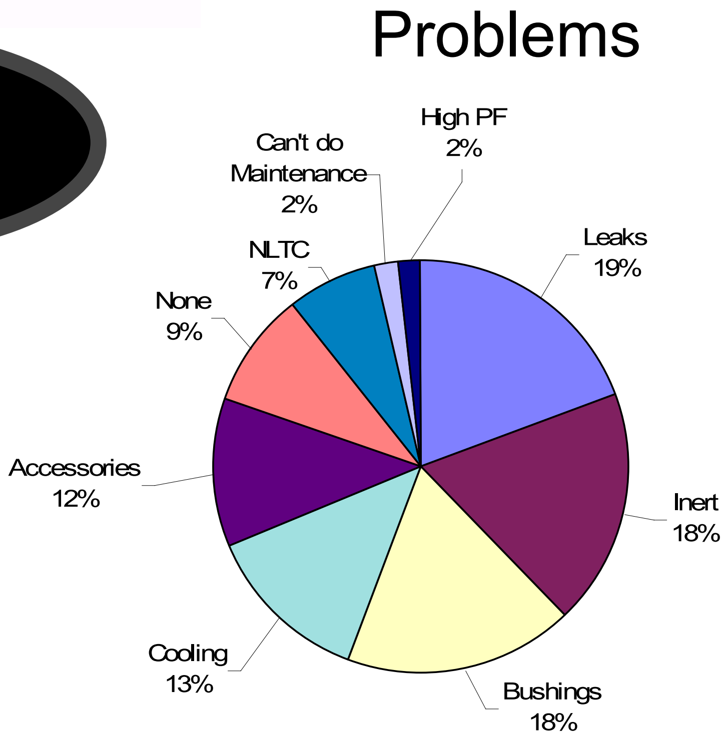


Industry Reported Failure Distribution



Utility Reported Failure and Trouble Distribution





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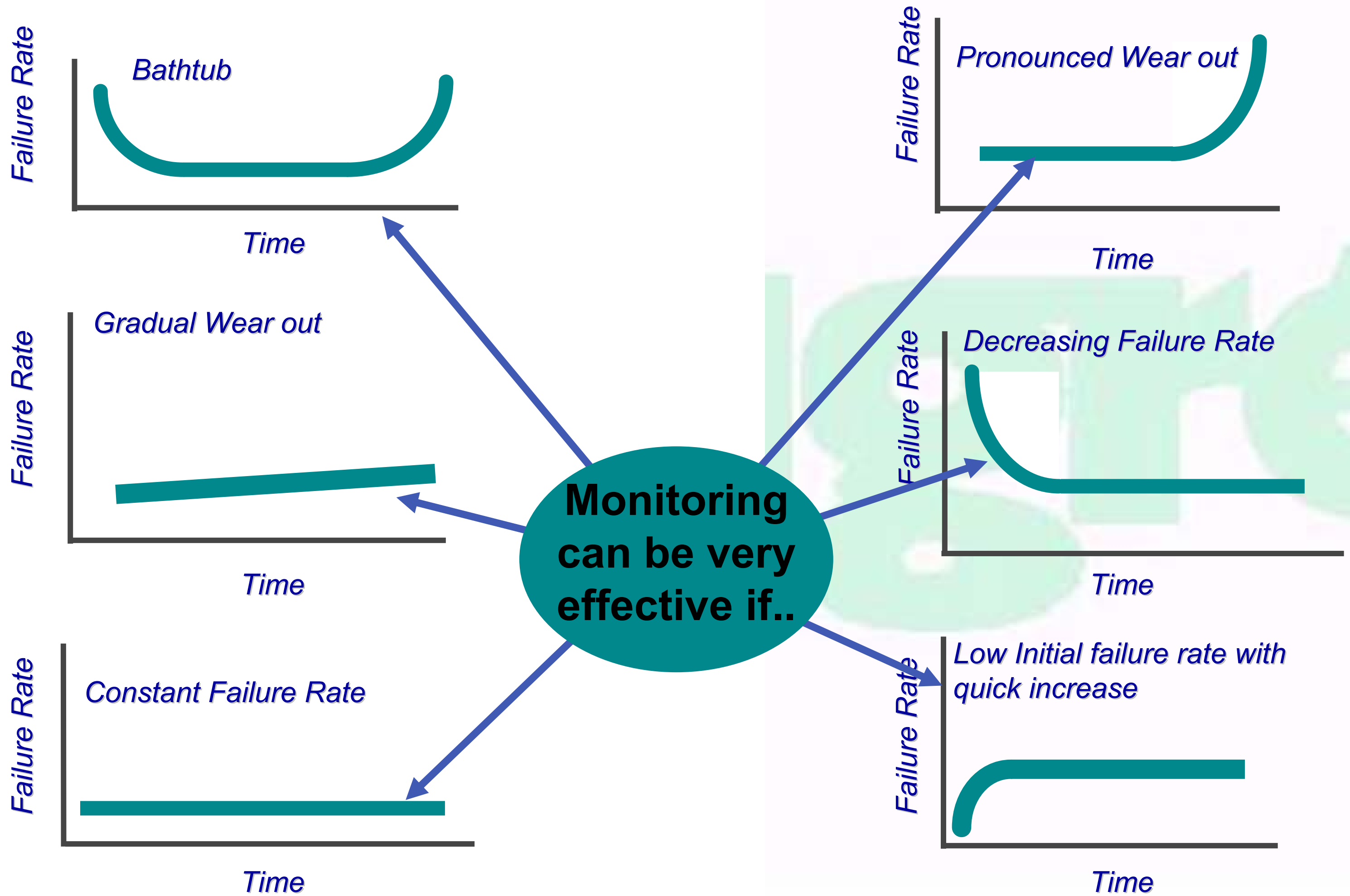
Age Reliability Patterns-Failure Probability



