RCM AND ENABLING PROCESS RELATIONSHIPS FOR CBM+ APPLICATION

David Nelson, CMRP
Sustainment Engineering Division

AGENDA

- CBM+ concept and goals
- Relationships
- Appropriate Processes
  - FMEA
  - RCM
  - Condition Monitoring, Diagnostics and Prognostics
- Decisions and approach
- Continuous Process Improvement

CONDITION BASED MAINTENANCE "PLUS"

- The application and integration of appropriate processes, technologies, and knowledge based capabilities to improve the reliability and maintenance effectiveness of DoD systems and components (DoD 4151.22)
- Part of the transformation of maintenance practices from the Industrial Age to the Information Age through the appropriate use of emerging technologies to analyze near-real-time and historical weapon systems data to provide predictive maintenance capability (DoD CBM+ Guidebook)

CONDITION BASED MAINTENANCE "PLUS"

- The "application and integration of appropriate processes … to improve reliability and maintenance effectiveness"
  - Multiple processes to apply and integrate
  - Processes are appropriate if they contribute to the goal to improve
- "Transformation"
  - Desirable and sustainable change leading to improvement
  - Alignment of people, processes and technology with business strategy and vision
  - Change of mindset that allows harnessing technological advances to gain a qualitative advantage (knowledge, speed, and precision) – Rumsfeld 'buzz words'

RELATIONSHIPS

- Reaching goals requires strategy, planning, and above all execution
- Appropriate processes are those that enable the goal
- Technology is attractive and engaging but not a magic bullet
- Strategy, planning, and process application may seem tedious but are always critical
- Execution
  - The most frequently cited reason for failure in sports
  - The least frequently cited reason for failure everywhere else

FAILURE MODES AND EFFECTS ANALYSIS

- FMEA is an enabling process, the starting point for postulating failure modes and effective way to organize and document
- Provides detailed insight into the systems interrelationships and potentials for failure at the failure mode level
- Hierarchical (top down or bottom up) with varying level of detail
- Can (and should) extend into criticality (FMECA)

FAILURE MODES AND EFFECTS ANALYSIS

- Failure mode definitions not all the same
  - Materials science (fatigue, overload, fretting)
  - Engineering
    - mechanism, manner, effect by which observed,
    - process which results in failure, condition causing failure,
    - state of operation or condition after or during failure,
    - specific condition causing failure,
    - circumstances or sequence of events,
    - event, which causes a functional failure
    - Appearance, manner, or form in which … failure manifests itself
- Failure modes are causal in nature, have definable conditions, sequences, and effects some of which can be observed

RELIABILITY CENTERED MAINTENANCE

- RCM is also an enabling process, essential and perhaps critical
- Identifies policies for mitigation at the failure mode level: “maintenance based on evidence of need”
- Looks at what should be done to prevent or predict (proactive task and interval)
  - Prevention – remove from service before failure mode ‘manifested’
  - Prediction – determine condition, usually through inspection, that indicates removal is required
- Predictive (i.e. On-condition) is the first step in determining what is ‘diagnosable’
  - Requires determination of ‘potential failure’ conditions that are indicators
  - Detection results in maintenance action but not necessarily diagnostic decision or prognostic assessment

CONDITION MONITORING AND DIAGNOSTICS

- Condition Monitoring enabling processes often very specific to the technology and/or application (ISO Standards good resource for guidelines and procedures)
  - Vibration and shock
  - Ultrasound
  - Thermography
- Looks more closely at what should be monitored (vice what can be) and prioritizing how it should be monitored based on rating detection, diagnostic and prognostic confidence
- Five distinct phases
  - Detection of problems
  - Diagnosis of the faults and their causes
  - Prognosis of future fault progression
  - Recommendation of actions
  - Post mortem

CONDITION MONITORING AND DIAGNOSTICS

- Not as simple as installing a sensor or doing an inspection
- Requires knowledge specific to each failure mode in the context of the technology
- ISO 13379 Generic steps for diagnostic study
  - First six steps can be performed in FMEA and RCM
  - Last three steps get more detailed for symptoms, descriptors, necessary measurements and devices
- Failure Mode System Analysis (FMSA) process
  - Modification of FMECA process
  - List all the symptoms produced by each failure mode
  - Select techniques with greatest sensitivity to detection and rate of change for a given symptom
  - Select monitoring technologies and strategies that maximize diagnostic confidence

