11th Annual Systems Engineering Conference

Prognostics to Improve Mission Readiness and Availability

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calce

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Mission Readiness and Availability

- Mission readiness of a product is a measure of the time needed for a product to be in full operational state.
- Mission readiness is directly proportional to the products availability to the customer.
- Availability is the probability that a product will in operational state at a given time.

$$Availaility = Uptime/(Uptime + Downtime)$$

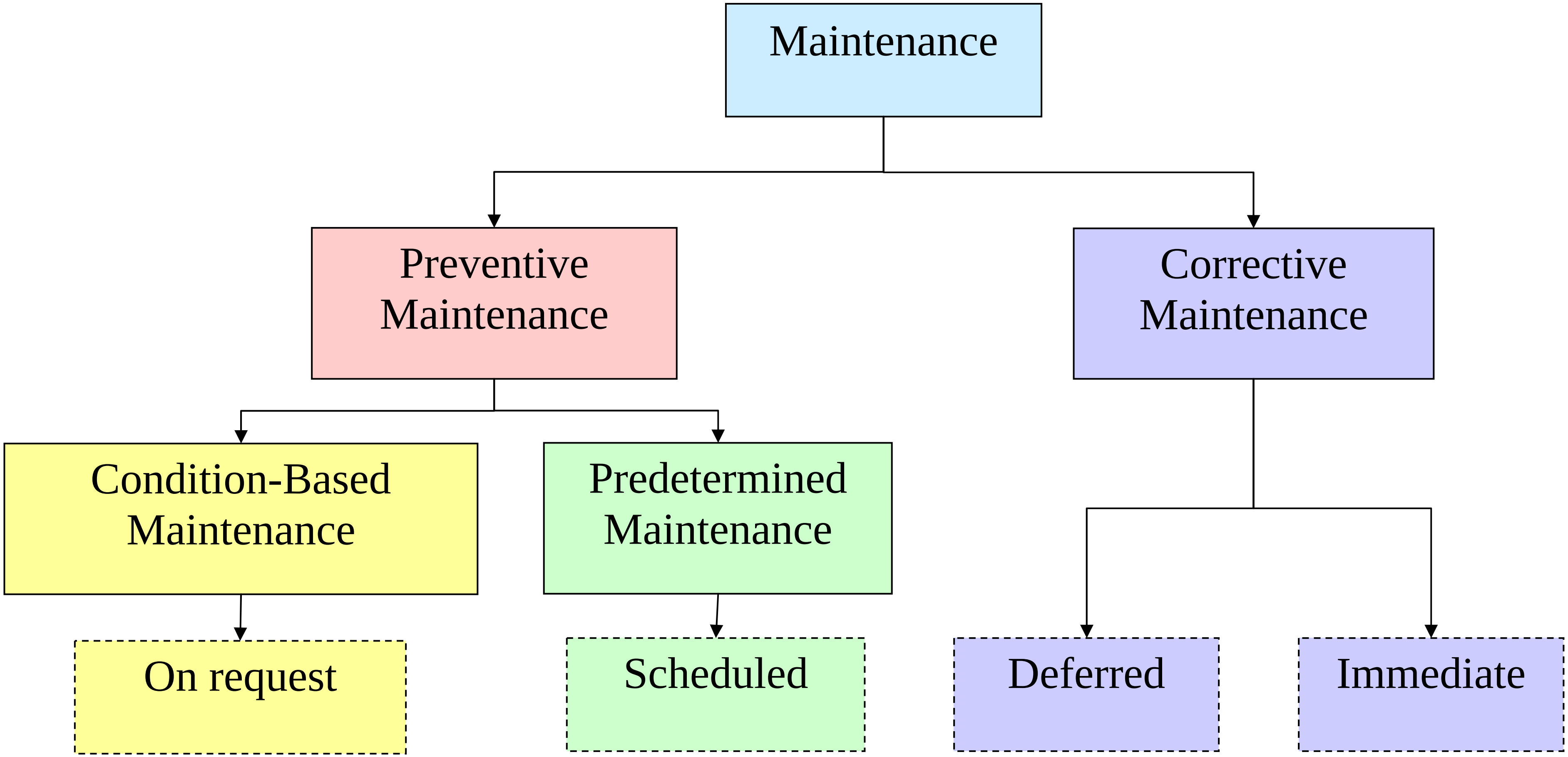
- Lower the down-time, higher will be the availability.
- Product maintenance and logistics play a major role in ensuring more availability and better mission readiness of the product.

Useful Terms

- **Health:** A product's health is the general state of the product with respect to the expected normal operating condition.
- **Health monitoring:** a process of measuring and recording the extent of deviation and degradation from a normal operating condition
- **Prognostics**: the process of predicting the future health of a product by analyzing the recorded deviation or degradation.
- **CBM** (Condition-Based Maintenance): is a preventive and predictive approach to maintenance based upon the evidence of need.

Condition Based Maintenance (CBM)

The objective of CBM is to assess a product's health during operation and determine if and when maintenance is needed.



