

# Risk-informed Equipment Reliability (ER) Risk Ranking

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“Equipment Reliability Best Practices”  
2005 Utility Working Conference  
Amelia Island, Florida  
August 9, 2005: 1PM



# Overview

Achieving equipment reliability (ER) requires identifying and managing risk. Risk-based processes that identify, select and control high-risk equipment failures bring focus to high-risk equipment maintenance. *Cost reductions and improved safety margins can result.*



# Nuclear Industry ER Risk Classification

## ◆ Background

- Good performance
- NRC focus: risk informed
- Though competitive, has high labor cost

## ◆ Nuclear

- Equipment focus
- AP-913 critical ER categories





# Equipment Reliability Steps

- ◆ Select equipment
- ◆ Apply ER process
- ◆ Standardize methods
- ◆ Format analytical results for use
- ◆ Systematize methods



# Risk Classification

- ◆ Based upon direct failure (SPV's)
- ◆ AP-913: eight categories
- ◆ Approximately three critical classifications
  - Safety (S)
  - Operations (O)
  - Cost (C)
- ◆ Noncritical (X): no foreseeable direct failure consequence





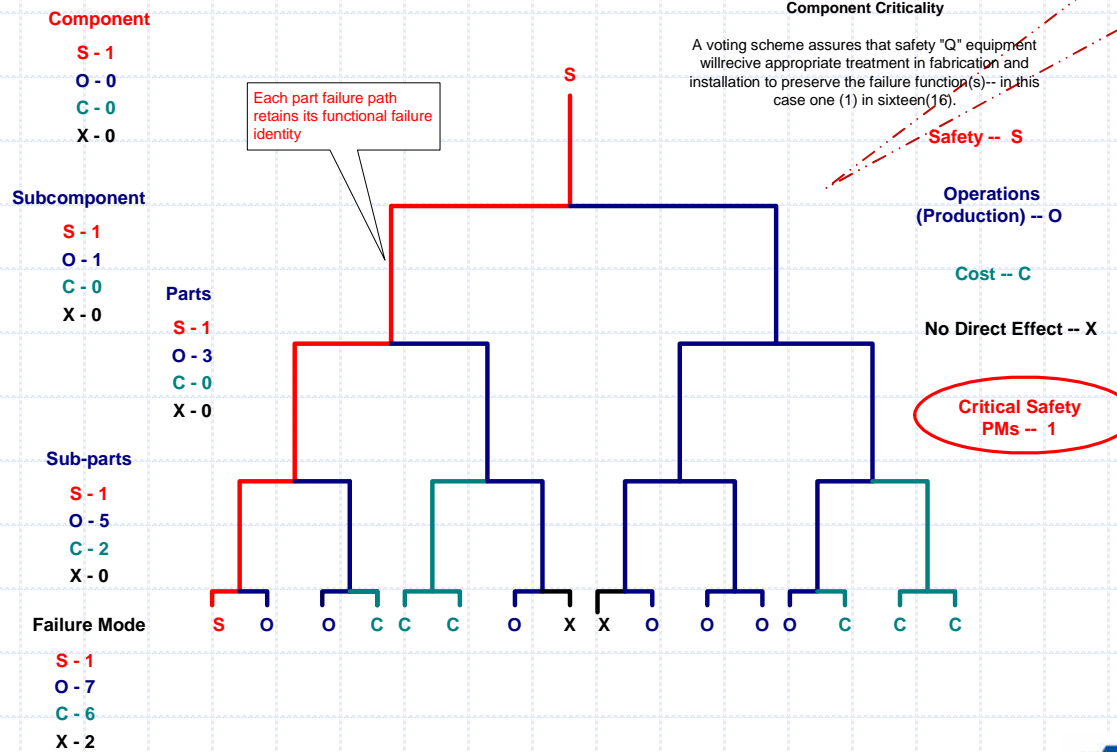
