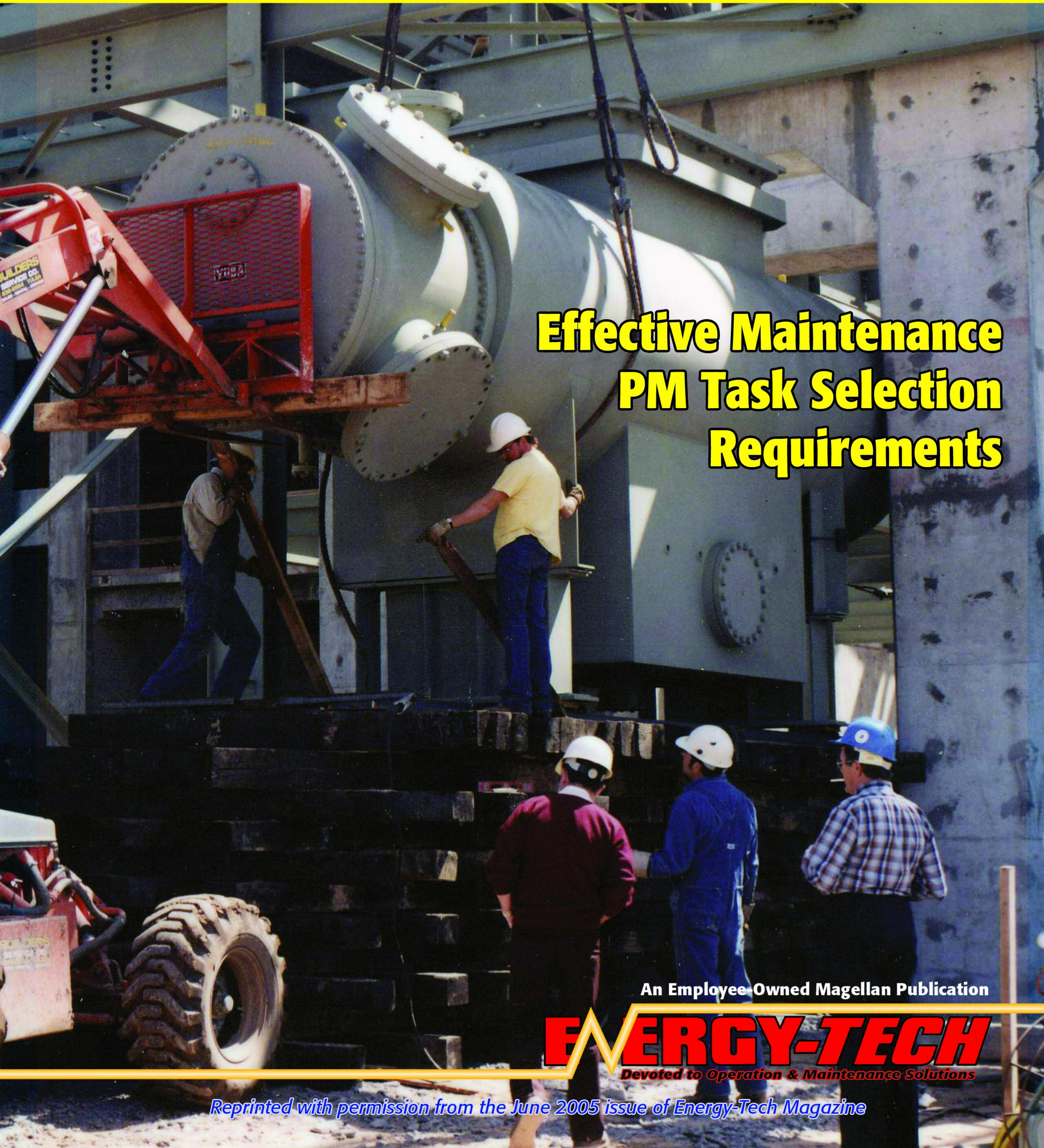
CORE, Inc.



Effective Maintenance PM Task Selection Requirements

An Employee-Owned Magellan Publication

ENERGY-TECH

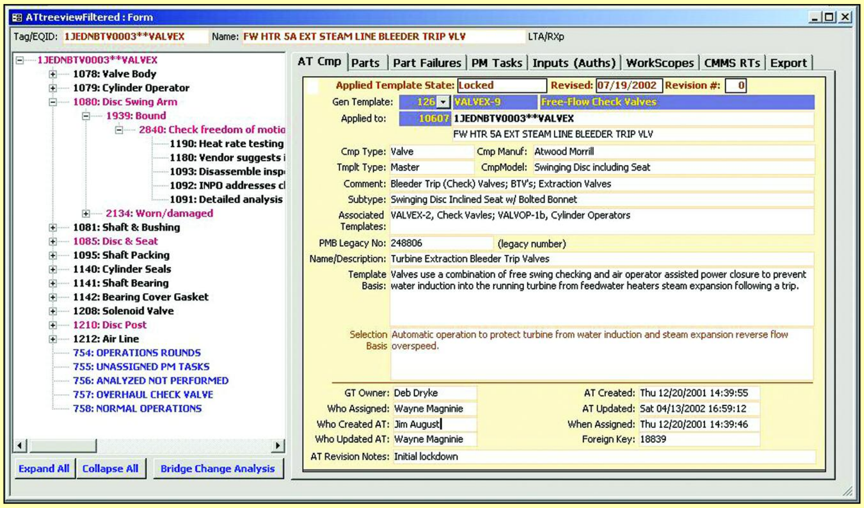
Devoted to Operation & Maintenance Solutions

Reprinted with permission from the June 2005 issue of Energy-Tech Magazine

Effective Maintenance PM Task Selection Requirements

By J.K. August, Krishna Vasudevan,
and W.H. Magninie

Selecting PM tasks for industrial maintenance plans has always been hard work. Identifying critical equipment failures requires focus. Picking effective tasks demands insights. Packaging selected tasks for implementation involves selling process stakeholders and demands even more time. Automating task selection offers many subtle benefits. These include standardization, faster development, improved consistency, and final tasks that more faithfully identify and address likely failures. This article describes a streamlined Reliability Centered Maintenance (RCM)-based PM development project. Streamlined analysis software – RCMtrim™ (Trim) complemented the process.