Outcomes of Maintenance Decisions

Corrective

Unanticipated Failure

- Hazardous
- Costly
- Unscheduled maintenance

Predetermined

Regular Maintenance

- Must inspect, repair or replace after fixed time or operational interval
- Can be costly
- Can induce failures
- Increased down-time

CBM

Health Monitoring

- Maintenance is forecasted
- Continuous monitoring of health can decrease down-time
- Product sustainment, and re-use options can be determined

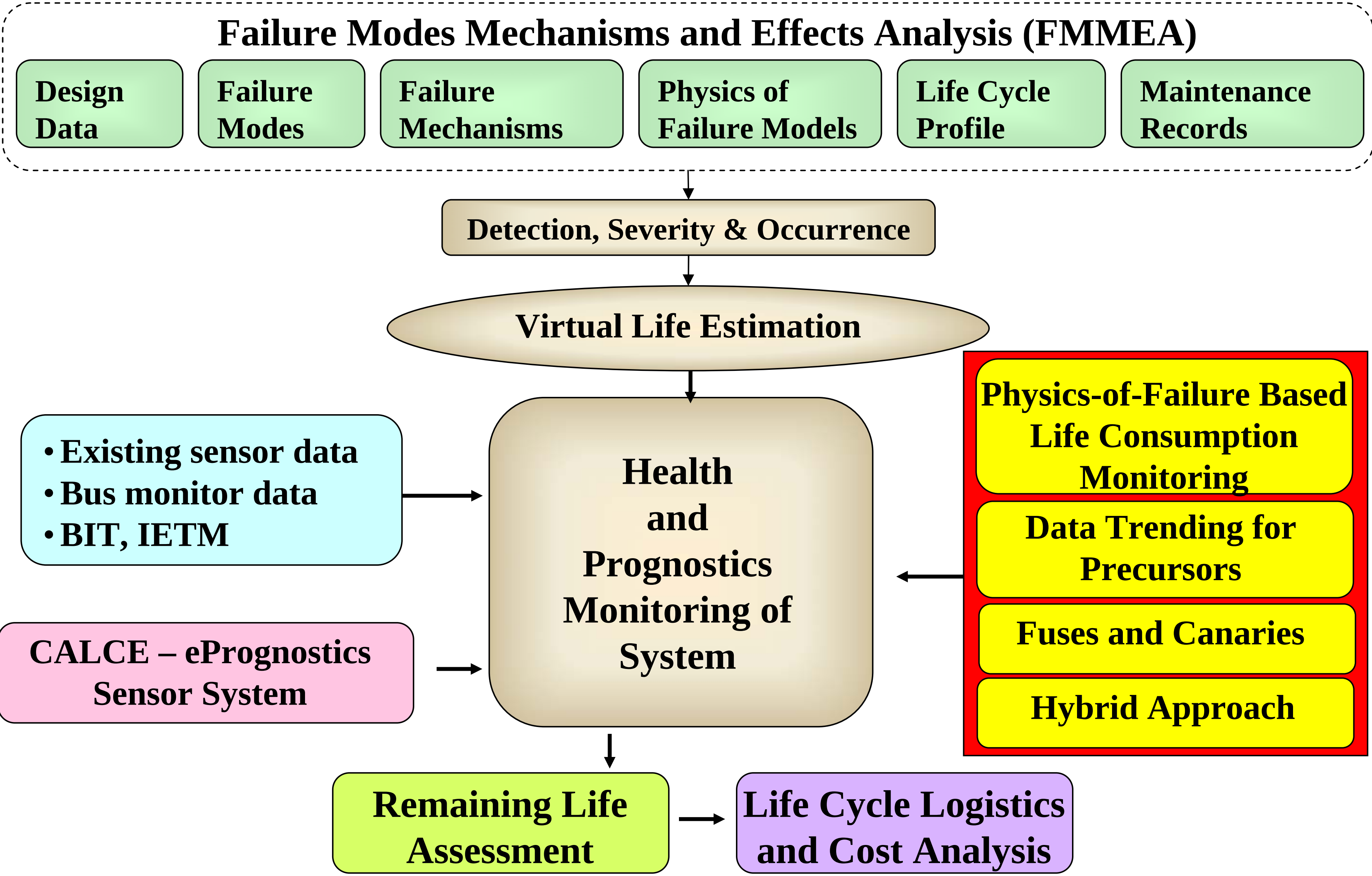
Prognostics for CBM

- One of the key enablers of CBM is the development of the PHM technology.
- PHM assesses and quantifies the extent of deviation or degradation from an expected normal operating condition.
- A symptom of impending failure or anomalous behavior can be identified with the aid of health monitoring and prognostics techniques.
- Knowledge of prognostic distance allows informed logistics and maintenance decisions.