# Failure context

- ◆ Loss of functions
- ◆ Systems
- ◆ Direct failure consequences



# Failure-based ER focus

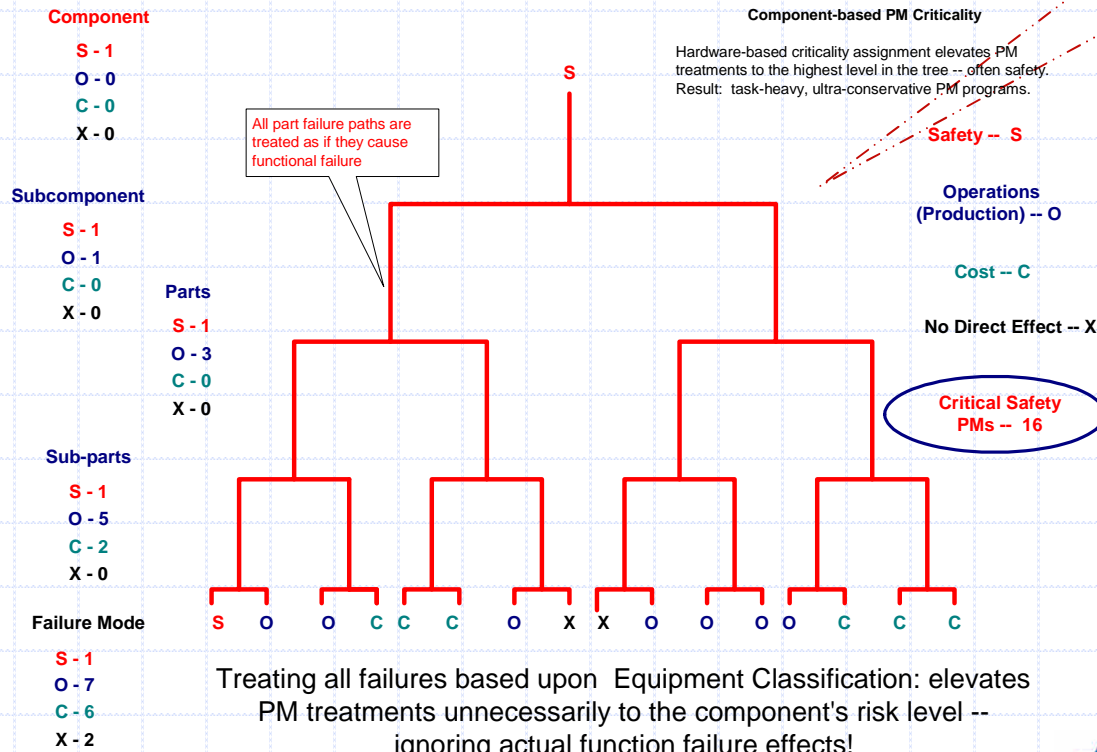
## Failure-based ER Ranking Voting-Ranked Equipment Classification: Appropriate for Q - treatments





# Equipment-based ER focus

## Component-based ER Ranking Component-Ranked Equipment Classification: Appropriate for PM-treatment





# Contrasts

- (1) Upward vs. downward
- (2) Event vs. hardware
- (3) Function vs. form
- (4) Internal viewpoint vs. external



# Classification Method Comparison

## Equipment Based

- (1) Hardware focused
  - Equipment classification drives program
- (2) Failure chain equivalence
  - Equal
  - Template source
- (3) Scheduled tasks – PM
  - Weighted equal
  - Redesign (rarely)
- (4) General
  - Expertise less important – common templates
  - More work volume

## Failure-based

- (1) Function-loss risk focused
- (2) Consequence based (e.g., risk-based)
  - Dominant/high-risk failures stand out
- (3) Discriminates and prioritizes failures by consequence
  - Focused on scheduled maintenance results
- (4) Contextual (Takes more technical expertise)
  - Focuses work
  - Assesses context





