LLNL-CONF-691104

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Optimization of Facility Maintenance Program through Application of Streamlined Reliability - Centered Maintenance (RCM)

K. Mohammadi

May 6, 2016

EFCOG Nuclear & Facility Safety Workshop
Lemont, IL, United States
August 6, 2016 through August 12, 2016

Optimization of Facility Maintenance Program through Application of Streamlined Reliability-Centered Maintenance (RCM)

Kazem Mohammadi
Safety Analysis Engineer
Safety Basis Division
Nuclear Operations Directorate
Lawrence Livermore National Laboratory
P.O. Box 808 (L-372)
Livermore, CA 94551
Phone (925) 423-5795
Mohammadi2@llnl.gov

Abstract

Reliability-Centered Maintenance (RCM) can be defined as an approach that employs predictive, preventive, proactive, and reactive maintenance practices and strategies in an integrated manner to increase the probability that a Structure, System, or Component (SSC) will function as designed over its life cycle with optimum maintenance. The goal of RCM is to preserve the SSC intended design function at the lowest cost by developing a maintenance strategy that is supported by sound technical and economic justification. RCM has been used extensively by the aircraft, space, defense, power generation, and manufacturing industries where functional failures of SSCs can have the potential to compromise worker or public safety, cause adverse environmental impact, cause loss of production, or result in excessive damage to critical SSCs. This paper provides a framework for performing a streamlined RCM analysis that is less resource-intensive than the classical RCM approach and thus more suitable for facilities with a large number of systems and components. The analysis may be done in support of DOE Order 430.1A (Life Cycle Asset Management) and DOE Order 420.1B (Facility Safety). The influence of RCM on the various aspects of the maintenance program including the work planning and control process is also discussed.

Optimization of Facility Maintenance Program through Application of Streamlined Reliability-Centered Maintenance (RCM)

Kazem Mohammadi, Safety Analyst

Lawrence Livermore National Laboratory

LLNL-PRES-XXXXXX
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

RCM - Definition

A logical discipline for the development of scheduled maintenance programs
[Original RCM Report - Nolan and Heap]

A disciplined methodology that employs proactive, predictive, preventive, and reactive maintenance practices and strategies in an integrated manner such that inherent reliability of SSCs is realized at lowest cost
[RCM II]

RCM - Background

RCM

Reliability-Centered Maintenance, Nolan and Heap, United Airlines (1978)

MIL-STD-2173

RCM Requirements for Naval Aircraft, Weapons Systems and Support Equipment (1986)

NAVAIR-00-25-403

Guidelines for the Naval Aviation RCM Process (1996)