Tag/EQID: 1JEDNBTV0003**VALVEX
Name: FW HTR 5A EXT STEAM LINE BLEEDER TRIP VLV
LTA/RXp

1JEDNBTV0003**VALVEX
  1078: Valve Body
  1079: Cylinder Operator
  1080: Disc Swing Arm
    1939: Bound
      2840: Check freedom of motio
        1190: Heat rate testing
        1180: Vendor suggests i
        1093: Disassemble insp
        1092: INPO addresses cl
        1091: Detailed analysis
    2134: Worn/damaged
  1081: Shaft & Bushing
  1085: Disc & Seat
  1095: Shaft Packing
  1140: Cylinder Seals
  1141: Shaft Bearing
  1142: Bearing Cover Gasket
  1208: Solenoid Valve
  1210: Disc Post
  1212: Air Line
  754: OPERATIONS ROUNDS
  755: UNASSIGNED PM TASKS
  756: ANALYZED NOT PERFORMED
  757: OVERHAUL CHECK VALVE
  758: NORMAL OPERATIONS

Applied Template State: Locked
Revised: 07/19/2002
Revision #: 0
Gen Template: 126 VALVEX-9 Free-Flow Check Valves
Applied to: 10607 1JEDNBTV0003**VALVEX
FW HTR 5A EXT STEAM LINE BLEEDER TRIP VLV
Cmp Type: Valve
Cmp Manuf: Atwood Morrill
Tmplt Type: Master
CmpModel: Swinging Disc including Seat
Comment: Bleeder Trip (Check) Valves; BTV's; Extraction Valves
Subtype: Swinging Disc Inclined Seat w/ Bolted Bonnet
Associated Templates: VALVEX-2, Check Vavles; VALVOP-1b, Cylinder Operators
PMB Legacy No: 248806 (legacy number)
Name/Description: Turbine Extraction Bleeder Trip Valves
Template Basis: Valves use a combination of free swing checking and air operator assisted power closure to prevent water induction into the running turbine from feedwater heaters steam expansion following a trip.
Selection Basis: Automatic operation to protect turbine from water induction and steam expansion reverse flow overspeed.
GT Owner: Deb Dryke
AT Created: Thu 12/20/2001 14:39:55
Who Assigned: Wayne Magninie
AT Updated: Sat 04/13/2002 16:59:12
Who Created AT: Jim August
When Assigned: Thu 12/20/2001 14:39:46
Who Updated AT: Wayne Magninie
Foreign Key: 18839
AT Revision Notes: Initial lockdown

Figure 1: PM Task Selection

Reliability-Centered Maintenance (RCM)

In the mid-1970s, RCM emerged as a proven aviation maintenance development process that had helped airlines improve operating reliability and reduce costs. RCM has not been widely adopted by other industries, however. The reasons include the inherent complexity of other industrial environments, such as electric generation, training requirements and work culture. Effective task selection requires statistical risk awareness, engineering knowledge, and plant operating experience. Senior maintenance workers become the planners and schedulers who select, package, and implement maintenance PM tasks. While their assignment facilitates maintenance development, it skirts difficult preventive maintenance (PM) task selection and implementation.

Traditionally, planners reviewed plant system equipment lists, pulled O&M manuals, and selected manufacturer-recommended tasks. This led to bulky, excessive PM programs. Just as auto owners never literally implement owner manual PMs, plants never exactly implemented vendor-recommended equipment PM programs. Resources simply weren't available. For just one large centrifugal compressor, a manufacturer recommended over 120 separate tasks! Upon review, these shrank to fewer than 20. Virtually all could be performed less frequently. Daily monitoring reduced the original hard-time specified tasks to a fraction. Time and again PM implementation audits show low PM performance rates in fully-developed programs (i.e., under 10 percent of the specified work completed as scheduled). Low PM completion rates characterize mature, traditional maintenance programs.

This is the maintenance story, over and over. What causes such huge discrepancies between intended and implemented PM program scopes? Most often, PM developers lack the technical skills and contextual knowledge to select applicable, effective PM tasks. Crafts people can readily identify failures, but effective PM selection requires technical failure analysis. Engineers must assess risk, define dominant failure modes, specify objective failure limits, and plan tasks that mitigate failure. Failure prevents equipment from fulfilling required functions. Preserving critical functions achieves operating objectives. Failures as slight as an alarm annunciator indicator lamp out, or major as a shed turbine blade, cause functional failures.

RCM captures the designer's thoughts in PM. A designer selects equipment to fulfill system design requirements, specifying redundancy, instrumentation, calibration, diagnostics and maintenance. The reliability engineer must also select PM tasks based upon risk. Risk-based task selection distinguishes RCM from other PM program development methods. That explains the difficulty applying RCM task selection principles and why RCM analysis sometimes bogs down.

Major Steps

Maintenance program development involves three simple steps: 1) Selecting the components, 2) Selecting component PM tasks, and 3) Packaging results to implement.

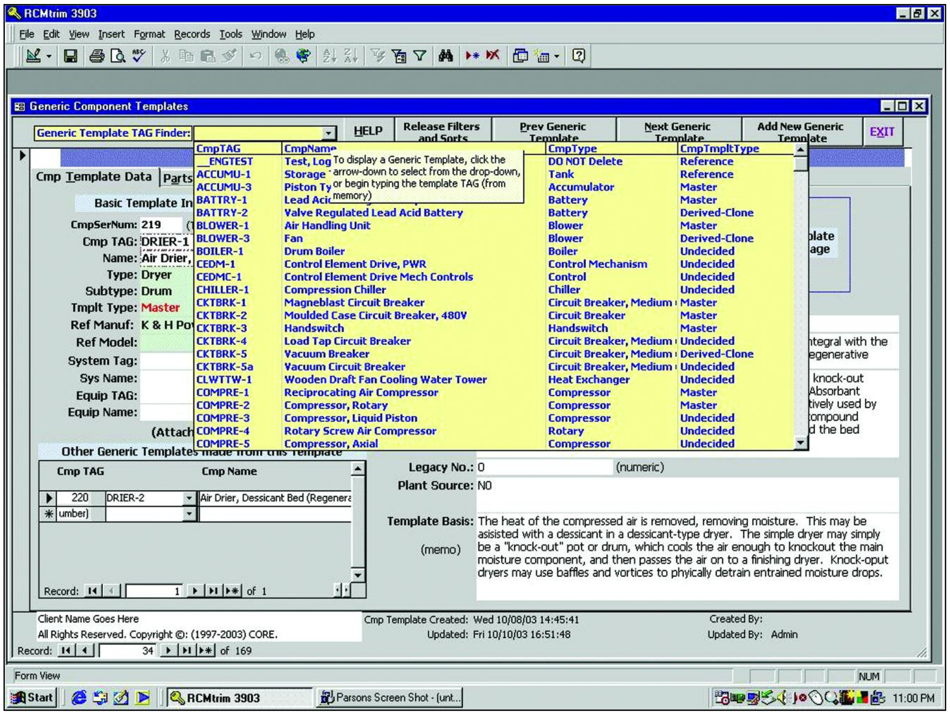
1) Selecting Components

Components that directly support system functions have been called "significant," "important," "critical," "essential," and "key". This equipment compromises system critical functions through single failure. Though terms can vary, single failure qualification is important; equipment that can't compromise system functions in single failure drops to a lower status. It becomes non-critical, to be addressed by a program of no scheduled maintenance, i.e., run-to-failure. This equipment can be safely, cost-effectively maintained upon engineering failure discovery. Run-to-failure equipment makes up most equipment in any complex industrial facility, and supports a strategy of no scheduled maintenance. Engineers should use run-to-failure equipment to their advantage building a maintenance strategy. Using inherent design characteristics, they reduce maintenance costs and improve reliability. This is the essence of RCM.