## Risk-Based ER Focus Benefits

- (1) Develops risk/reliability understanding
- (2) Provides more exact work basis
- (3) Simple checks & tests increase
- (4) Total PM workhours drop
  - Eliminate non-critical failure PMs
  - Extend critical PM to justifiable, appropriate intervals
  - Convert time-based to condition-directed tasks

*Reduce costs, while improving reliability*





# Management Support Required

- ◆ Executive Sponsorship
- ◆ Maintenance planner involvement
- ◆ Aggressive “can do” mentality
  - Avoid compromising fundamentals
  - Retain cost focus
  - Avoiding bogging on details
  - Implement results
- ◆ Organizational Change Support
  - “Uncompartmentalizing” maintenance
  - Applying results
  - Example: Maintenance performing recommended-delete non-critical PMs
- ◆ Teamwork
  - Build joint engineering/maintenance/operations teams





# Strategy

## ◆ For credible equipment failure

- Interrupt next fault node
- Use redundancies, margins & instrument/alarms

## ◆ Options

- Simple checks/inspections
- Discovery tests unveiling hidden failures
- Condition assessment (predictive/diagnostic)
- Replacement/rework (including overhaul)
- Combination
- [Redesign]

Increasing cost  
↓





# Condensate System Risk Map

RCMtrim 3.9

File Edit View Insert Format Records Tools Window Help

Component Spreadsheet (Cmp Fast Manipulation)

EQID Finder: [ ] Group: CD Scope

SYS	EQID/CmpRegTag	EQID/Cmp Reg Name	Cmp Cr	Eng Data A	MM	Key	Selection Basis	Primary	Associated Equip
CD	1JCDNUV0214A**VALVEX	LP HTR TRN A INLET ISOL VLV	VALVEX	GATE		HC	Minor seat leakage not critical; valve must operate to isolate offset rupture heater tube leak for turbine protection. Significant cost impact to isolate (cost).		1JCDNUV0214A** VALVOP
CD	1IMCDNE04C**HTEXCH	LOW PRESSURE FEEDWATER HEATER	HTEXCH	HEATER/SUPE		O	Potential load reduction; reduce load to protect turbine, single train only.		
CD	1JCDNH50045**CKTBRK	SWITCH HAND VACUUM BREAKER	CKTBRK	SWITCH		H5	Required to manually break vacuum in emergency for turbine safety.		
CD	1JCDNPSV0222**VALVEX	LP HEATER TRAIN C THERMAL RELIEF	VALVEX	NOZZLE		HC	Equipment protection required by code. Could drift. If gagged closed, can't isolate heater train. (10 year period interval).		
CD	1JCDNFY0028C**ISODEV	ISOLATOR OUTPUT CONDENSATE PUMP C	ISODEV	VOLTAGE		HO	CD Pump interlock -- protects CD Pump from low flow condition (C). A low failure trips its CD Pumps (O).		1JCDNF0028**IX MITR
CD	1JCDNHCV0003**VALVEX	CONDENSATE PUMP A HOTWELLSIDE ISOL VLV	VALVEX	BUTTERFLY		HC	Allows condensate pump isolation maintenance. Valve stroked during operation.		
CD	1JCDNHCV0004**VALVEX	CND5 PP C SUCT ISOL VLV	VALVEX	BUTTERFLY		HC	Allows condensate pump isolation maintenance. Valve stroked during operation.		
CD	1JCDNHCV0155**VALVEX	CONDENSER HOTWELLS 2 MKUP VALVE	VALVEX	BUTTERFLY		H5	Safety role -- manual operation (backup to automatic valves) for makeup water. Valve stroked during operation. No other maintenance available.		
CD	1IMCDNE03A**HTEXCH	LOW PRESSURE FEEDWATER HEATER	HTEXCH	HEATER/SUPE		O	Potential load reduction; reduce load to protect turbine, single train only.		
CD	1JCDNH50013**CKTBRK	SWITCH HAND CONDENSATE PUMP	CKTBRK	SWITCH		HC	All pumps normally in service. Although could manually start pump locally if needed in startup, there would be a significant cost impact due to tube leak.		
CD	1JCDNUV0215A**VALVEX	LP HTR TRN B ISOL VLV	VALVEX	GATE		HC	Minor seat leakage not critical; valve must operate to isolate offset rupture heater tube leak for turbine protection. Significant cost impact to isolate (cost).		1JCDNUV0215A** VALVOP
CD	1JCDNH50215**CKTBRK	SWITCH HAND LOW PRESSURE HEATER	CKTBRK	SWITCH		HC	Allows manual Fast isolation of a heater due to tube leak flooding. Backed by automatic operation but at increased risk to turbine.		
CD	1JCDNH50216**CKTBRK	SWITCH HAND LOW PRESSURE HEATER	CKTBRK	SWITCH		HC	Allows manual Fast isolation of a heater due to tube leak flooding. Backed by automatic operation but at increased risk to turbine.		
CD	1IMCDNE05C**HTEXCH	CONDENSER HIGH PRESSURE SECTION	HTEXCH	CONDENSER		S	Avoid unit trip (Mrule) and generation losses.		

