The U. S. Army
Prognostics Framework
Research and Development

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PROGNOSTICS FRAMEWORK (PF) TEAM

- DR. LI PI SU, U. S. ARMY (OVERSEES PF PROJECT TECHNICAL AND SYSTEM DEVELOPMENT, TECHNOLOGY INSERTION)
- Ms. Mary Nolan, GAC (MANAGES PF SYSTEM DEVELOPMENT & COORDINATES WITH THE US ARMY LIA AND RELATED AGENCIES)
- Mr. Greg Demare, GAC (CHIEF SOFTWARE ENGINEER)
- Mr. Dave Carey, GAC (CHIEF SYSTEM APPLICATION ENGINEER)
No existing data available for predictive analyses
No system-level diagnostic technology
Most “diagnostics” are troubleshooting procedures
Need to define requirements of predictive data
No integrated diagnostics and prognostics technology
Why A Prognostics Framework

- Point Solutions too Expensive; Risky (Outcome unsure)
- Generic, Tailorable Approach will save time, money, and program-specific funds; fastest way for Army to converge on Prognostics capability
- Information to be provided to operational & maintenance crew should be normalized/standardized across Army systems
- Prognostic Mechanisms at various stages of maturity; system-level implementations are non-existent
- Need to Tie-in to logistics infrastructure is critical (e.g., IETM, logistics planning, mission planning, spare parts provisioning)
- Prognostics should be integrated with Diagnostics to provide a total "Health Management Capability"
Why This Approach?

Diagnostician uses a design-based model of fault/symptom relationships to isolate faults

INFORMATION:  
Operational Data  
Performance Monitoring  
BIT/BITE Results  
Prognostic Indications  
Raw Sensor Data  
Pilot/Crew Debrief  
Historical Fault Data

- Open architecture; generically applicable
- Single knowledge base for embedded and off-line
- Software structure is extendible
- Hierarchical approach enables system integration
- Can be used for legacy systems and new designs
What is the Prognostics Framework?

- A *generic*, structured information architecture and tools to implement Prognostics by supporting:
  - PMs in application of Prognostics
  - Operational Crew in Situational Awareness
  - Maintainers in Optimal Logistics Support
- Integrates current LIA TEDANN Program
- Can be applied to existing and new weapon systems
- Can be embedded or off-board
- Enables PMs to *Converge* on Prognostics as technology evolves
- Makes maximum use of existing Sensor/BIT data
- Automatically logs Historical Data

Approach Makes Sense! Supports Army Policy Direction and Initiatives: RML, Operational Readiness, Reduced Logistics Footprint, Force XXI, AAN
## Prognostics Framework Schedule

<table>
<thead>
<tr>
<th>Activity Description</th>
<th>TIM</th>
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<tbody>
<tr>
<td><strong>PHASE 1 - (9 Months)</strong></td>
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<tr>
<td>Development of Information Architecture</td>
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<td>Compile Prognostics Methodologies</td>
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<td>Develop Data Logging Methodology</td>
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<td>Expand Diagnostic Knowledge Base</td>
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<td>Expand Diagnostician Algorithms</td>
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<td>Testbed Selection</td>
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<td><strong>PHASE 2 - (9 Months)</strong></td>
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<tr>
<td>Application Engineering</td>
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<td>Demonstration</td>
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<td><strong>PHASE 3 - (6 Months)</strong></td>
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<tr>
<td>Technology Refinement &amp; Transition</td>
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<tr>
<td>Enhance Basic Algorithms/Logging</td>
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<tr>
<td>Generate Implementation Guide</td>
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9/98 6/99 3/00 8/00
Prognostics Framework Architecture
Prognostics Framework
Complements Other Prognostics Efforts

☑ Integrates Diagnostic/Prognostic Mechanism Outputs From Many Subsystems

☑ Provides Supplemental Prognostics

☑ Provides Diagnostic Analyses

☑ Ties-in to logistics infrastructure

☑ Prepares Information for Use By Both Operator & Maintainer
Prognostics Framework
Integrates Data From Many Subsystems

Subsystem X

Prediction Mechanism
e.g. TEDANN

Subsystem 1

Sensor Data

BIT / BITE

Subsystem n

Sensor Data
Prognostics Framework
Integrates Data From Many Subsystems

System X
Battery

Voltage

System Y
Turret

Angle
Diff

Prognostics Framework
( Relationships Between Systems )

Voltage Low and Angle Failure = Bad Battery
Voltage Ok and Angle Failure = Bad Turret
Prognostics Framework
Provides Diagnostics and “Supplemental” Prognostics Analyses

- Battery Voltage
- Generator Output
- System X Voltage
- Clutch Pad Thickness
Prognostics Framework
Supports Operations and Maintenance

- **Missions**: Mission Possible or Not, Predicted Mission Success or Failure
- **Operations**: Functions Available/Unavailable, Predicted Function Times To Failure
- **Maintenance**: Components Requiring Repair, Components Needing Repair Within Time Period X, Spares & Tools Required for Fix