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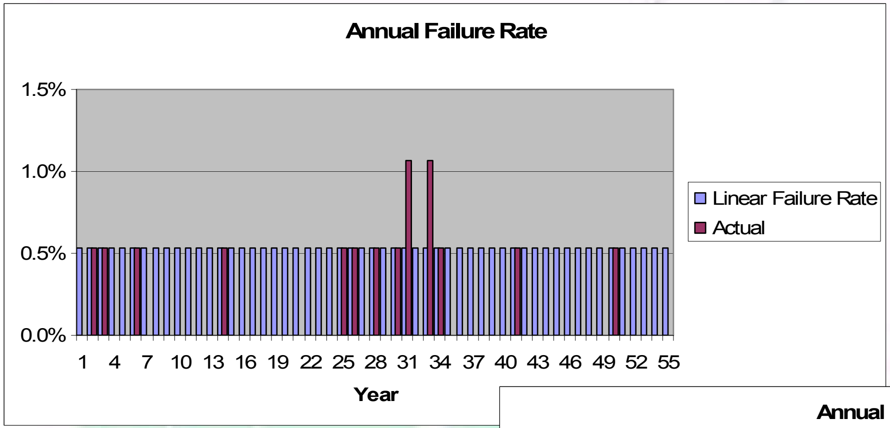
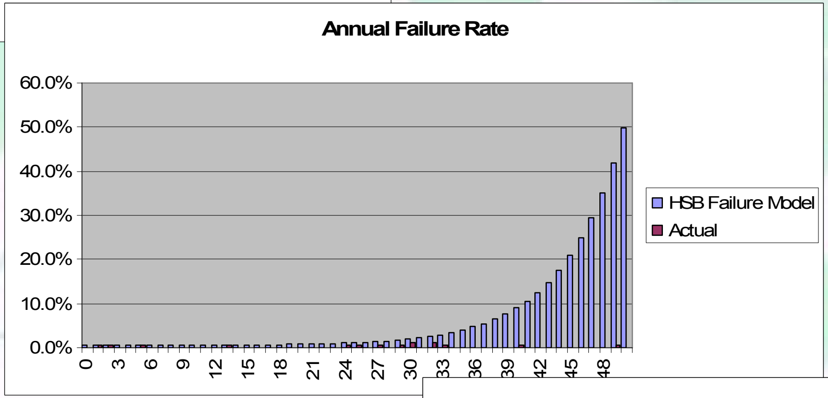