"Single-failure" criteria generate concise critical equipment lists. Excluding non-critical equipment from scheduled maintenance focuses on remaining critical equipment. Assigning risk by safety, operations, or cost (SOC) class ranks system failure risks. Risk differentiates equipment that can benefit from scheduled maintenance from that which can't, ranking relative equipment functional value. Developing a risk profile for evaluating failed equipment during plant operations guides workers. Besides complementing the PM plan, the risk profile prioritizes failed equipment for condition-directed maintenance. Following the designer's logical intentions providing margin and spares, the risk profile identifies plant design depth for efficient maintenance. Using design depth manages risks and develops efficient maintenance plans.

Effective maintenance programs dictate resource scheduling. By focusing on single failures, programs avoid unnecessary resources addressing improbable, coincident multiple-failures. Reduced scope obligates performing timely condition-directed maintenance. Scheduled maintenance uncovers equipment needing maintenance. Discovered, that maintenance must be performed or functional failures will eventually result. PM and condition-directed maintenance performance complement each other closely and must be nearly 100% complete!

Failure effects reveal critical equipment. Critical equipment failures affect safety, operations, or cost goals, which can be ranked and coded mnemonically as "S," "O," and "C." This simple coding scheme reflects three criticality classes excluding non-critical –"X". These classes separate qualitative failure effects by orders of magnitude. Safety losses are at least ten times as risky as operational ones; operational loss costs outweigh maintenance costs by at least another factor of ten, when ultimately reduced to a common cost denominator.



Generic Template TAG Finder:

To display a Generic Template, click the arrow-down to select from the drop-down, or begin typing the template TAG (from memory)

CmpTAG	CmpName	CmpType	CmpTmpltType
__ENGTEST	Test, Log	DO NOT Delete	Reference
ACCUMU-1	Storage	Tank	Reference
ACCUMU-3	Piston Ty	Accumulator	Master
BATTRY-1	Lead Acic	Battery	Master
BATTRY-2	Valve Regulated Lead Acid Battery	Battery	Derived-Clone
BLOWER-1	Air Handling Unit	Blower	Master
BLOWER-3	Fan	Blower	Derived-Clone
BOILER-1	Drum Boiler	Boiler	Undecided
CEDM-1	Control Element Drive, PWR	Control Mechanism	Undecided
CEDMC-1	Control Element Drive Mech Controls	Control	Undecided
CHILLER-1	Compression Chiller	Chiller	Undecided
CKTBRK-1	Magneblast Circuit Breaker	Circuit Breaker, Medium	Master
CKTBRK-2	Moulded Case Circuit Breaker, 480V	Circuit Breaker	Master
CKTBRK-3	Handswitch	Handswitch	Master
CKTBRK-4	Load Tap Circuit Breaker	Circuit Breaker, Medium	Undecided
CKTBRK-5	Vacuum Breaker	Circuit Breaker, Medium	Derived-Clone
CKTBRK-5a	Vacuum Circuit Breaker	Circuit Breaker, Medium	Undecided
CLWTTW-1	Wooden Draft Fan Cooling Water Tower	Heat Exchanger	Undecided
COMPRE-1	Reciprocating Air Compressor	Compressor	Master
COMPRE-2	Compressor, Rotary	Compressor	Master
COMPRE-3	Compressor, Liquid Piston	Compressor	Undecided
COMPRE-4	Rotary Screw Air Compressor	Rotary	Undecided
COMPRE-5	Compressor, Axial	Compressor	Undecided

CmpSerNum: 219
Cmp TAG: DRIER-1
Name: Air Drier,
Type: Dryer
Subtype: Drum
Tmplt Type: Master
Ref Manuf: K & H Po
Ref Model:
System Tag:
Sys Name:
Equip TAG:
Equip Name:
(Attach

plate
age
ntegral with the
egenerative
knock-out
Absorbant
tively used by
ompound
d the bed

Cmp TAG		Cmp Name
220	DRIER-2	Air Drier, Dessicant Bed (Regenera
umber)		

Record: 1 of 1

Legacy No.: 0 (numeric)
Plant Source: NO
Template Basis: (memo) The heat of the compressed air is removed, removing moisture. This may be asisisted with a dessicant in a dessicant-type dryer. The simple dryer may simply be a "knock-out" pot or drum, which cools the air enough to knockout the main moisture component, and then passes the air on to a finishing dryer. Knock-oput dryers may use baffles and vortices to phyically detrain entrained moisture drops.

Client Name Goes Here
All Rights Reserved. Copyright ©: (1997-2003) CORE.
Record: 34 of 169
Cmp Template Created: Wed 10/08/03 14:45:41
Updated: Fri 10/10/03 16:51:48
Created By:
Updated By: Admin

Figure 2: Template Selection from Library.

Discussing cross-discipline failure effects helps quantify risks developing equipment risk profiles. Discussions suggest strategies that improve facility operations and maintenance. Participants reveal and gain risk awareness. Diverse experience yields different failure insights and risk perspectives. Capturing tribal knowledge assures future use of shared experience.

Assessing risk plant operators, workers, and owners should reach consensus. Physical construction freezes operating risks in a design. Architect-Engineer (AE) design descriptions document system functions. Designs reveal equipment functionality. Unnecessary maintenance costs stem from unnecessary work tasks, compounding costs over facility life. (Hidden maintenance costs are embedded in program assumptions.) Making PM cost-effective requires realizing improved operations with maintenance. Keeping PM program development objectives at the forefront assures developing PM projects on-time, with near-term payback.

Design thumbrules emerge from risk analysis. Manual valves, for example, enable maintenance. Manual valve failure consequences are typically cost-based. Manual valves can be treated as "run-to-failure." This numerically reduces component analysis by 25 percent. For 40,000 installed plant components, analysis declines by 10,000 tagged equipment items!

Rules have exceptions, however. One manual valve may be necessary under special conditions to realign an equipment train. That valve becomes critical. Whether PM can be effective still remains unanswered, but the risk can't be ignored. Thumbrules improve with successive system analysis, superseding ad hoc PM task selection. Revealing unique facility design insights provides practical reliability benefit.