RCM II

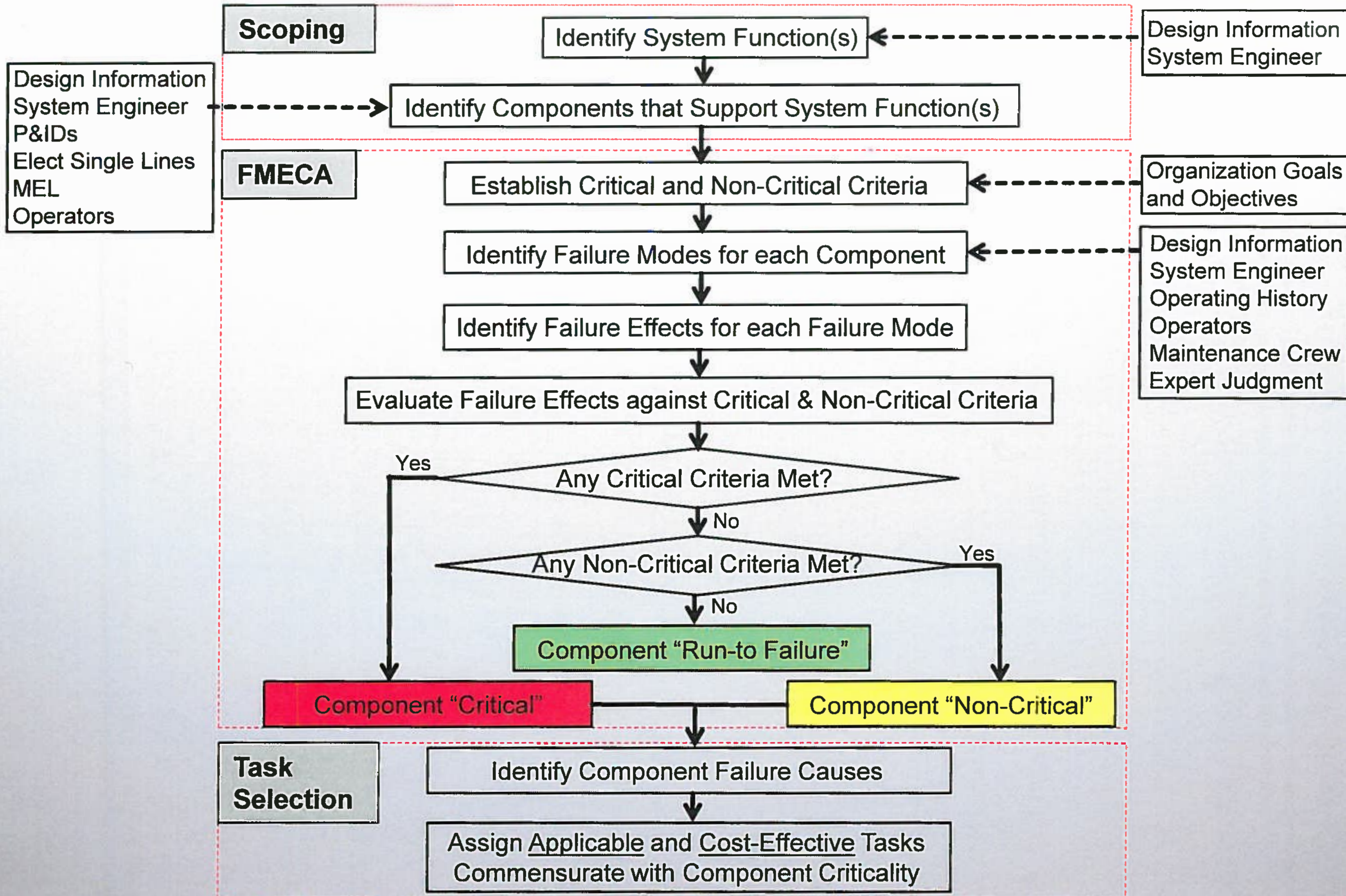
Reliability-Centered Maintenance (RCM) II (1997)

Other derivatives

INPO AP-913 (Equipment Reliability Evaluation Process) (2001)

***Streamlined RCM* (focus of this presentation)**

Streamlined RCM - Overall Approach



Streamlined RCM – Scoping

Identify System Function(s)

- Review design documents/System Engineer
- Identify functions at system or subsystem level (generally functions identified at higher level than in classical RCM)
- Define function performance standard
- Define function operating context

Streamlined RCM – Scoping (cont'd)

Identify System Function(s)

Example

System	Function
Water Supply	provide water to main header at 1000 gpm

Streamlined RCM – Scoping (cont'd)

Identify Components that Support System Function(s)

- Review design documents
- System Engineer
- Operators
- P&IDs
- Electrical single lines
- Master Equipment List (MEL)
- System walk-down

Streamlined RCM – Scoping (cont'd)

Identify Components that Support System Function(s)

Example

System	Function	Boundaries
Water Supply	provide water to main header at 1000 gpm	equipment within function boundaries include tank T-101A, pumps P-101A/B, main header, and associated piping, valves, and instrumentation

Streamlined RCM – FMECA

Establish Critical and Non-Critical Criteria

Example Critical Criteria

- C1: significant safety impact
- C2: significant environmental impact
- C3: impact on programmatic mission/availability
- C4: loss of redundant safety function
- C5: unplanned entry into an LCO
- C6: actuation of a safety system
- C7: excessive equipment damage > $200K