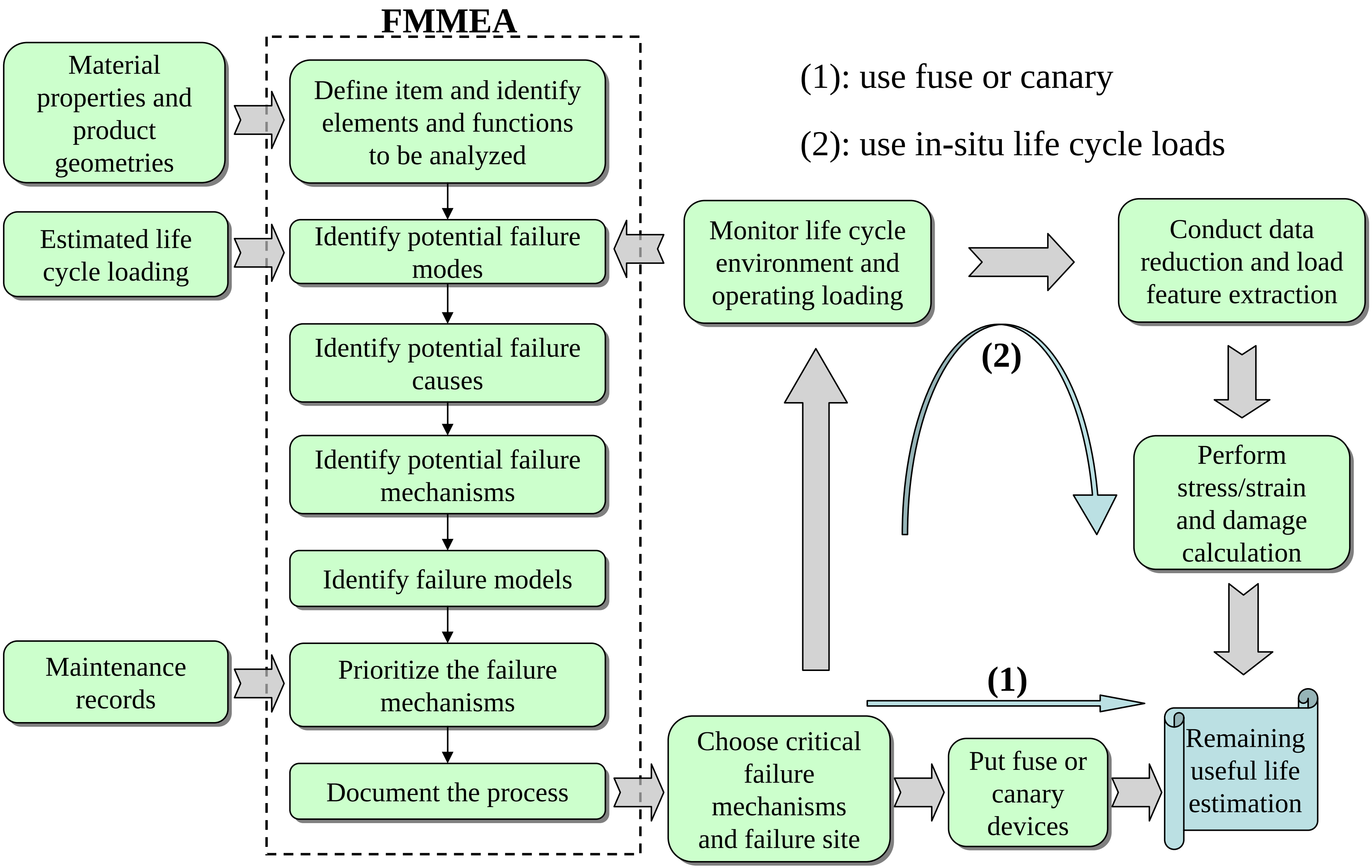
Why PHM?

- Provide an early warning of failures
- Forecast maintenance as needed: avoid scheduled maintenance and extend maintenance cycles [condition based maintenance]
- Predict the product’s reliability
- Assess the potential for life extensions
- Provide efficient fault detection and identification, including evidence of “failed” equipment found to function properly when re-tested (no-fault found).
- Improve future designs and qualification methods
- Reduce amount of redundancy