2) Selecting PM Tasks

Components determine dominant failure modes. Vendor O&M manuals recommend many PM tasks, implicitly documenting failure modes. Applied indiscriminately, however, vender-recommended PM programs produce lengthy, enumerative work lists – many tasks of which lack direct failure applicability. At complex plants, equipment risk drops based on design redundancy, low utilization, and absence of failures over economic life. Eliminating low-risk equipment from scheduled maintenance consideration in strategy development, before detailed failure modes and effects analysis (FMEA), streamlines projects. Pre-developed template use also speeds work.

Classifying critical parts by failure speeds analysis and simplifies risk assessment. For example, a pump may "fail to start," "fail to deliver flow at pressure," or "leak." Several part failures can lead to the same pump failure mode. Consider "fail to deliver flow at pressure." For a centrifugal pump, worn seals, impeller erosion, volute erosion, or even a single-phased motor can cause low pressure at flow. A loose bearing guide, however, won't cause failure to deliver flow at pressure. Design makes most part failures inconsequential. Consolidating part failures under component failure modes simplifies system effects analysis. Failure modes and effects analysis (FMEA) identifies likely failures that cause system failures – a direct benefit. (Figure 1, PM Task Selection)

3) Packaging Results: Workscope

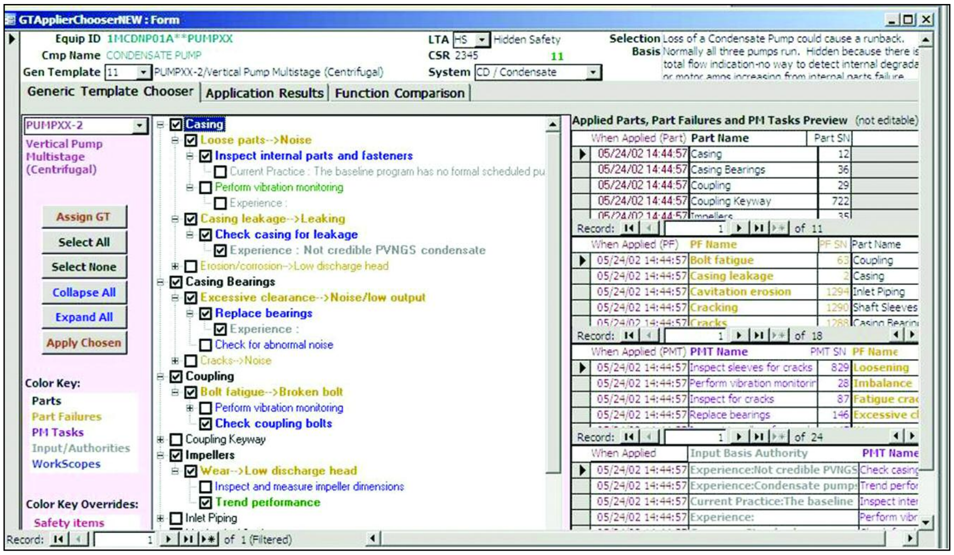
A workscope organizes PM tasks into blocks for performance. Organizing tasks into workscopes eases implementation. Consolidated into work order scopes (workscopes), tasks present fewer demands on the station's work order system.

Grouping tasks into blocks must be easy; it reoccurs over and over. Software subroutines must efficiently block and re-block tasks developing workscopes. Some software applications use point and click workscope task reassignment techniques to enhance speed; others use drop-down reselection. Whichever method selected, it must be user-friendly. Template application to equipment tags requires re-blocking tasks at completion based upon work context like tag-out boundaries.

Failure Mode Assessment

Aging degrades equipment over time. Perfect aging is predictable, while random deterioration requires probabilistic assessment. Real-world behavior falls between aging/random failure deterioration extremes. Developing effective PM requires identifying tasks that address failure modes based on aging behavior. The reliability engineer must identify component failure modes, parts causing failure, and failure mechanisms considering aging and only then – applicable PM tasks. Applicable tasks cost-effectively address failure. To be suitable for preventive maintenance, failures must be reasonably likely, exhibit discernible symptoms detectable using commercial technology, and be addressable by maintenance. Theoretically-defined failure modes simply confuse PM, leaving ineffective plans.

Failure consequences determine system function effects. Displaying component failure modes with a system's functions helps identify failure effects. Knowing system functional effects assists selecting the few critical equipment failure modes that matter – dominant failure modes.



Equip ID 1MCDNP01A**PUMPXX
Cmp Name CONDENSATE PUMP
Gen Template 11 PUMPXX-2/Vertical Pump Multistage (Centrifugal)
LTA HS Hidden Safety
CSR 2345 11
System CD / Condensate
Selection Basis Loss of a Condensate Pump could cause a runback. Normally all three pumps run. Hidden because there is total flow indication-no way to detect internal degrada or motor amps increasing from internal parts failure

PUMPXX-2
Vertical Pump Multistage (Centrifugal)

- ☑ Casing
  - ☑ Loose parts-->Noise
    - ☑ Inspect internal parts and fasteners
      - ☐ Current Practice : The baseline program has no formal scheduled pu
    - ☐ Perform vibration monitoring
      - ☐ Experience :
  - ☑ Casing leakage-->Leaking
    - ☑ Check casing for leakage
      - ☑ Experience : Not credible PVNGS condensate
  - ☐ Erosion/corrosion-->Low discharge head
- ☑ Casing Bearings
  - ☑ Excessive clearance-->Noise/low output
    - ☑ Replace bearings
      - ☑ Experience :
    - ☐ Check for abnormal noise
  - ☐ Cracks-->Noise
- ☑ Coupling
  - ☑ Bolt fatigue-->Broken bolt
    - ☐ Perform vibration monitoring
    - ☑ Check coupling bolts
- ☐ Coupling Keyway
- ☑ Impellers
  - ☑ Wear-->Low discharge head
    - ☐ Inspect and measure impeller dimensions
    - ☑ Trend performance
- ☐ Inlet Piping

Color Key:
Parts
Part Failures
PM Tasks
Input/Authorities
WorkScopes

Color Key Overrides:
Safety items

Record: 1 of 1 (Filtered)

Applied Parts, Part Failures and PM Tasks Preview (not editable)

When Applied (Part)	Part Name	Part SN
05/24/02 14:44:57	Casing	12
05/24/02 14:44:57	Casing Bearings	36
05/24/02 14:44:57	Coupling	29
05/24/02 14:44:57	Coupling Keyway	722
05/24/02 14:44:57	Impellers	35

Record: 1 of 11

When Applied (PF)	PF Name	PF SN	Part Name
05/24/02 14:44:57	Bolt fatigue	63	Coupling
05/24/02 14:44:57	Casing leakage	2	Casing
05/24/02 14:44:57	Cavitation erosion	1294	Inlet Piping
05/24/02 14:44:57	Cracking	1290	Shaft Sleeves
05/24/02 14:44:57	Cracks	1288	Casing Bearin

Record: 1 of 18

When Applied (PMT)	PMT Name	PMT SN	PF Name
05/24/02 14:44:57	Inspect sleeves for cracks	829	Loosening
05/24/02 14:44:57	Perform vibration monitorir	28	Imbalance
05/24/02 14:44:57	Inspect for cracks	87	Fatigue crac
05/24/02 14:44:57	Replace bearings	146	Excessive cl

Record: 1 of 24

When Applied	Input Basis Authority	PMT Name
05/24/02 14:44:57	Experience:Not credible PVNGS	Check casin
05/24/02 14:44:57	Experience:Condensate pumps	Trend perfor
05/24/02 14:44:57	Current Practice:The baseline	Inspect inte
05/24/02 14:44:57	Experience:	Perform vibr

Figure 3: Template Application.