**Bottom Line:** *Increased Operational Readiness & Battlefield Situational Awareness*
Prognostics Framework
Integrates Prognostics Mechanisms and Interprets Results For Users

TEDANN

Other ANN

Historical Data

Sensor Data

Function
Availability
Mission Capability

Operation Output

Maintenance Output

IETM Interface

Component Failure & Predicted Failure

Prognostics Framework
Accept Inputs from Multiple Sensors, BIT and Prognostic Mechanisms
Correlate failure predictions to Time and Mission
Provide Notification to Users

Not shown:
- Inputs from Multiple Sensors, BIT and Prognostic Mechanisms
- Correlate failure predictions to Time and Mission
- Provide Notification to Users
Prognostics Framework
Simplifies Health Management By Using a “Divide & Conquer” Strategy

Possibly Faulty Electronics

Can Ignore Electronics

Mechanical Equipment

TEDANN

Integrates TEDANN and Covering Unpredictable Failures
Prognostics Framework
Design Approach
Prognostics Framework
Design Goals

- Provide a Generic Solution to Prognostics Implementations
- Open Architecture allows complementing and enhancing Existing and Future Prognostics Mechanisms
- Minimize Cost of Development and Maintenance of Prognostics Framework Applications
Top Level Prognostics Framework Design

Development/Maintenance

System Design

Historical Data

Engineering Inputs

Prognostic Profiler

Prognostics Database

Operation

Embedded Tables

Sensor & Prediction Inputs

Prognostic Reasoner

Bias Table

Maintenance Data

Operation Data

Mission Data

Historical Data
Prognostics Framework
Prognostics Profiler Software Module

**Purpose:** Support both development and maintenance of an operational Prognostics Framework System.

**Design Goals:** Provide Services for developing and maintaining an operational Prognostics Framework System that are easy to understand and to use.

**Approach:** Provide developer interfaces that are similar to the Diagnostic Profiler in feel but extending support to prognostics.
Prognostics Framework
Prognostics *Reasoner* Software Module

**Purpose**: Analyze the test and prediction inputs and provide results that are understandable from the mission and maintenance point of view whenever those results are needed

**Design Goals**: Provide software that (1) can be embedded on a weapons platform, (2) can be tailored using the Prognostics Profiler, and (3) acquires, analyzes, and interprets input data for the use of maintainers, operators, and mission planners

**Approach**: Provide algorithms based on a three dimensional fault-symptom-time matrix and other tables to acquire data, analyze the results, and generate outputs
Prognostics Reasoner Block Diagram

Customizing Tables

- Get Prediction Mechanism Values and Sensor Values
- Interpret The Implication of Each Input Value On Each Future Time Point
- Prognose Failures for Each Future Time Point
- Extract the First Failure Times for Each Predicted Failure
- Identify the Components, Functions & Missions Affected By the Predicted Failures
- Provide Operator & Maintenance Outputs
Prognostics Reasoner Design
Prognose Failures for Each Future Time Point

- Captured Prediction Mechanism and Sensor Data
- Time 0 Data
- Time 1 Data
- Time N Data
- Diagnostician Algorithms
- Time 0 Faults
- Time 1 Faults
- Time N Faults
Prognostics Reasoner Design
Diagnostician Algorithms - Cones of Evidence

Pass Data Clears Some Faults

Failure Data Is Explained By Faults

Pass & Fail Data May Identify Multiple Faults
Prognostics Mechanisms
Survey Results
Prognostics Framework
Research & Development Efforts

- **Machines and Systems**: Tanks, rotorcrafts, Navy ships, process and power plants, Joint Strike Fighter, obstacle guidance, etc.

- **Development works**: Sensors, Health and Usage Monitoring, Condition Based Maintenance (CBM), Mission Readiness, obstacle Guidance Systems

- **Types of Prognostics**: Turbine engines, rotor stability, system vibrations, gears, shafts, power plants, wind tunnel compressors, etc.
Prognostics Framework
Current Major R&D Efforts

- Turbine Engines: PNNL; ARL (D)
- Helicopter gearbox prognostics: Princeton and Boeing/Office of Naval Research (ONR) (E)
- CBM for Intelligent Ship: Penn State/ONR (D)
- Obstacle avoidance: Univ. Southampton & UK Dept. of Defense (R/E)
- Power plants Intelligent Data Acquisition & CBM: PAC & PROSIG (U)
- Wind tunnel compressors automated reasoning expert system: AMES Research Center (D)
- Power transmission systems (MURI IPD): Penn State/ONR (R)
- Statistical Network Modeling (ModelQuest): AbTech/Rome Labs (U)
PROGNOSTICS FRAMEWORK

DELIVERABLES

- Generic Model Structure for Predictive Analysis
- Prognostics Framework Development Tool and Implementation Guide
- Prototype Prognostics Framework on a Testbed subsystem