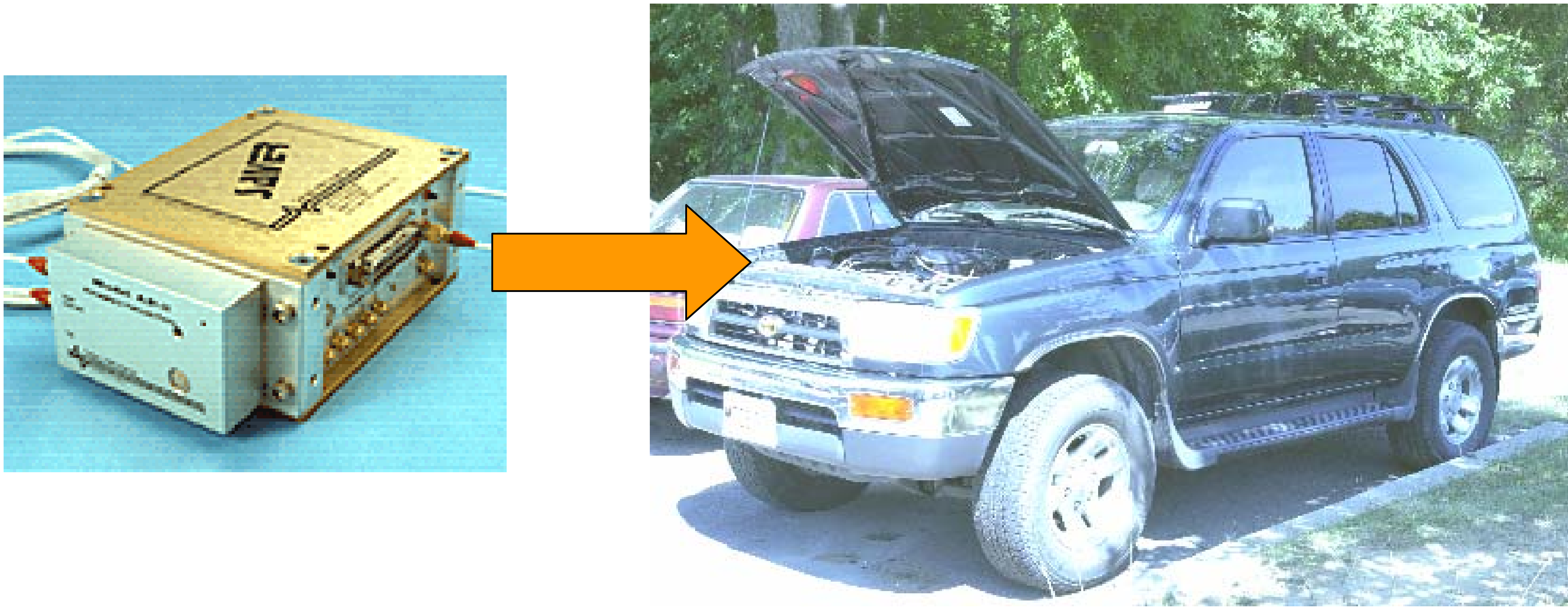
CALCE Approach



CALCE PoF based PHM Methodology

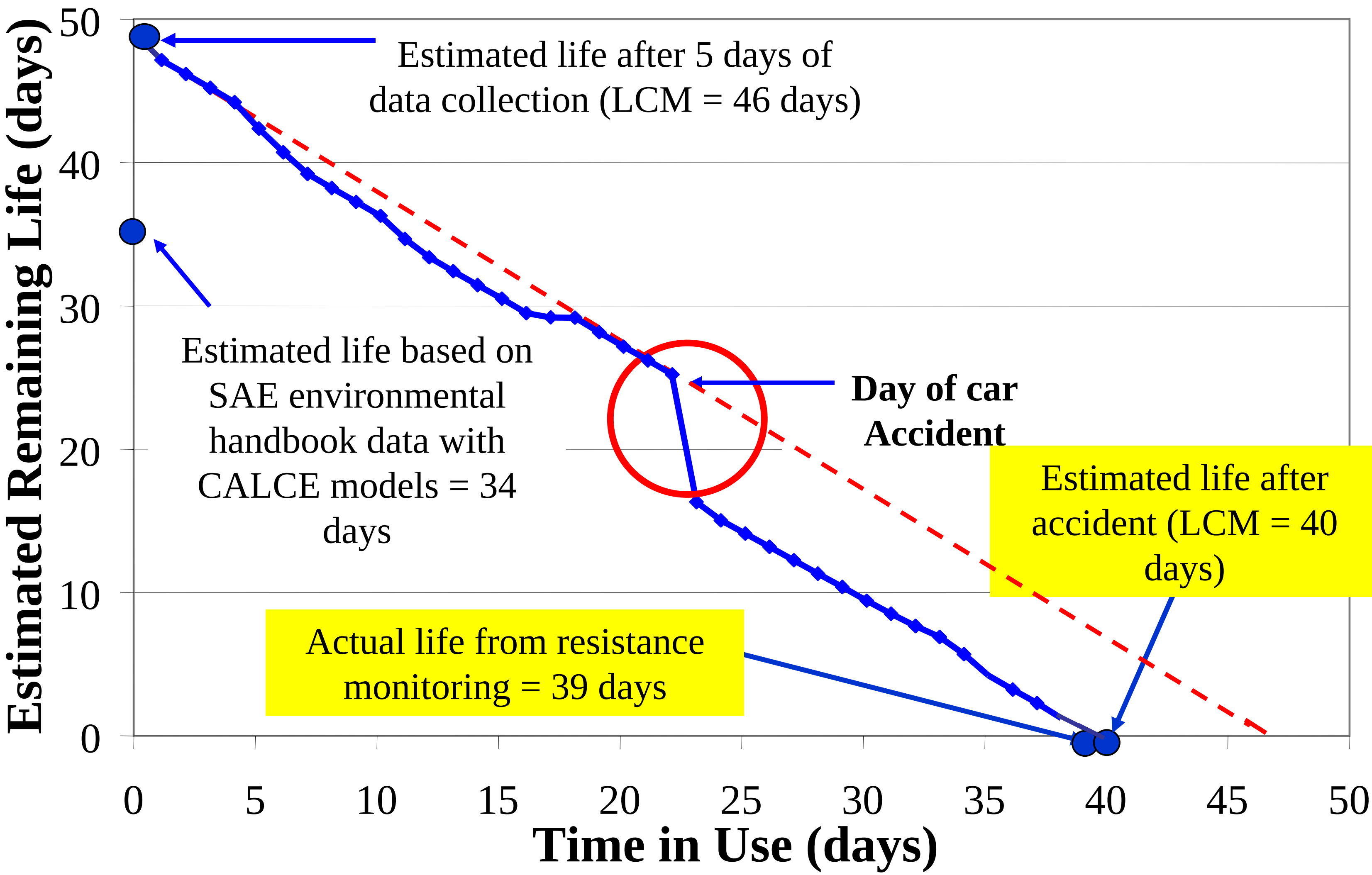


Predicting Remaining Life Based on Physics of Failure (1/2)