Example Non-Critical Criteria

- NC1: simple, cost-effective, task exists to ensure reliability
- NC2: high repair/replacement cost if run-to-failure
- NC3: failure could lead to costly failure of other equipment
- NC4: increased personnel safety hazard if run-to-failure
- NC5: increased environmental hazard if run-to-failure
- NC6: required for effective process control and monitoring
- NC7: long lead time for spare parts

Streamlined RCM – FMECA (cont'd)

Identify Failure Modes for each Component

- Failure modes represent "how a component fails"
- Only consider **credible** failure modes
- Consider failure modes associated with both **primary** and **secondary functions**
- **Evident** versus **hidden** failure modes

Streamlined RCM – FMECA (cont'd)

Identify Failure Effects for each Failure Mode

Failure Effects

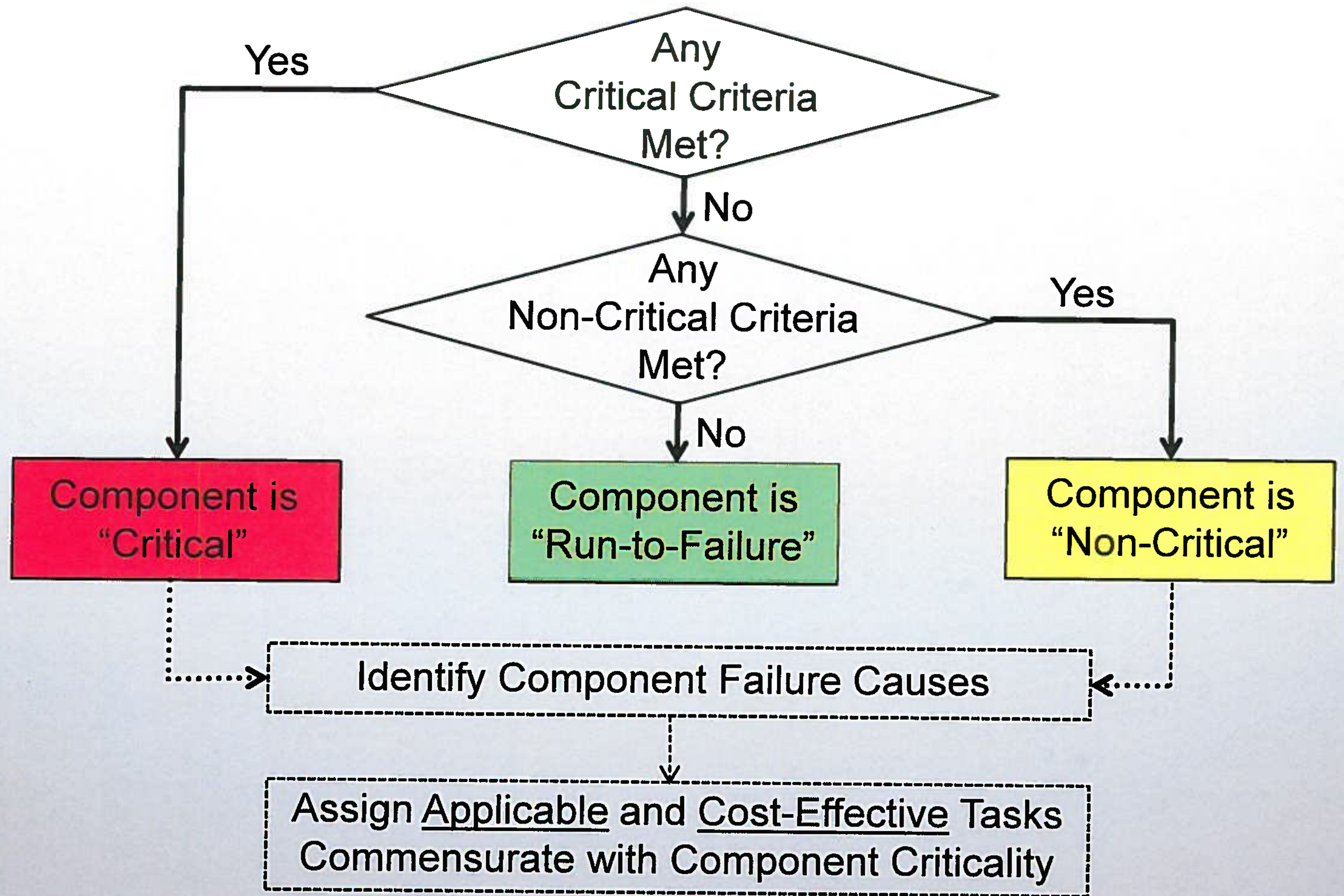
- Impact on operation
- Impact on product quality
- Startup delay
- Releases to environment
- Personnel safety hazard
- Excessive equipment damage
- Excessive noise