PM tasks must address parts, and their associated engineering failure causes. Failure processes like stress corrosion cracking, fatigue, or material erosion are fundamental engineering deterioration causes. Preventing fatigue-induced crack failures requires reworking cracks. Eliminating the failure mode cause is usually beyond maintenance scope – redesign is required. Successful programs need not identify root causes (although that helps) nor be perfect. Failure modes can usually be managed without elimination – this is the principle of design redundancy and PM itself.

Clearly defining credible failure modes requires effort. Studying many equipment types and failure mechanisms over years of plant support, the authors' conclude that most industrial failure mechanisms are well-known. The challenge is recognizing and selecting applicable (failure-mitigating) PM tasks, efficiently. Standard templates (Figure 2, Template Selection from Library) addressing common components and their parts based upon known dominant failure mechanisms helps assure appropriate task selection.

Selecting Tasks

Without knowing a failure mechanism – failure mode and cause, selecting applicable PM technology is impossible. Custom diagnostic technologies specify fault-identification characteristics. Ultrasonic wall thickness measurement – a type of non-destructive evaluation (NDE), measures wall thinning. Eddy current testing identifies tube pitting. Standardized part-focused PM tasks address common failures likely to be expressed as dominant failures. Efficient templates identify failure candidates quickly. Providing template models not only simplifies new template development, but speeds template application. Applied equipment PM development reduces to simply choosing the likely failing parts, failures, and preventive tasks from template pick-list options.

Failure symptoms determine condition assessment choices. To be effective, instrumentation must identify incipient failure. Selecting diagnostic instruments requires equipment as well as instrumentation expertise. Suppliers often provide fault-identifying instruments with their equipment, distinct from "status only" ones used for startup, status or monitoring. (Status-only instruments are run-to-failure.) Critical instruments identify critical faults, often revealing hidden failures. Critical instrument failure risk corresponds to the hidden-failure that instrument reveals. In coal handling systems, a non-redundant instrument alerting methane gas presence would have "safety" risk classification, based on the safety risk of a hidden methane gas leak causing fire or explosion.

Applied Template

Template application translates standards into practice. The applied template models installed plant equipment – real equipment in a plant context. Streamlining template application simplifies to (1) defining installed equipment functions, (2) identifying equipment providing those functions, and (3) correcting standard templates for contextual service and risk factors. The last step associates PM tasks with dominant failures. The result is an applied template – or application. Equipment operating cycles, environment, and other contextual factors determine applied template content. Applied templates provide traceability, enable re-analysis, and provide the foundation for risk-based, template-developed PM scopes. They capture expressed equipment failures from standard part-failure-PM task lists, automating PM task selection. (Figure 3, Template Application)

In an application's "applied template," the word "template" recognizes the high degrees of physical and functional symmetry in large plant design. Combining system symmetry mapping with applied template development identifies identical applications for symmetrical, functionally equivalent equipment. Extending the application to symmetrical equipment tags streamlines PM development, reusing PM analysis for similar equipment by reference to the application's equipment tag number.

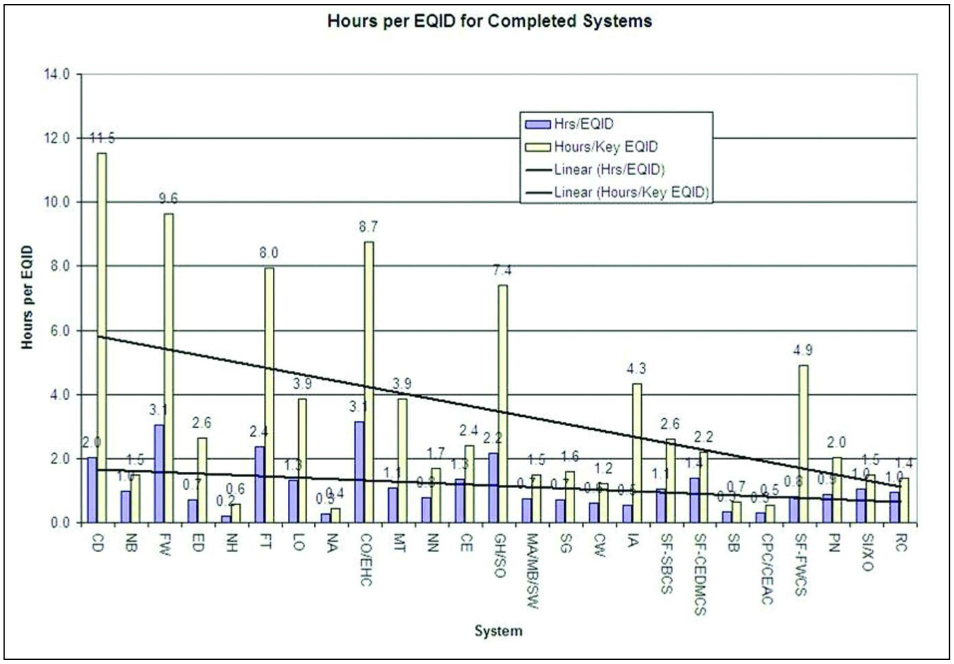


Figure 4: Statistics Summary.

Project

Engineers developed risk exposure maps and applied templates developing a three-unit nuclear generating plant's PM program on 33 non-nuclear but "risk significant" systems. These included systems like condensate, feedwater, extraction, main steam, turbine, and turbine hydraulic control – all outside the regulatory-controlled nuclear island. Objectives included improving reliability, developing risk-based processes, identifying single-failures (up to recommending redesign), and simplifying the PM plan to improve plant reliability. (The PM "basis" justifies and documents PM plan performance.)

Station personnel performed analysis with initial contract support. System size varied from feedwater (several hundred equipment tags) to 480V electrical (several thousand). Simplified equipment risk symmetry maps, templates and their applications (applied templates) characterized the process. Process and instrumentation drawing (P&ID) markups expedited symmetry mappings and critical equipment selection.