Monitored environmental and operating conditions of test board → Simplified data (e.g., data reduction, and cycle counting) → Performed physics-of-failure based stress and damage assessment → Obtained the remaining life

Predicting Remaining Life Based on Physics of Failure (2/2)



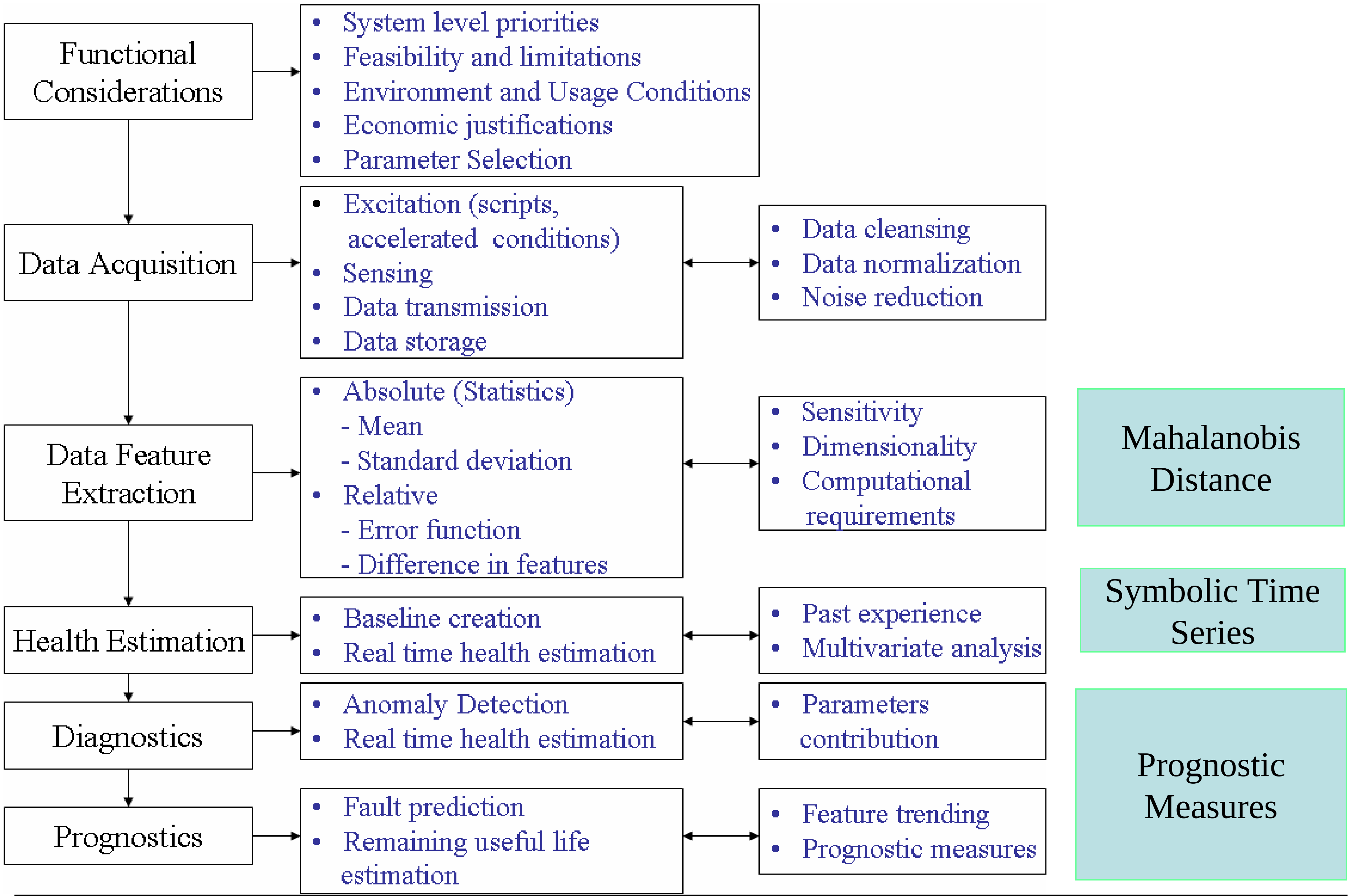
Remaining Life Assessment of NASA Space Shuttle Remote Manipulator System (SMRS) Electronics

- The SRMS is used to place satellites, space station equipment and other payloads in orbit. The first SRMS flew on the space shuttle mission STS-2 in November 1981.
- By using the existing sensor data, along with inspection and physics-of-failure software analysis, it was found that there was little degradation in the electronics and they could be expected to last another 20 years.