Master Model EQID Copier: [ ] Primary/Assoc Kernel EQID Copier: [ ]

Record: 5 of 284 (Filtered)

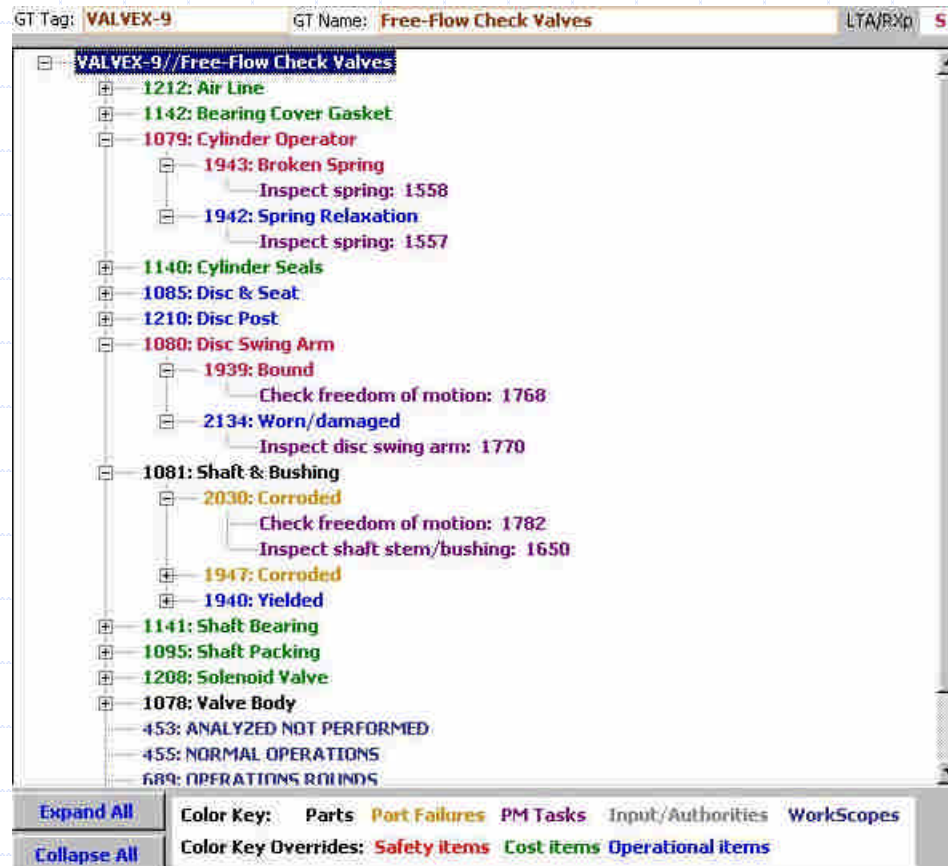
Record: 170 of 218

Enter LTA code such as: H, S, O or C. Identifies "Key" and "NonKey" from 060101 since not used directly here; used on Applied Template form