Engineers redefined architect-engineer (AE) system boundaries, associating circuit breakers with driven loads. They also simplified ad hoc craft-based system boundaries like Lubricating Oil (LO) into risk-based ones. (The original lubrication oil (LO) system included all separate lube oil subsystems – not particularly useful for risk.) On average, the first review assessed 60 percent of equipment non-critical. More rigorous RCM criteria suggested another twenty-percent would drop in rank, once criticality classification confidence grew.

During the project, risk definition evolved. "Defense in depth" drives nuclear risk processes. This historical nuclear principle requires multiple risk management strategies such as redundancy, diversity, and independence for nuclear safety. General Design Criteria, 10CFR50 Appendix A requires "such capabilities will be implemented" referring to defense in depth. Practically, conservative interpretation of Appendix A elevates all nuclear plant equipment to the highest risk class – safety. This substantially adds to nuclear maintenance costs, and partially explains the high-cost of nuclear operations today. "Risk-informing" nuclear regulations force technical design committees, regulatory bodies and operators to apply graded risk concepts to risk-inform nuclear design and operations. Industry-specific rules require flexible database design. Database (re)analysis automatically updates all finished plans as standards, processes and understandings change, contrasting sharply with spreadsheet or other manual methods. Local area network application installation eliminated hard-copy routing for expert reviews and approval.

Spreadsheets

In the project, reliability engineers learned a relational database application. Early in the project, familiarity with MS Excel™ invited informal spreadsheet development and use. Some engineers found transition to a database software application too constraining. Two reliability technicians assisted four engineers develop risk exposure symmetry, components templates and template applications. They also generated reports for non-computer operations and maintenance reviewers. Technicians coordinated other workgroup support, especially system teams and work planners. Technicians quickly became highly-proficient entering risk assessment and applying templates. Process immersion developed expertise. Engineers, maintenance reviewers, operations staff and maintenance system teams developed system risk exposure profile. System teams approved each system's final risk profiles. Reliability engineers developed standard templates from component template libraries or built them from scratch. These templates provided the sources for application to select parts, failures and tasks, customizing task intervals based on failure mechanism.

Though popular, spreadsheets proved problematic. Popularity stemmed from familiarity; engineers love spreadsheets. Exporting source records, developing data, and re-importing results to the main database from spreadsheets was burdensome. Spreadsheets can manipulate data, but time required preparing and using spreadsheets constantly increases. Users manipulate spreadsheet format, freelancing design (changing column/row locations, headers, even row primary keys themselves) until analyzed data can't be returned into its source CMMS/EAMS database. Then records are manually reconciled or purged. Manual data manipulation grew substantially over time.

Risk-based PM development reduces cost, improves reliability

- Substantially exceeds required standards for risk-based operations
- Cost-competitive with other PM development methods

Though harder, risk-based PM development benefits are well worth it!

Accommodating users who preferred developing analysis externally in MS Excel™ complicated efforts. Selling users on MS Access™ for their personal database customization needs afforded partial solution; Access™ at least was relational. Accommodating users had the undesirable side-effect of supporting and eventually freezing inefficient work processes. Reducing external work temptation ultimately provided the practical solution. Performing as much data entry directly into the database as possible became a goal. Eventually external work moratorium ended concerns.

PM task selection requires equipment failure research. Information can be developed from operating log reviews, work orders history, operating events, and other performance history. Interviews supplemented documented sources. While no failure analysis is perfectly objective, oral recollections introduce opinions that lack validating failure statistics. Most analytical work depended on oral reporting and tribal knowledge. Engineers developed templates, applying those templates creating template applications. Their strategies varied, revealing several template-application styles. At one extreme, some created a new template for each new component type encountered. At the other, one addressed many components with one very general component template. The database software accommodated either style. Detailed, customized templates (at the cost of generality) applied completely, must be balanced against numerous specific template applications extensively customized on application from very general source templates. Applying exhaustively-customized templates required less effort, but had less overall utility. A more generic template approach required more customization on application, making its template utility broader. In both cases, subroutines sped template development and customization at template and application levels.

Productivity

Time study showed most time was spent performing engineering system analysis. For each system, a lead engineer learned the system. Familiarized with the functions, equipment, and process flows he developed a system equipment risk exposure/symmetry list. Once approved, this equipment list identified the exact system equipment symmetry and risk context required for template application. Average systems used thirteen templates in thirty applications to model a system of one-thousand coded components. The application step selected templates based on component type, picking part failure details with the risk symmetry map. Encountering new equipment component types could require a new template. If this occurred, reliability engineers customized standard library templates, or developed new templates from scratch. Subroutines that copied existing templates for customization speeded new template development. Copying/editing an existing “diaphragm operator” template created a “cylinder operator” in lieu of building the cylinder operator template entirely from scratch. Obviously, this required customization editing on many levels, but functionally similar designs enabled using a common parent. Saving analysis time justified this process, upholding fundamental risk standard requirements.

Achieving productivity required overcoming two limitations. First, all assigned engineers needed to master reliability as a subject. Some found applying templates with critical equipment failure focus hard. Like manufacturers, they addressed rare failures with PM. Analysis to find exact dominant failure modes proved tedious. (Formal RCM requires basing PM tasks on statistically-derived failures.) Validating craft tasks in focus-type working groups provided “poor-boy” failure validation. Utility engineers had little failure statistics training and lacked data reduction tools to extract, summarize and define dominant failures and their mechanisms. So PM tasks based upon hypothetical, inadequately defined, and even rare, low consequence failures added to work plans.

Second, database utilities needed simplification. Some software routines, like relating template tasks to functional failures, were made optional. While formal RCM relates equipment failure to a system function, enforcing this requirement proved too difficult. Dropped, documenting equipment failure effects became less exact. Displays helped apply templates, navigate the database quickly, and further streamlined development. With a database, effective template application required quickly selecting dominant failure mode(s), parts, failures, and PM tasks. Modified, rebuilt and streamlined software displays (as application interface views) expedited application. Modifying template application methods into visual, GUI displays with tree hierarchies and checkboxes simplified use. New software formats exploited equipment hierarchy, automating record navigation, providing more visual process decision support.

Component/equipment symmetry risk assignment required half the total system review time. Applying templates creating the scheduled maintenance plan demanded the remainder. System-level template application failure review varied depending on system, failures and detail level sought. Process changes, group discussion, comments and rework diminished steadily throughout the project. Early in the project, several reanalysis stand-down periods incorporated lessons-learned, standardizing results, improving the core process. (Figure 4, Statistics Summary)

Interim Results

During the project, the three units’ turbine trip rate fell. Unit trip experience approached “breaker-to-breaker” performance. Actual measured reliability steadily improved, though even before final PM tasks implementation. Fairly, one could ask, “How could RCM analysis cause plant reliability benefit, then?” We believe the answer lies in the Hawthorne effect: that is, it didn’t, directly. During analysis reliability awareness, methods, and strategies improved for those participating in project equipment failure discussion and reviews. In daily plant use these new skills yielded gains. PM task selection processes improved cost efficiencies. At 20%

completion, over one work-year of non-critical PM reductions had been identified (>2000 hours). The tools had been developed to measure exact benefits shifting to risk-based maintenance.