Army AMSAA –CALCE Project
Two Year Demonstration System

- The objective of this project was to demonstrate predictive capabilities for the remaining life of electronic components mounted in military vehicles.
- The project centered around exposing test boards with electronic components mounted on them to on and off road terrain.
- Field failures agreed quite well with the predicted failure using the monitored PWB strain and existing CALCE failure models.

Considerations for Data-Driven PHM



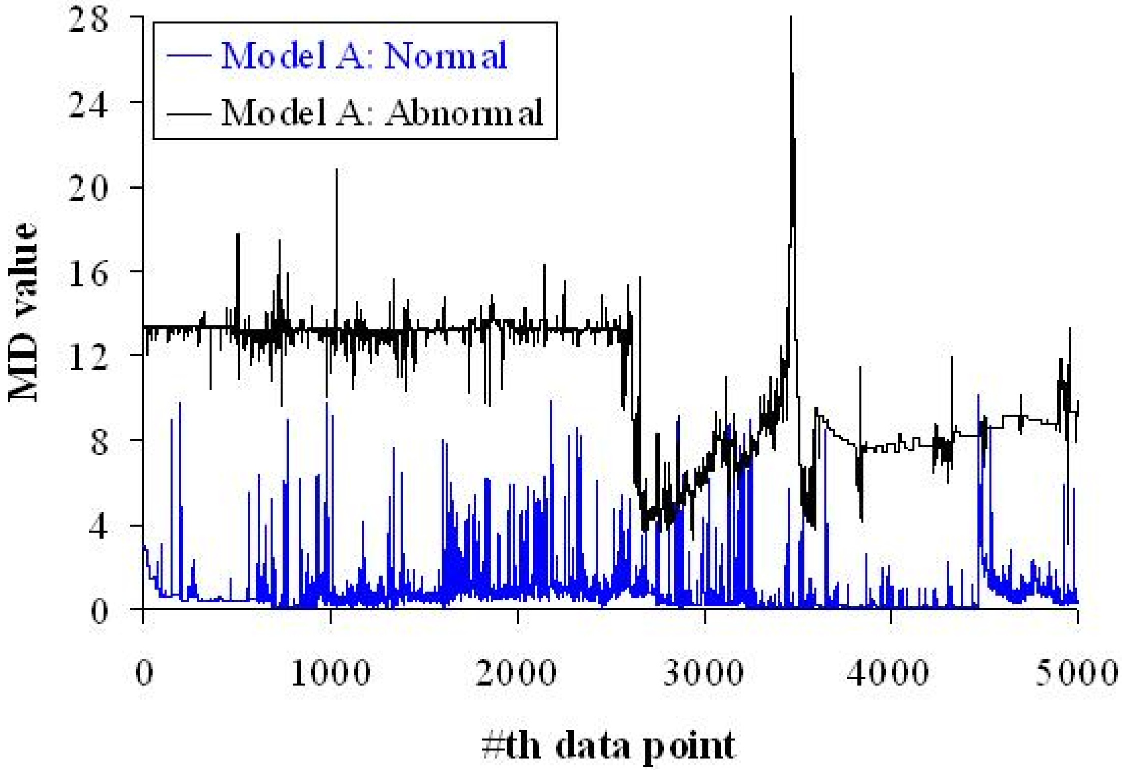
Case Study: Data Driven Approach

- Computers are complex electronics systems and can be used as a test vehicle for developing robust prognostics methodologies.
- A baseline was generated using 10 new computers.
- A total of 72 experiments were conducted.
- Duration of data collection at each setup was approximately three hours.

- Environmental conditions
  1. 5°C with uncontrolled Relative Humidity
  2. 25°C with 55% RH
  3. 25°C with 93% RH
  4. 50°C with 20% RH
  5. 50°C with 55% RH
  6. 50°C with 93% RH
- Usage Levels
  1. L1: Benign
  2. L2: Low
  3. L3: Medium
  4. L4: High
- Three Power Settings

- Parameters identified for health monitoring
  - Device information
    - fan speed, LCD brightness
  - Thermal information
    - CPU temp, motherboard temp, graphics card temp
  - Performance management information
    - %CPU usage, %C1, %C2, %C3, % CPU throttle