FLTR CAPS NUM

Start Microsoft Word - ASM... Exploring - C:\RCMtrim... RCMtrim 3.9 3:32 PM

# Template







# Applied Template Structure: Fault Nodes

RCMtrim 3903

File Edit View Insert Format Records Tools Window Help

AT Component | Parts | Part Failures | PM Tasks | Inputs (Authorities) | WorkScopes

Tag/EQID: 1JEDNBT0003\*\*VALVEX Name: FW HTR 5A EXT STEAM LINE BLEEDER TRIP VLV LTA/Rxp: S 10607

1JEDNBT0003\*\*VALVEX

- 1078: Valve Body
- 1079: Cylinder Operator
- 1080: Disc Swing Arm
  - 1939: Bound
    - 2840: Check freedom of mot
  - 2134: Worn/damaged
    - 2831: Inspect disc swing arr
- 1081: Shaft & Bushing
- 1085: Disc & Seat
  - 1937: Worn
  - 1938: Separated
    - 2833: Inspect disc and seat
- 1095: Shaft Packing
- 1140: Cylinder Seals
- 1141: Shaft Bearing
- 1142: Bearing Cover Gasket
- 1208: Solenoid Valve
- 1210: Disc Post
  - 2143: Worn/damaged
    - 2836: Inspect disc post
- 1212: Air Line
  - 754: OPERATIONS ROUNDS
  - 755: UNASSIGNED PM TASKS
  - 756: ANALYZED NOT PERFORMED
  - 757: OVERHAUL CHECK VALVE
  - 758: NORMAL OPERATIONS

PF Tag: C1 PF Name: Bound PF Effect Visibility:  Hidden:  LTA: S

Symptom: Arm seized

Cause Description: Deposits

Effect Desc: Risk of turbine overspeed on trip

Beta Type: 3.4 PF Effect Type: Safety Symptom Limit: 3600 isolated valve

Safe Life Est: 6 SLE Units: Years

PM Tasks Aver Life Est: 4 Estd 2 Std Dev: 4

PM Task Name	Part	Primary Failure	Strategy	Interval/Units
Check for air leakage	2144 Air Line	Damage/Fatigue	ROUI C	1 M (month)
Check for air leakage	2031 Cylinder Seals	Worn/damaged	ROUI C	1 M (month)
Check for air leakage	2135 Solenoid Valve	Gasket/seal failure	ROUI X	1 M (month)
Check for leakage	2033 Bearing Cover Gasket	Corroded	ROUI O	1 M (month)
Check for leakage	1947 Shaft & Bushing	Corroded	ROUI O	1 M (month)
Check for leakage	2142 Shaft Packing	Worn/damaged	ROUI O	1 M (month)
Check freedom of mot	1939 Disc Swing Arm	Bound	NORI S	1 M (month)
Check freedom of mot	2030 Shaft & Bushing	Corroded	NORI HS	1 M (month)
Check freedom of mot	2145 Shaft Packing	Overtightened	NORI S	1 M (month)
Inspect bearing	2032 Shaft Bearing	Corroded	OCM O	5 C (refuel c)
Inspect disc and seat	1938 Disc & Seat	Separated	OCM S	5 C (refuel c)
Inspect disc post	2143 Disc Post	Worn/damaged	OCM S	5 C (refuel c)
Inspect disc swing arr	2134 Disc Swing Arm	Worn/damaged	OCM S	5 C (refuel c)

Record: 1 of 25

IDTemplate: 126 CmpSerReg: 10607

PFSerNum: 1939 PFSNAN: 1319 PartSerNum: 1080

RCMtrim39... NUM

Estd "2 sigma" - a range to cover 95% of failing population. Enter a number.