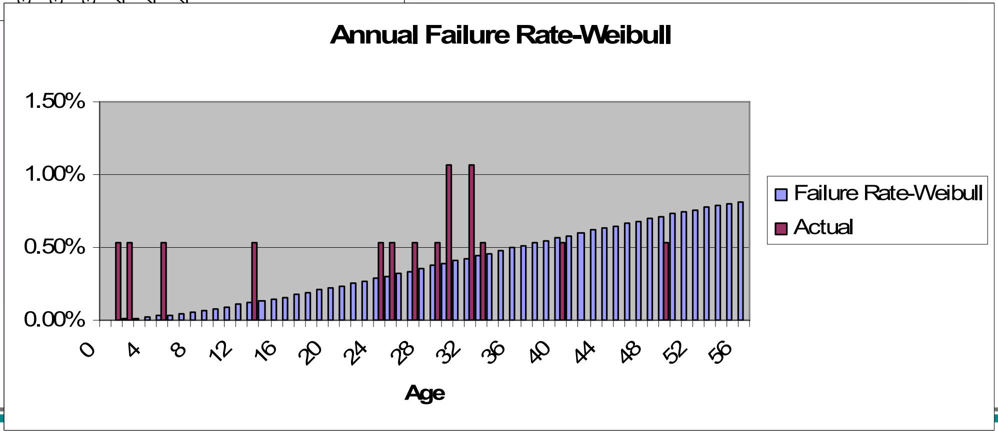
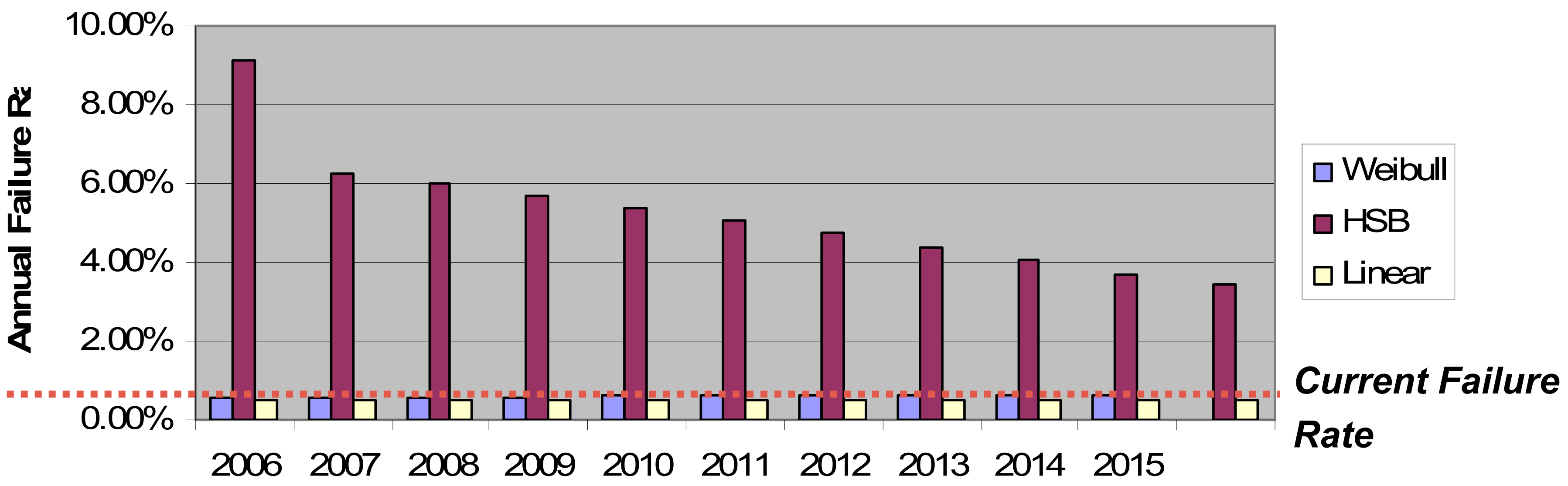
Typical Reliability Predictive Models