Conclusions

Developing and justifying generating plant PM, improving reliability with limited resources can effectively use RCM-based processes. Simple process steps, rework control and focused reviews achieve near-term maintenance reliability benefits. Streamlined processes with software make RCM application for PM development feasible. Streamlined, risk-based task selection processes accessible to more users benefit all. General site reliability awareness, as well as direct PM improvements, benefits plant reliability performance.

Plant reliability is abstract, but culture shapes work processes. Few individuals know existing plant overall designs completely. Organizations share collective design awareness. Reliability awareness improves plant reliability and reduces cost. Specific RCM processes and tools – relational database software – provide a means to improve plant reliability while reducing costs.

Acknowledgments

The authors would like to thank Steve Coppock, Director, Plant Reliability & Modification, and Brian Ramey, Section Leader, Reliability Engineering, Palo Verde NGS for their process development, engineering analysis, and data support. The author would also like to thank PVNGS Reliability Engineering for assistance developing operating examples, paper development ideas, and other advisory tasks. Last, we are indebted to Frank Novachek, Special Projects Manager, and Marty Block, Xcel Energy for technical support and draft review comments.

We would also like to acknowledge previous efforts at Cooper NGS (NPPD), Pawnee & Arapahoe Generating Stations (Xcel Energy), Colstrip SES (PPL Montana), Carmen-Smith HGS (EWEB), and Susquehanna NGS (PPL) for their generous efforts supporting applied RCM technology development.

References

Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes, SAE JA1011, 1999

Equipment Reliability Process Description, INPO AP-913, Institute of Nuclear Power Operations, 2001

Reliability-Centered Maintenance, A.M. Smith, 1993, McGraw-Hill

Reliability-centered Maintenance RCMII, John Moubray, 2002, Industrial Press, 2nd edition, 1997

Reliability-Centered Maintenance, S. Nolan & H. Heap, United Airlines, 1978

Applied Reliability Centered Maintenance, J.K. August, Penn-Well, 2000

RCM Guidebook: How to Build a Reliable Plant Maintenance Program, J.K. August, Penn-Well, 2004

Guide to Reliability Data for Nuclear Generating Stations, IEEE Standard 500, 1984

RCMtrim‘ Software Users Guide ”CORE, Inc. 2002

RCMtrim‘ Software, version 3.9 ”CORE, Inc. 2003

MSG-3, (Maintenance Steering Group) Maintenance Program Development Document, ATA 1993

CMMS (PPMIS) PM Implementation Studies, 1990-1997, J.K. August, PSC, OME, Inc., CORE, Inc.

Hawthorne Effect, Western Electric Hawthorne Plant Studies, Cicero, IL1932: Process improvement caused by the intrusive observation of a process; improvement stimulated by management interest.

Regulatory Guide 1.178, "An Approach for Inservice Inspection of Piping," US NRC, www.nrc.gov, 2003

Defense in Depth: Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment," US NRC, www.nrc.gov, 2002

10CFR50 Appendix A, General Design Criteria for Nuclear Power Plants, US NRC, www.nrc.gov, 1974

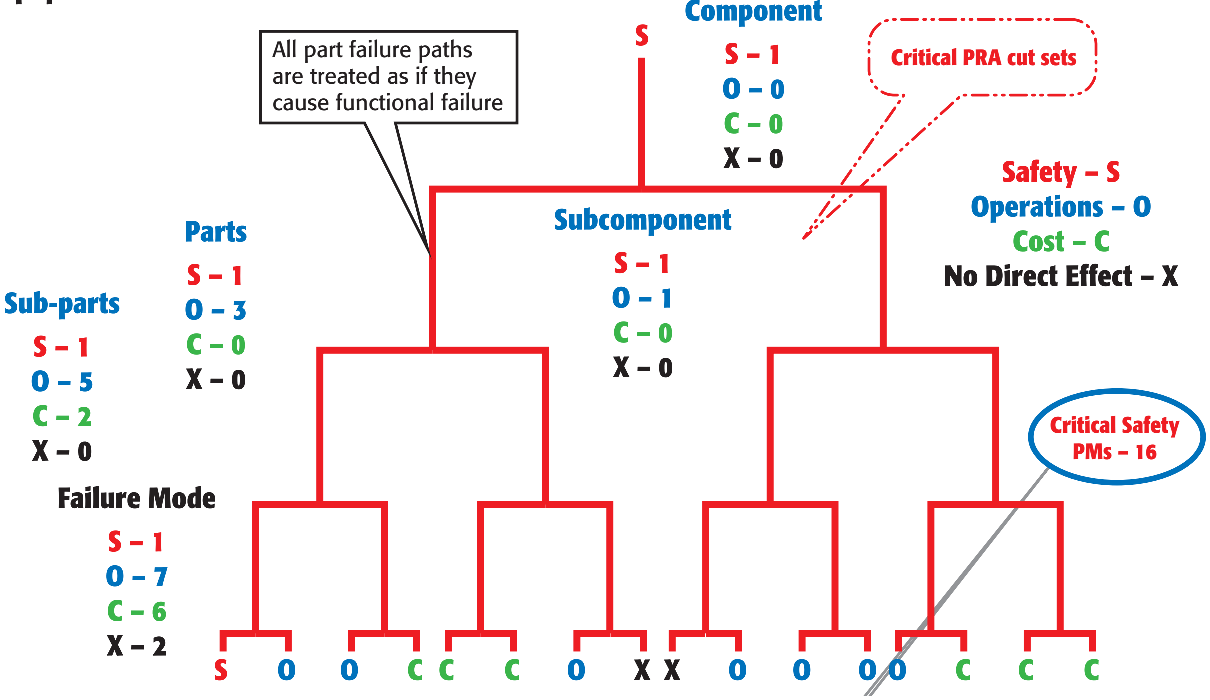
Jim August, PE, consults in the power industry providing maintenance development and optimization services for generation, transmission, and distribution. He is a principal of CORE, Inc., a firm providing maintenance and reliability software & engineering services. (CORE developed, sells and supports "RCMtrim" aka "Trim" PM optimization software.) He has authored many maintenance publications as well as two books, Applied Reliability Centered Maintenance and RCM Guidebook: Building a Reliable Plant Maintenance Program. He has over 25 years experience in power generation maintenance, engineering, and management. He graduated from the Universities of Colorado (1981, 1992) and Cornell University (1975) and holds BS and ME degrees in mechanical engineering, physics, and engineering management. He is chairman of the ASME's Power Division Reliability Availability and Maintainability (RAM) Subcommittee, Vice Chairman of the American Nuclear Society Committee 28 developing Modular Helium-cooled Reactor Design Standards, and licensed in the state of Colorado, as well as a certified SMRP professional.