CONDITION MONITORING AND DIAGNOSTICS

- Detection is only part of the story
- The real issue is accurate ‘dia’ (by) ‘gnosis’ (knowledge) decisions
  - Rarely as simple as yes/no
  - No sensor has <u>ever</u> detected a failure, sensors detect symptoms
  - Detection almost always involves a ‘certain’ probability, almost never a true certainty
  - Symptoms and descriptors rarely unique to one failure mode, usually relatable to more than one
- Appropriate data interpretation and diagnostic approach are essential

CONDITION MONITORING AND DIAGNOSTICS

- Data interpretation (ISO 13379) involves more than readings from sensors (measurements)
  - Measurements usually the raw result from the sensor
  - Descriptors are more selective, often a combination of measurements associated with the symptom
  - Symptoms are descriptors in context with things like location, circumstance, time, etc
  - Machine data also applies
    - Kinematics – speed, number of gear teeth, number of rollers, etc
    - Lubrication – oil path, elemental content of oil wetted components, filtration
    - Surface IR emissivity
    - Surrounding structure – cases, shielding, etc
- Data must be categorized to separate 'normal' from 'failure'
  - Example: Not categorized – threshold too low (2.82% alarm at 10 hour rate)
  - Example: Categorized – threshold value doubled (0.2% alarm at 10 hour rate), 141X <u>lower</u> alarm and 6X more accurate than not categorized

CONDITION MONITORING AND DIAGNOSTICS

- Diagnostic approach, the strategy that is appropriate for the technology and application
- Two main approaches
  - Numerical methods
    - Requires only rudimentary knowledge of mechanism and initiation
    - Need data, particularly failure data to improve
  - Knowledge-based methods
    - Fault/symptoms approach
      - Only rudimentary knowledge of mechanism and initiation
      - Need data, but apply associations between symptoms and faults
      - Validate, hypothesize, confirm associative model
      - Improve as more knowledge gained
    - Causal tree approach
      - Need in-depth knowledge of mechanism of initiation and propagation
      - There will be limits to knowledge

PROGNOSTICS

Engineering:

"Failure will occur in 6 days, 14 hours, 3 minutes, and 7 seconds."

Management:

"Can you stretch that to a week?"

Logistics:

"I need at least two weeks notice to get the parts."

Maintenance:

"We want to change it now."

PROGNOSTICS

- Diagnostics (by knowledge) is a decision about something that has already happened (with a ‘certain’ probability)
- ‘Pro’ (fore) ‘gnosis’ (knowledge) is about something that will happen in the future (again, with a ‘certain’ probability)
- These two concepts/terms are not synonymous, they are dependent
  - Prognosis is dependent on diagnosis
  - Diagnosis can be highly accurate and have prognosis that is inherently unpredictable

PROGNOSTICS

- Prognosis is an estimate of time remaining to functional failure and/or the associated risk
  - The estimate is usually not based on the average but on the minimum
  - Risk will influence the estimate (safety, operational, economic)
- Calculation will never be exact, only an estimate
  - Statistics will help some
  - Experience will help more
- Operational profile after diagnosis (notice I did not say detection) will have significant influence

PROGNOSTICS

- Modeling is essentially the only approach
  - In most cases, including seeded fault tests, observing actual progression to failure is impractical (expense, collateral damage, safety)
  - Analytical methods, computer modeling, model validation, and testing apply
- Experience will enhance knowledge and improve prognostic model
- The post mortem is critical

POST MORTEM

- Post mortem – after death, or in this case end of service period
- In my opinion, this is the most important factor in the whole process
  - Verifying condition post diagnosis/prognosis puts the goal in reach
  - Improvement is limited without it
- The requirements of the post mortem vary
  - Maintenance level
  - Repairable vs. non-repairable
  - Specifics of failure mode and mechanism

DECISIONS AND APPROACH

- CBM+ is a transformational vision
- Decisions regarding appropriate processes and other critical elements are essential to realizing the vision
  - Some failure modes will not be diagnosable requiring RCM or other process for mitigation
  - Some sensors and strategies will not perform as predicted requiring a change in approach
- The approach must be robust (i.e. less susceptible to assumptions)

CONTINUOUS PROCESS IMPROVEMENT

- All the processes discussed are ‘living’ processes
  - Will <u>not</u> be enabling if they are done once and put on the shelf
  - Sustainment needed to realize benefit, part of the transformation
- Like all the “Good Change” processes inappropriate application, inadequate planning, misguided strategies, and poor execution lead to failure with the ‘blame game’ resulting in misdirection and wasted resources
- Strong leadership is required

DISCUSSION AND COMMENT