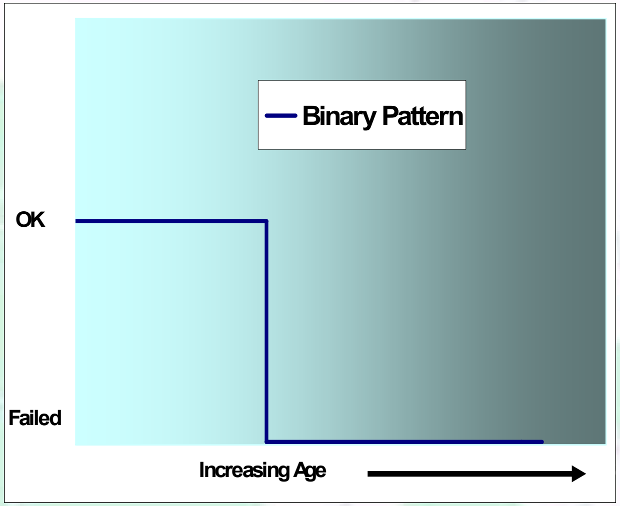


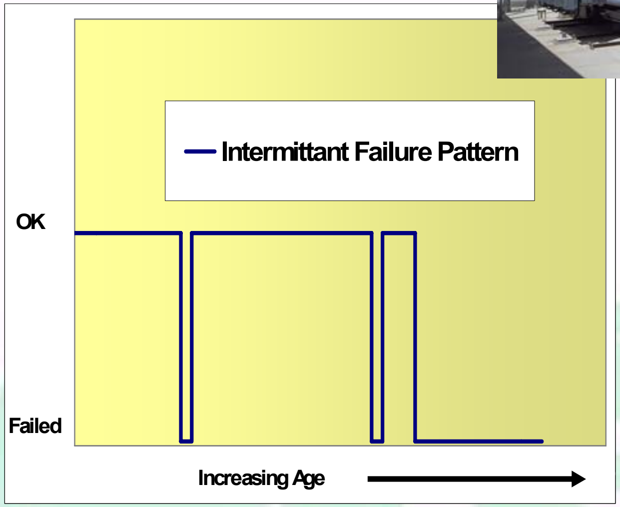


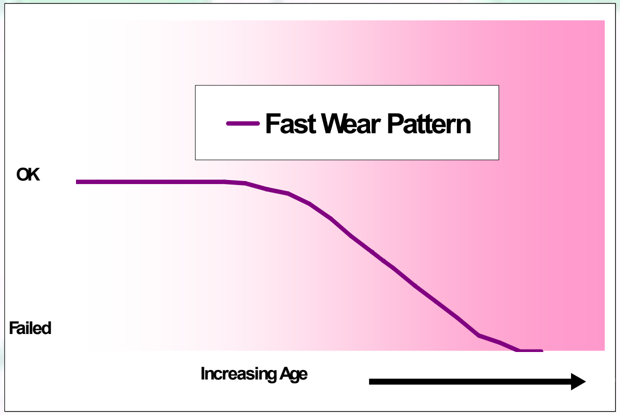
Model Comparison Applied to Existing Fleet