Consider the following when identifying failure effects

- Only consider one failure at a time
- Evaluate failure effects associated with component primary function
- Evaluate failure effects associated with component secondary function
- Consider feasibility of operator action to mitigate failure effects
- Redundancy
- Assume no maint. tasks currently exists to anticipate, prevent, or detect failures
- Assume no spare parts available

Streamlined RCM – FMECA (cont'd)

Evaluate Failure Effects against Critical & Non-Critical Criteria



Streamlined RCM – FMECA (cont'd)

Evaluate Failure Effects against Critical & Non-Critical Criteria

Example

Comp ID	Description	Comp Type	Failure Mode(s)	Failure Effect(s)	Evaluation Criteria Met	Critical? (Yes/No)	Comments
P-101A	Pump P-101A, Centrifugal, Sulzer	PUMPC	• External Leakage • Fails to Run (includes degraded performance standard)	• Loss of redundancy • No functional impact • High repair/ replacement cost	C7: excessive equipment damage > $200K	Yes	P&ID: D24F1050 C2. Two redundant pumps. External leakage can be detected by operators and mitigated without significant impact. If pump fails to run, redundant pump will auto start. Pump repair/ replacement cost > $200K

Streamlined RCM – Task Selection

Identify Component Failure Causes

- Failure causes represent "why a component fails"
- Failure causes identified at a level sufficient to allow for identifying applicable maintenance tasks
- Component reliability achieved depends on the degree to which failure causes will be prevented by maintenance tasks

Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

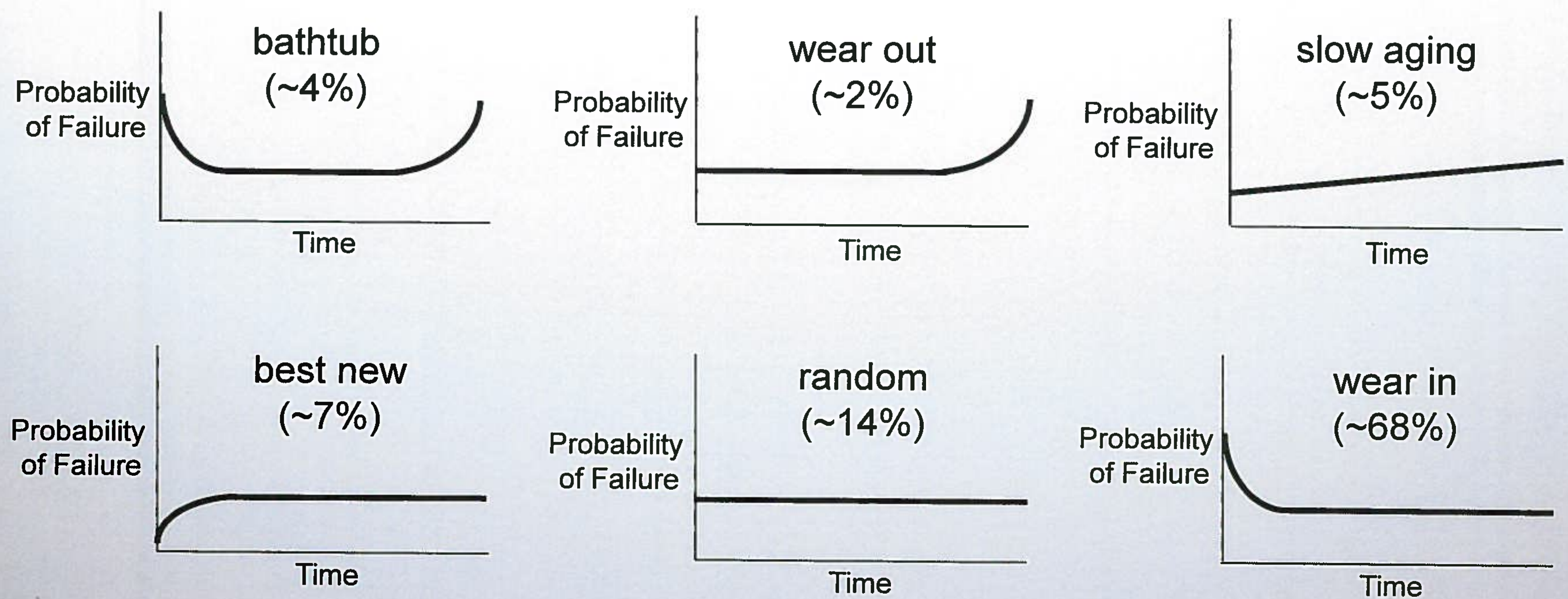
Task Type Hierarchy

- **Primary effects monitoring** (e.g., product quality, speed, flow rate, pressure, temperature, power, current, noise, smell, leakage)
- **Condition monitoring/predictive** (e.g., vibration monitoring, lube oil analysis, infrared thermography, motor current signature analysis, ultrasonic inspection, etc.)
- **Time-Directed** (e.g., scheduled inspection, overhaul, replacement, eddy current testing, megger/polarization index testing, hi-pot testing)
- **Failure Finding** (e.g., interlock functional test, diesel generator functional test, fire pump functional test)

Streamlined RCM – Task Selection (cont'd)