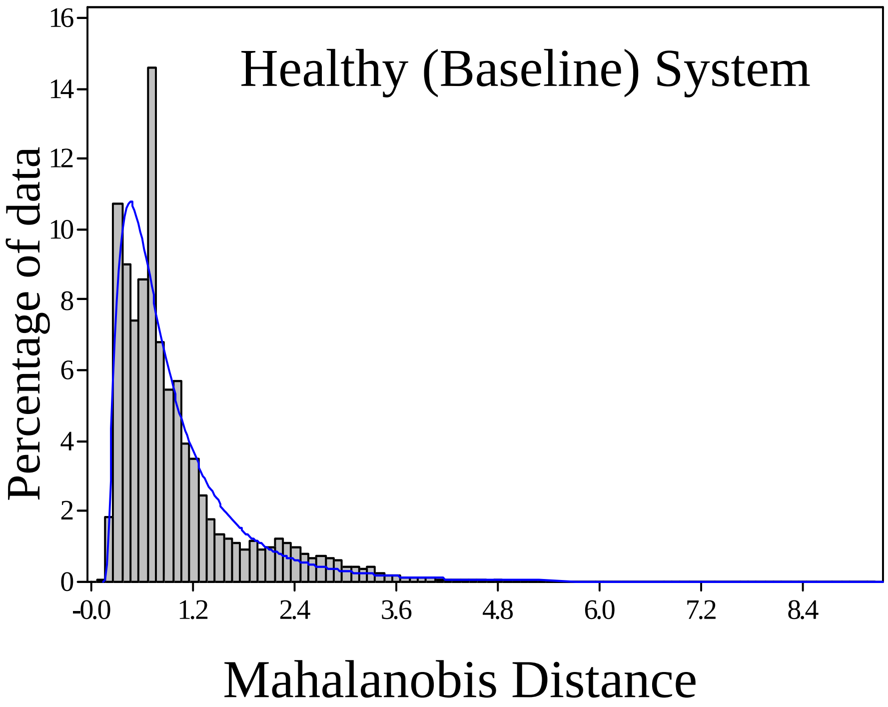
Comparison of Mahalanobis Distance (MD) Values for Normal and Abnormal Systems



Stats (Model A)	Normal	Abnormal
Mean of MD	0.83	10.72
Std.dev of MD	1.16	3.13

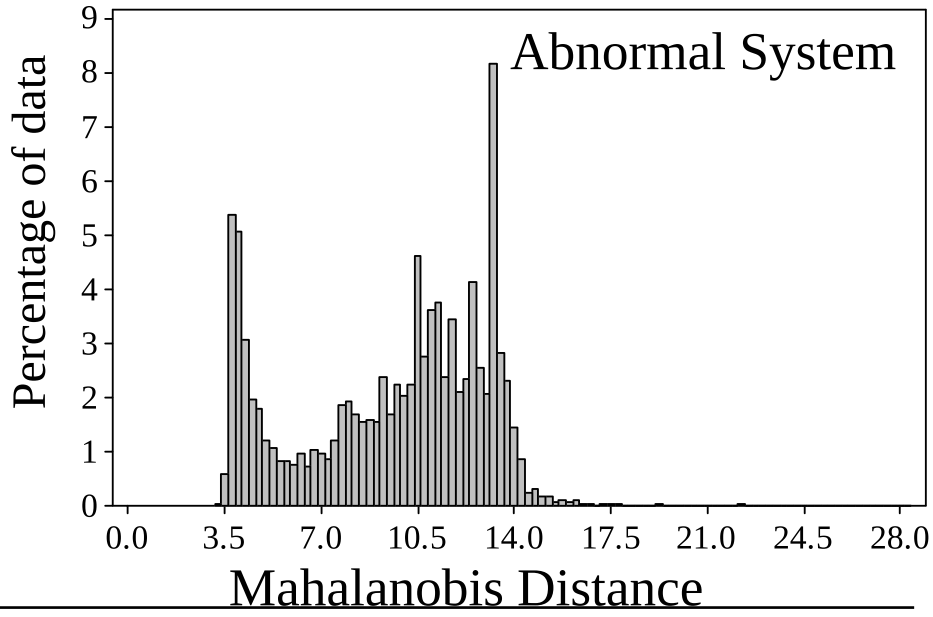
- The data from the 10 new computers used to form the baseline.
- Utilizing the correlations between the measured parameters MD reduces the multivariate data to a univariate data.
- An NTF computer (Abnormal) was tested and the same parameters were recorded as for the baseline computers.
- The MD values for the Abnormal system showed faulty behavior at time zero.

Comparison of Histogram of MD Values



- 3-parameter lognormal distribution fit for the baseline MD value and more than 95% data is covered by the distribution

- Test computer shows different distribution of MD values as compared to baseline computer
- This demonstrates the test computer has different signature