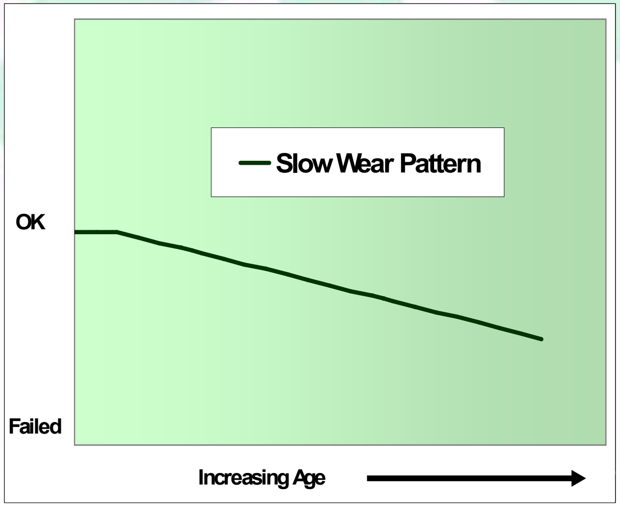


Failure Mechanisms









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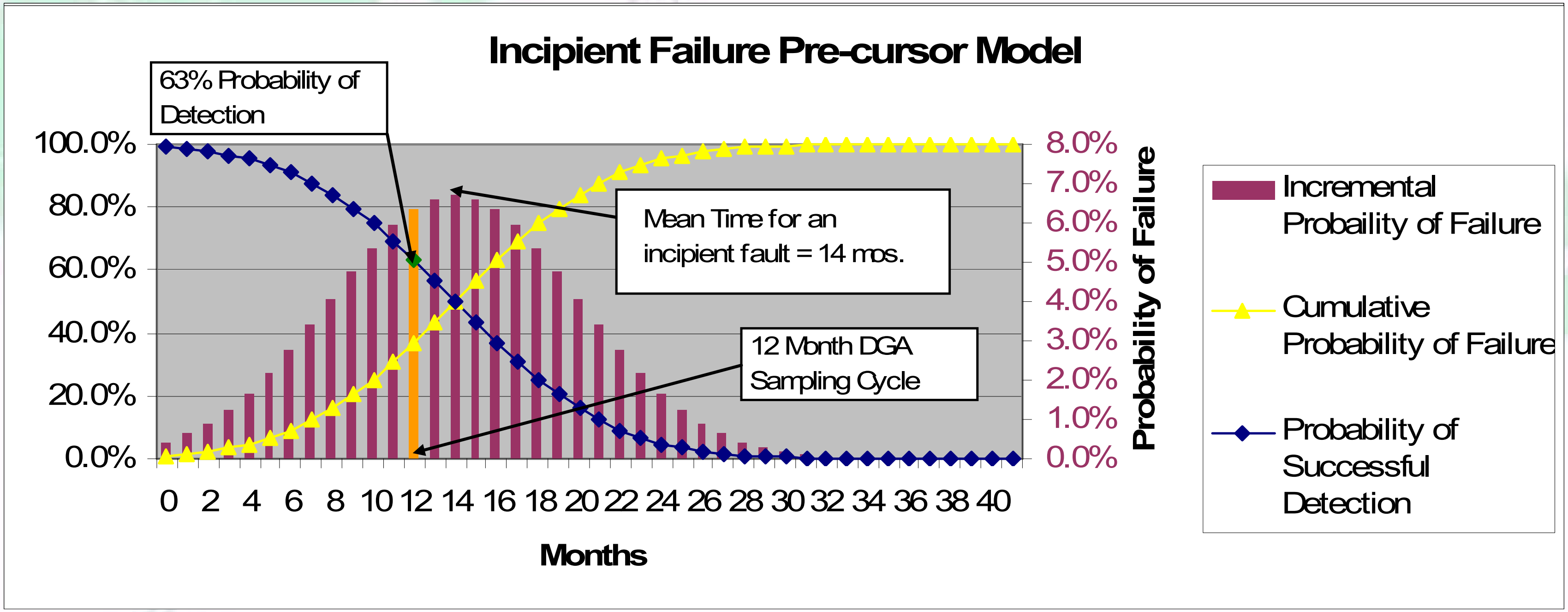
Incipient Failure Model