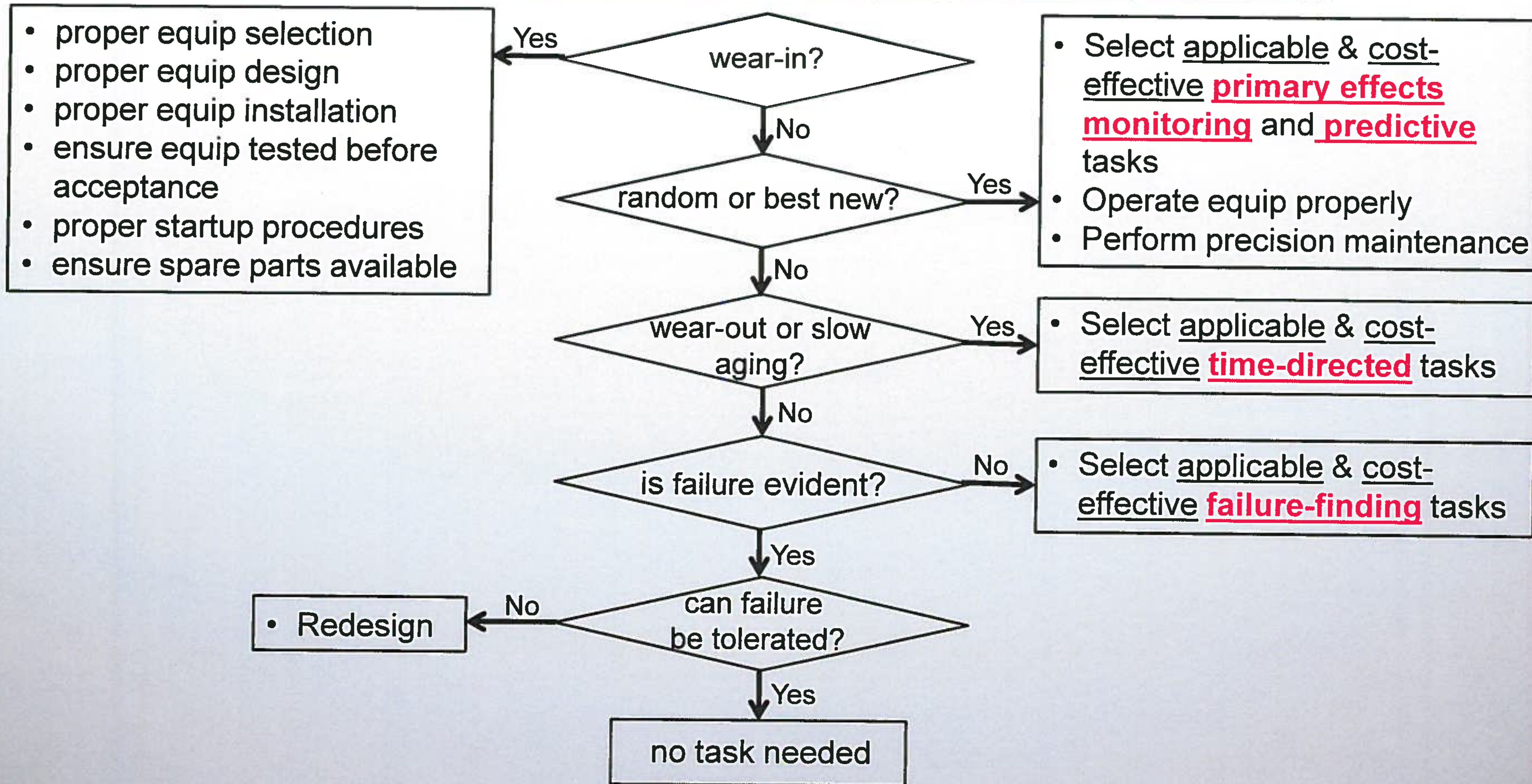
Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