# Deliverable: Generator Overhaul WO Tasks

The screenshot displays the RCMtrim 3.9 software interface. The main window is titled "Generic Component Templates" and shows a work order for "OVERHAUL" of a "GENERATOR". The interface includes a menu bar, a toolbar, and several panels. The central panel displays a table of PM tasks with columns for PM Task Name, Part, Part Failure Mechanism, Strategy, and Interval/Units. The right panel shows a "Workscopes Preview" with a list of workscopes and their parameters. The bottom status bar shows the current record and total records.

PM Task Name	Part	Part Failure Mechanism	Strategy	Interval/Units
Inspect rotor visually	Rotor Forging	Unbalanced phase currer	TBM	6:C (refuel)
Perform NDE examination	Rotor Forging	Retaining ring failure	TBM	6:C (refuel)
Perform wedge tightness test	Stator Winding	Loose coils	TBM	6:C (refuel)
Visually inspect for loose coils	Stator Winding	Loose coils	TBM	6:C (refuel)
Inspect coils for damage	Stator Winding	Damaged coils	TBM	6:C (refuel)
Perform capacitance mapping	Stator Winding	Coil stator cooling leakag	OCM FF	6:C (refuel)
Inspect visually for water leak	Stator Winding	Coil stator cooling leakag	TBM	6:C (refuel)
Perform stator visual inspectio	Stator Winding	Insulation damage	OCM Pre	4:C (refuel)
Inspect bearing pits	Grounding Brushes	Inadequate electric cont:	OCM Pre	18:M (mont)
Check brushes for glaxing & w	Grounding Brushes	Inadequate electric cont:	OCM Pre	18:M (mont)
Inspect cooler tubes	H2 Coolers	Cooling water leaks	OCM Pre	0:
Check cooling water heat remc	H2 Coolers	Inadequate water H2 co	OCM Pre	0:
Check (sample) tube deposits	H2 Coolers	Inadequate water H2 co	OCM Pre	36:M (mont)
Check stator cooling water ten	Stator Cooling Water 5	Fails to cool stator & rotc		0:



# Challenges

- ◆ Redundancy
  - Handling indirect failure risk with defense-in-depth
- ◆ Direct risk focus (e.g., SPV's)
  - Maintaining direct failure threat risk focus
  - (Ultimately didn't)
    - ◆ Treated redundancy levels as if they didn't exist, classifying
- ◆ Simplicity
  - Defining simple risk classification standards: SOCX
  - Safety
  - Operations
  - Cost





# Results

- ◆ Quick hits
  - Quick assessments of likely hitters (expansion joints...)
- ◆ Non Critical PM WO identification
  - Cancellation of many lesser component RT's
  - Status instrument calibrations
  - Recognition of tasks better address at point of discovery
- ◆ Numbers
  - 65,000 EQID's
  - 15,000 critical: approximately 30/20/50 (%-age, SOC)
  - 450 Master/Normal Model EQIDS with Templates Applied
  - 60 Templates





# Results

- Culture
  - ◆ Engineering role acceptance
  - ◆ Risk based methods
  - ◆ Streamlining



# Fundamental Lessons

## ◆ Process speed

- Output lagged expectations
- Details hindered analysis production
- Complex, non-standard risk classifications slowed development

## ◆ Conservatism

- Safety-classed equipment maintenance rule interpretation
  - ◆ Possible vs. certain failure cause interpretation
  - ◆ Multiple PM tasks addressing WO's (non-safety failure risk)

## ◆ Difficulty

- Developing failure data
- Finding sound PM intervals
- Reducing scope (once complete)