Krishna Vasudevan is a principal of CORE, Inc., a software firm providing preventive maintenance (PM) optimization software Trim™ (RCMtrim™) and reliability engineering services. He has authored software publications and developed numerous relational databases design on platforms as simple as Microsoft Access or complex as Microsoft SQL Server or MySQL. He has over 30 years software development experience in power generation, engineering, and information technology. He graduated from the University of Madras (Madras, India), the University of Florida and Colorado State Universities (1969, 1972, & 1975, respectively) and holds BS and MS degrees in Chemistry.

Wayne H. Magninie, Jr., has 27 years of industrial experience in the area of nuclear operations, technical writing, training, process engineering, and emergency preparedness. Comprehensive experience in training program development and implementation, technical writing, developing and implementing operational exercises, project management, computer hardware/software, and management facilitation. Magninie worked for the Public Service Company of Colorado, the Resource Technologies Group, Inc., and Precision Resources. He served in the U.S. Navy from 1969 to 1976 and graduated from its Electronics Technician School in Nuclear Power Theory & Operation. He holds Batchelor and Masters Degrees in Education from the University of Southern Colorado.

Failure-Based Equipment Reliability (ER) Focus

Equipment-based ER focus



All part failure paths are treated as if they cause functional failure

Component

S – 1
O – 0
C – 0
X – 0

Critical PRA cut sets

Subcomponent

S – 1
O – 1
C – 0
X – 0

Safety – S
Operations – O
Cost – C
No Direct Effect – X

Parts

S – 1
O – 3
C – 0
X – 0

Sub-parts

S – 1
O – 5
C – 2
X – 0

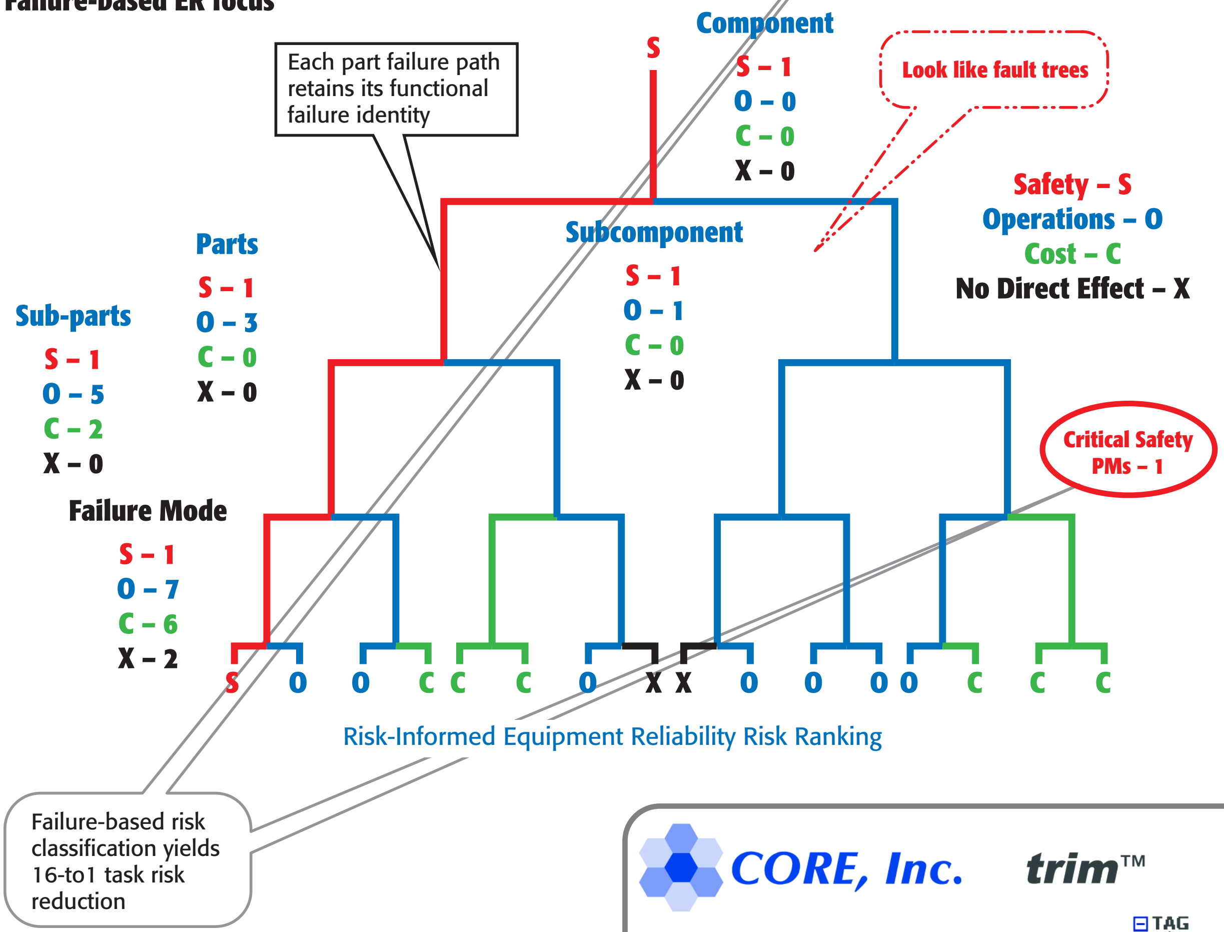
Failure Mode

S – 1
O – 7
C – 6
X – 2

Critical Safety PMs – 16

Treating all failures based upon Equipment Classification: elevates PM treatments unnecessarily to the component's risk level – ignoring actual function failure effects!

Failure-based ER focus



Each part failure path retains its functional failure identity

Component

S – 1
O – 0
C – 0
X – 0

Look like fault trees

Subcomponent

S – 1
O – 1
C – 0
X – 0

Safety – S
Operations – O
Cost – C
No Direct Effect – X

Parts

S – 1
O – 3
C – 0
X – 0

Sub-parts

S – 1
O – 5
C – 2
X – 0

Failure Mode

S – 1
O – 7
C – 6
X – 2

Critical Safety PMs – 1

Risk-Informed Equipment Reliability Risk Ranking

Failure-based risk classification yields 16-to1 task risk reduction

CORE, Inc. *trim*™

TAG
PART
FAULT
TASK

Reliability Tools and Services