Component/Part Failure Patterns



Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality



Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

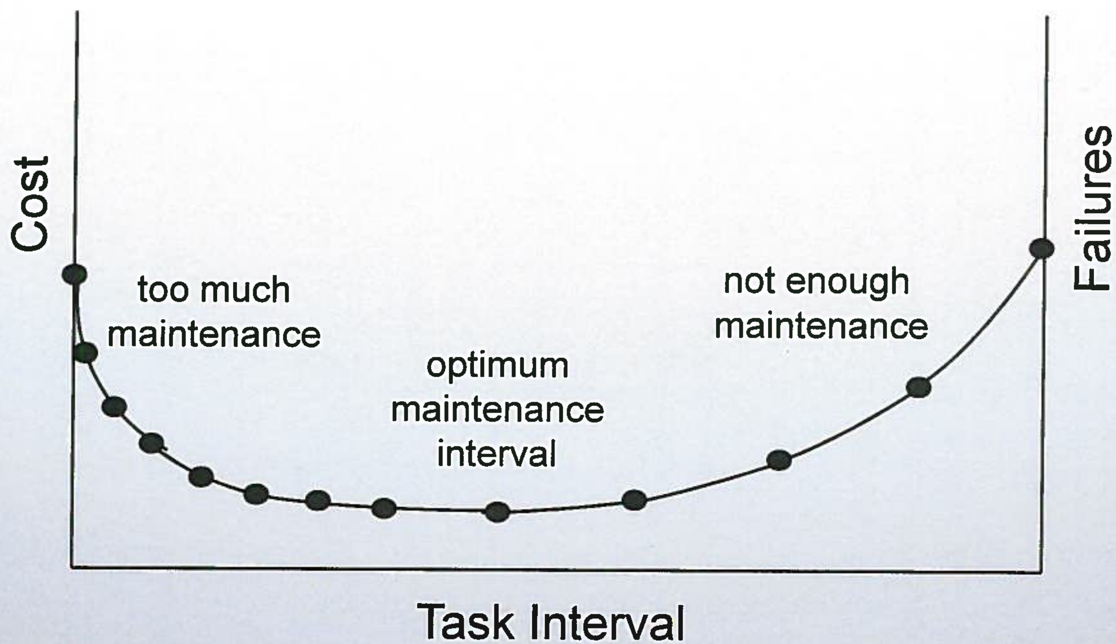
Task Intervals

- Initially establish conservative internals and baseline
- Adjust interval on maintenance history (i.e., failures and inspection results)
- Quantitative (statistical) assessment of failure data
- Generic databases (e.g., EPRI)
- Engineering judgment
- Vendor recommendations

Streamlined RCM – Task Selection (cont'd)

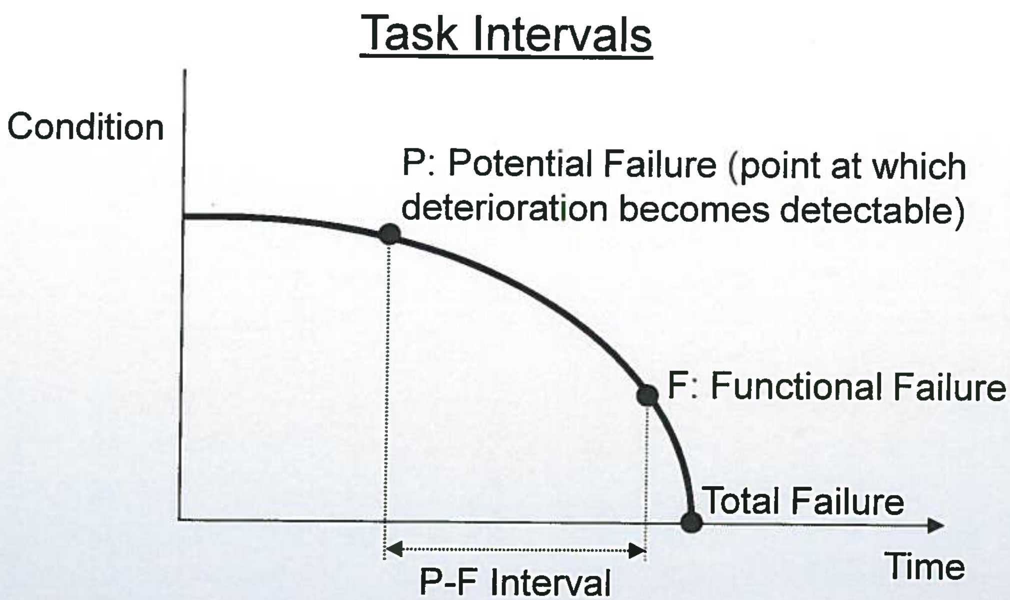
Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