# Conclusions

- ◆ Risk-based PM development
  - Reduces cost
  - Improves reliability
- ◆ Cost-competitive with other ER development
  - Same costs for similar project scope as PMO
  - Long-term cost-savings much greater
  - Reduce costs by reducing over-prescribed work
- ◆ *Substantially* exceeds AP-913 requirements
  - Supports risk-based operations
  - Improves all ER risk management
- ◆ ***Though harder to learn and apply, risk-based method benefits offered are worth it!***



(Supporting Material)

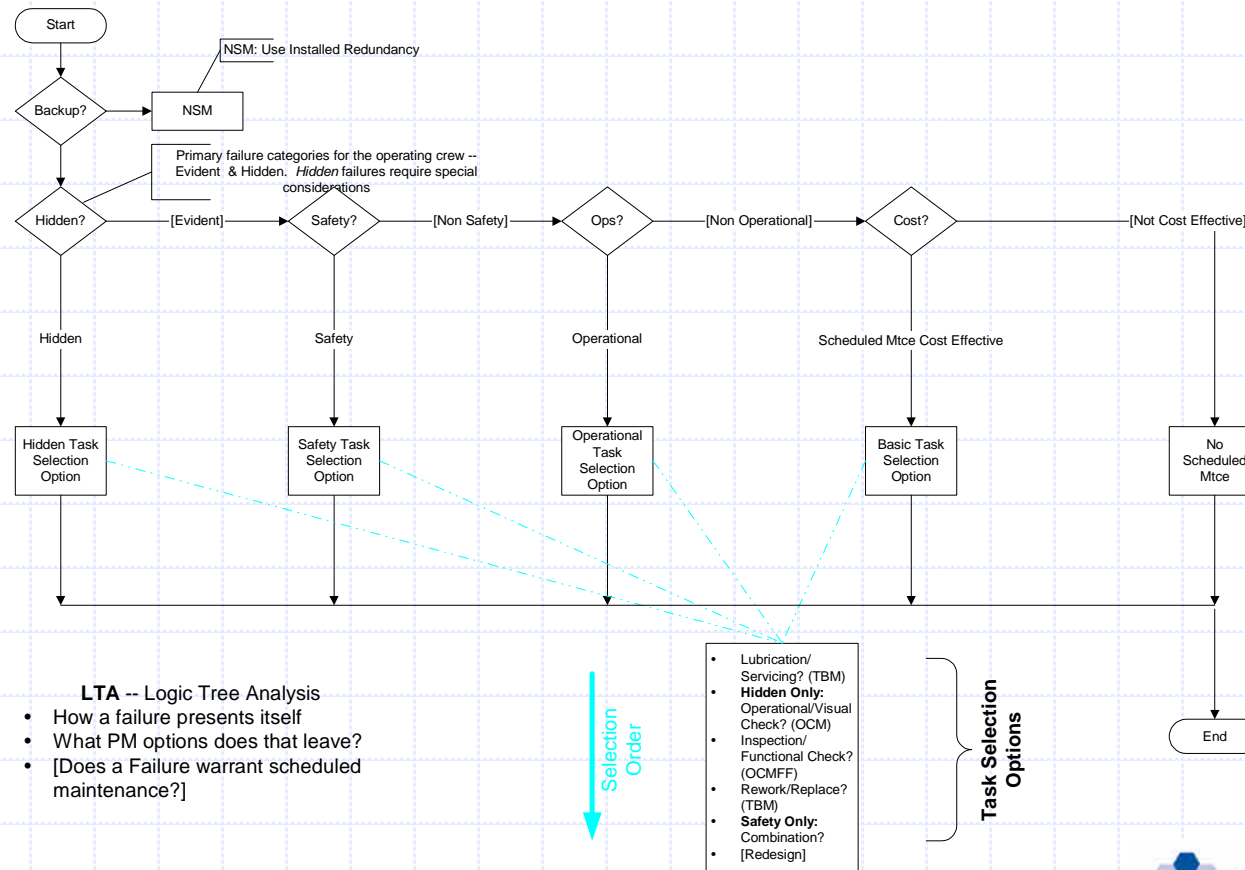


8/10/2005

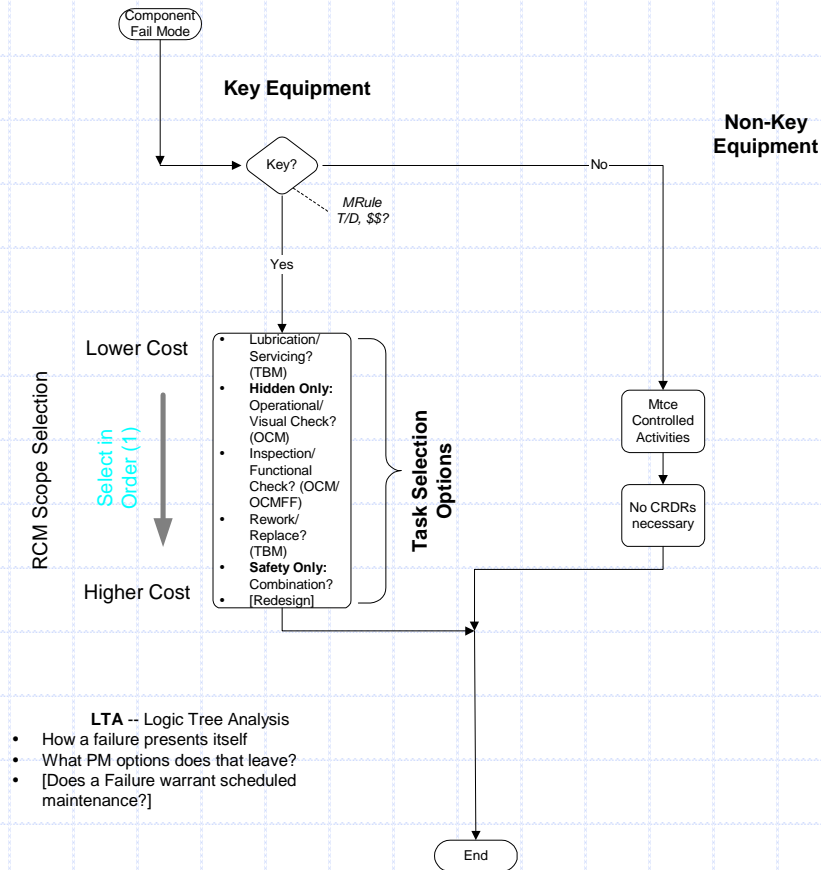
Risk-Informed Equipment  
Reliability Risk Ranking

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# Component Failure Risk Classification



# Critical Equipment Task Selection



- LTA -- Logic Tree Analysis**
- How a failure presents itself
  - What PM options does that leave?
  - [Does a Failure warrant scheduled maintenance?]





# Effort Breakdown

(1) Classify equipment (risk)	50%
(2) Develop equipment list partition	15%
(3) Apply templates	30%
(4) Generate reports	5%
(5) Interpret results	10%
	<hr/>
	100%

Classifying risk context allows subsequent template application and development as an “applied template”





# Cost

- ◆ Analysis drives ER program development cost
- ◆ “System study” engineering analysis contributes significantly (~50% total time)
  - Reduced using pre-developed standard rules
  - Most significant project cost risk factor
- ◆ ‘Learning’ pronounced
  - Especially early systems
  - Maintaining learning rate requires avoiding rework and ‘reprogramming’





# ER Process

- ◆ Select functional requirements
- ◆ Partition equipment
  - Develop symmetries; establish components/scope (critical/non-critical)
- ◆ Rank equipment (excluding low-risk equipment)
  - Based upon credible failures
  - Exploits design symmetries
- ◆ Develop normal cases as reusable models
- ◆ Apply templates
  - Consider risk
  - Use operating context
  - Customize application based on context