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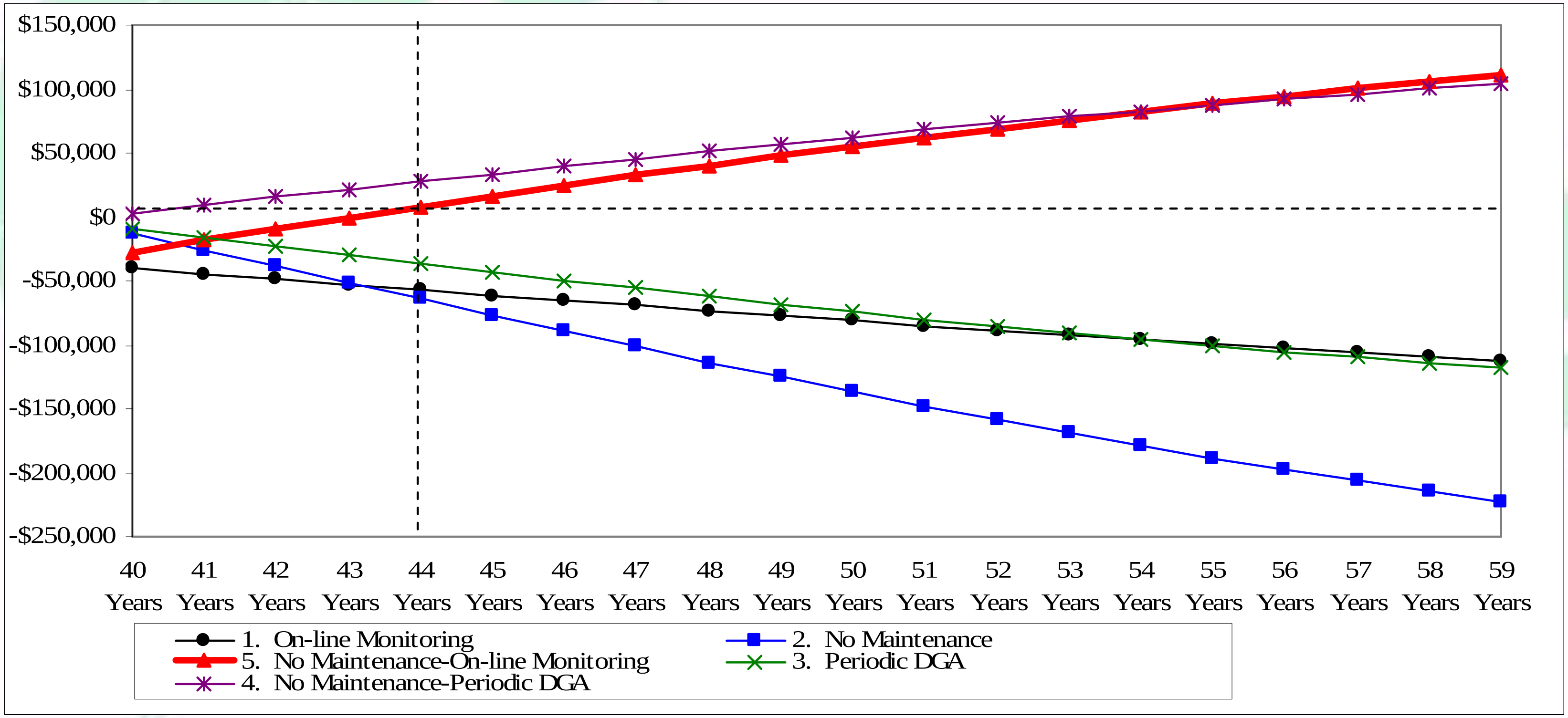
On-line Monitoring Decision Model

- Failure Model
- Direct Costs
  - Transformer
  - Collateral Damage
  - Fines
- Indirect Costs
  - Commissions and Ratepayers
  - Insurance
  - Stress on other units
  - Supply impacts
- True Risk Reduction
- Fleet Replacement Impacts

