The U. S. Army
Prognostics Framework
Research and Development

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Advanced Technology Office
The U.S. Army TMDE Activity
The U.S. Army Aviation and Missile Command

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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
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

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- Phase 1: Develop Framework & Supporting Tools
- Phase 2: Apply Framework to Testbed
- Phase 3: Refine Framework & Develop Implementation Guide
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 1
- Sensor Data
- BIT / BITE

Subsystem n
- Sensor Data

Subsystem X
- Prediction Mechanism (e.g. TEDANN)

Example Subsystems:
- TEDANN
Prognostics Framework
Integrates Data From Many Subsystems

System X Battery

Voltage

System Y Turret

Angle Diff

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

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

Operation Output
- Function Availability
- Mission Capability

Maintenance Output
- IETM Interface
- Component Failure & Predicted Failure
Prognostics Framework
Simplifies Health Management By Using a “Divide & Conquer” Strategy

- Possibly Faulty Electronics
- Mechanical Equipment
- TEDANN

Integrates TEDANN and Covering Unpredictable Failures
Prognostics Framework
Integrates TEDANN and Predicts

- Possibly Faulty Electronics
- Mechanical Equipment
- TEDANN

Behaves Differently When Electronics Is Faulty
Can Ignore Case Of Faulty Electronics
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
- Embedded Tables

Operation

- Embedded Tables
- Sensor & Prediction Inputs
- Historical Data
- Maintenance Data
- Operation Data
- Mission Data

Prognostic Reasoner
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.
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
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**
  - Diagnostician Algorithms
  - Time 0 Faults

- **Time 1 Data**
  - Diagnostician Algorithms
  - Time 1 Faults

- **Time N Data**
  - Diagnostician Algorithms
  - Time N Faults

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Prognostics Reasoner Design
Diagnostician Algorithms - Cones of Evidence

Pass Data Clears Some Faults
- Pass
- Pass

Failure Data Is Explained By Faults
- Fail
- Fail
- Fail

Pass & Fail Data May Identify Multiple Faults
- Pass
- Fail
- Fail
- Fail
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: Pen 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**