Task Intervals



Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

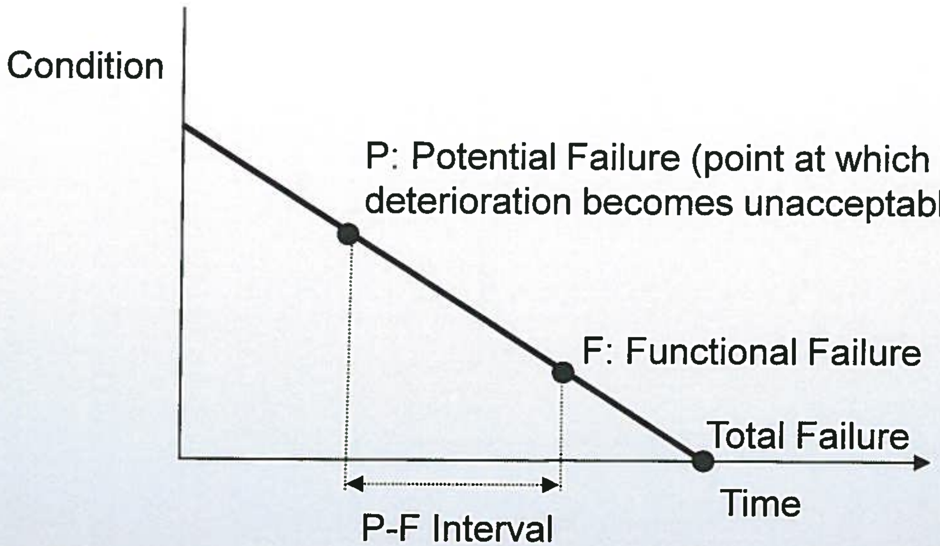


Task Interval for Predictive Tasks (non-linear P-F curve)

Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

Task Intervals



Task Interval for Predictive Tasks (linear P-F curve)

Streamlined RCM – Task Selection (cont'd)

Assign Applicable and Cost-Effective Tasks Commensurate with Component Criticality

Example

Comp ID	Description	Comp Type ID	Failure Mode(s)	Failure cause(s)	Task(s)	Freq.	Resp. Discipline	Comments
P-101A	Pump P-101A, Centrifugal, Sulzer	PUMPC	• External Leakage	• Mechanical seal degradation	• check pump for external leakage	OR	OPS	
			• Fails to Run (includes degraded or <1000 gpm)	• Bearing inadequate lubrication	• Check bearing oil level and add as needed	OR	OPS	
					• Change oil	1Y	OPS	A sample of used oil will be used for lube oil analysis.
				• Impeller wear	• Check discharge pressure (PI-1)	OR	OPS	Trend data.
					• Check discharge flow rate (FI-1)	OR	OPS	Trend data.
				• Unbalance • Misalignment • Bent shaft • Foundation flexibility • Looseness • Resonance	• Check for excessive noise	OR	OPS	
					• Perform vibration monitoring and analysis (TL-2000)	1M	TECH	Trend data.
					• Perform lube oil sample analysis (TL-1000)	1Y	TECH	Trend data.

Streamlined RCM – Comparison with Classical RCM

Classical RCM	Streamlined RCM
Suitable for smaller systems with many critical components (e.g., aircraft)	Suitable for large facilities (e.g., power plants, refineries) with a large number of systems and many components
Risk ranks failure modes based on frequency and consequence	Categorizes components into Critical, Non-Critical, and Run-to-Failure based on effects consequences or Criticality
May include in-depth analysis of failure modes and causes based on failure data	Assessment of failure modes and causes is performed qualitatively through expert judgement
Task intervals (e.g., components with wear-out failure pattern) may be established quantitatively	Task intervals generally established qualitatively through expert judgement
Rigorous	Less rigorous
Resource intensive	Less resource intensive
Achieves excellent results	Achieves results that are nearly the same as classical RCM if experts involved

Streamlined RCM – Benefits

- Provides a documented basis for the Maintenance Program
- Binning of equipment into Critical, Non-Critical, and RTF can facilitate work order prioritization and spare parts optimization
- Identification of applicable & cost-effective tasks results in higher equipment reliability and lower overall maintenance cost
- Emphasize on primary effects monitoring and predictive maintenance can extend equipment life
- Evaluation of each component at appropriate level will allow for better failure and cost tracking
- Identification of reliability issues, that if resolved, can enhance overall operation

Streamlined RCM – A Living Maintenance Program

- Periodically revisit equipment operating context and performance expectations to see if they have changed
- Periodically revisit failure modes/causes/effects based on new operating experience
- Periodically revisit maintenance tasks and task intervals for applicability based on new operating experience
- Perform RCFA on Critical SSCs and incorporate into Maintenance Program
- Look for and apply new/better predictive technologies
- Establish Key Performance Indicators (KPIs) (e.g., MTBF for Critical SSCs, downtime, maintenance cost, etc.)

  ***"It is not possible to manage what you cannot control and you cannot control what you cannot measure"* (Peter Drucker)**

- Periodically revisit training requirements for operators and maintenance crew

Questions?

Lawrence Livermore
National Laboratory