Cumulative Cash Flow for Multi-Gas Monitors



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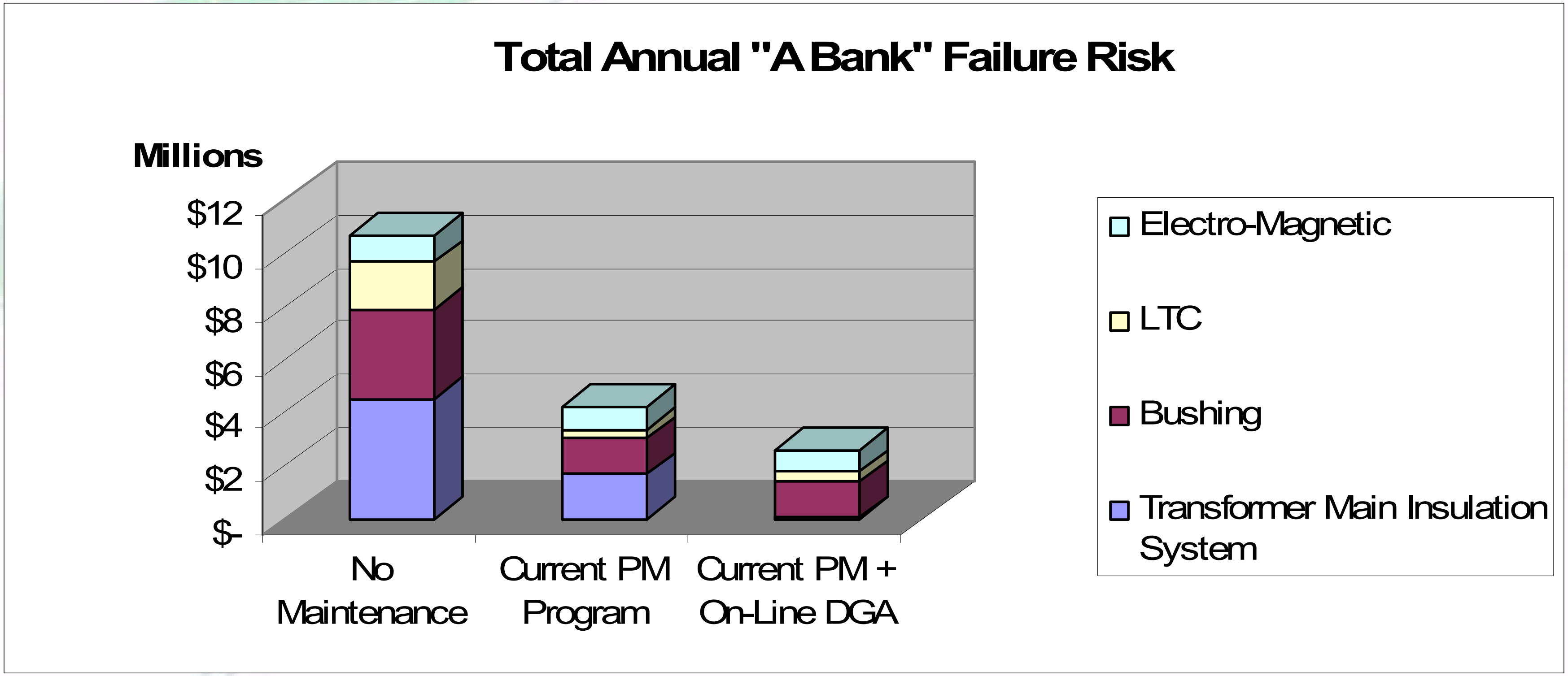
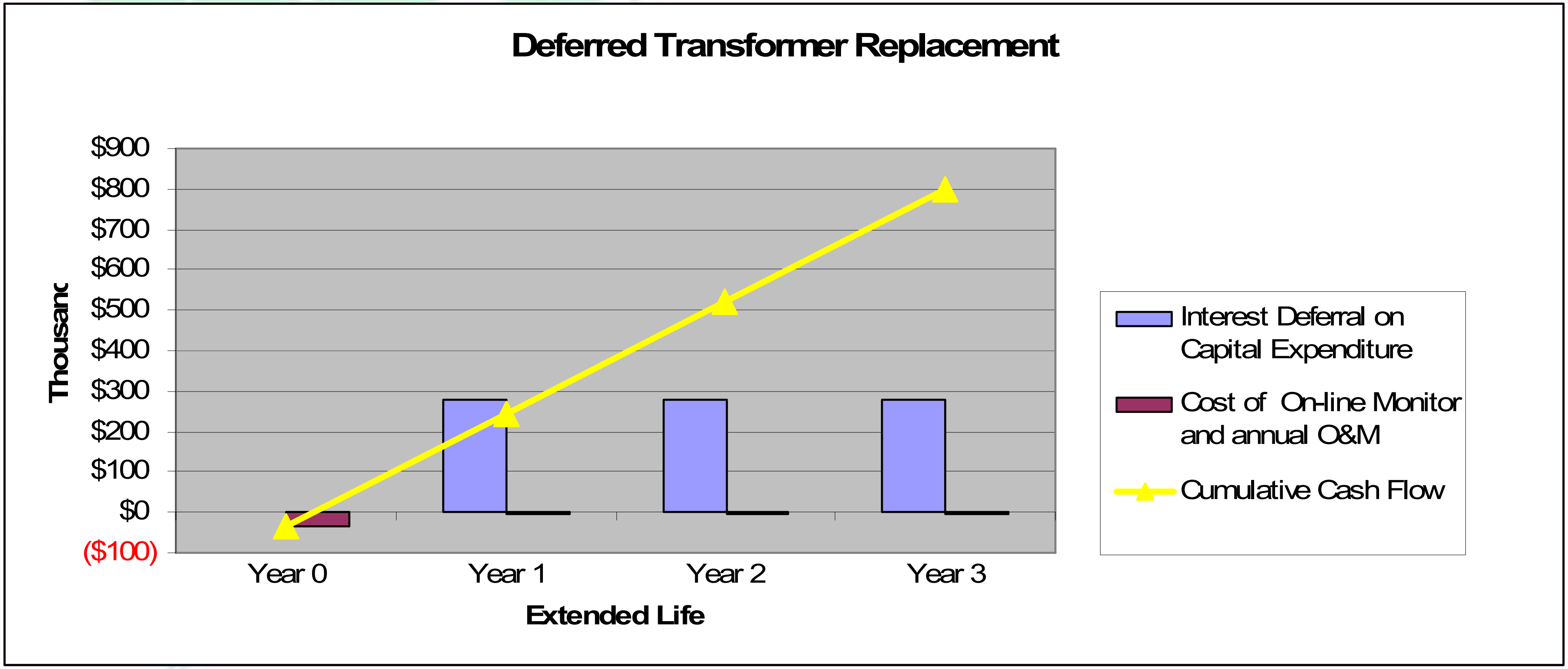
Transformer Fleet Risk Exposure Profiles



Extended Useful Life



Conclusions from PFM Approach:

Substantial benefit can be obtained from installation of multi-gas monitors across a large fleet of power transformers

- Improved transformer reliability
- Reduced failure impacts
- Realization of full transformer useful life
- Identification of units in urgent need of repair/replacement.
- Substantial reduction in overall transformer operating risks

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Future Trends in Maintenance

- Sharing of Failure and Trouble data
  - Mode and Cause Level
  - Demographics
    - Application
    - Type
  - Population
    - Age models vs. Failure Rate
- Full Asset Utilization
- Risk Reduction
- Key Performance Indicators
  - Asset Family
  - Maintenance Process
  - Life Cycle Costs

Open Discussion and Questions:

Need More Information?

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