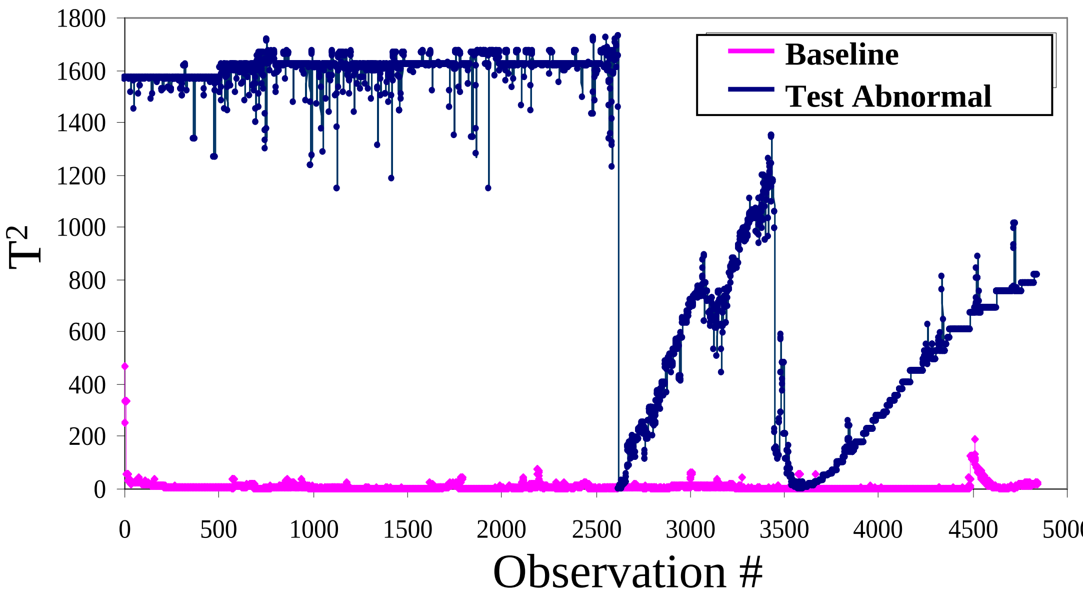


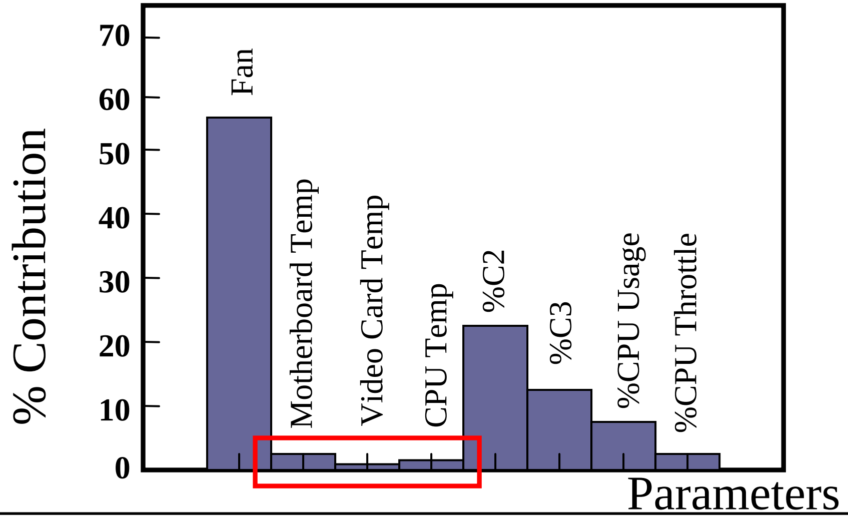
Principal Component Analysis

- Principal Components Analysis (PCA) is used in a wide array of applications to reduce a large data set to a smaller one while maintaining the majority of the variability present in the original data.
- Two statistical indices, the Hotelling Squared (T^2) and squared prediction error (SPE) are used in the PCA.
- The SPE statistic is related to the residuals of process variables and is a reliable indicator to a change in the correlation structure.
- The Hotelling T^2 score measures the Mahalanobis Distance from the projected sample data point to the origin in the signal space defined by the PCA model.

Projection Pursuit: Analysis Results – T^2

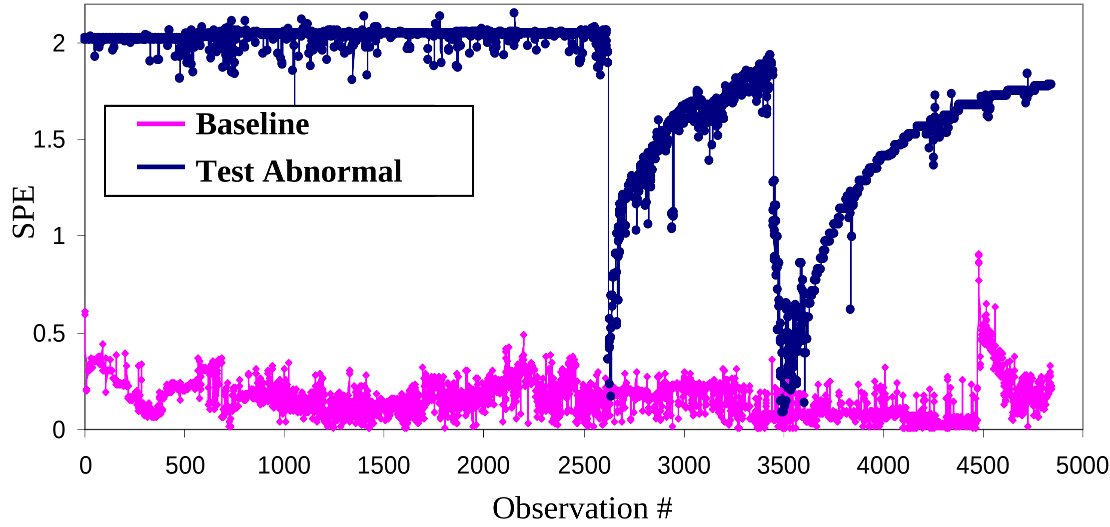
- Tested a computer showing abnormal behavior against a baseline.
- From the T^2 analysis, test computer shows a distinction from the baseline data
- The contribution plot identifies the fan speed as the dominant parameter that contributes to the shift from the baseline.

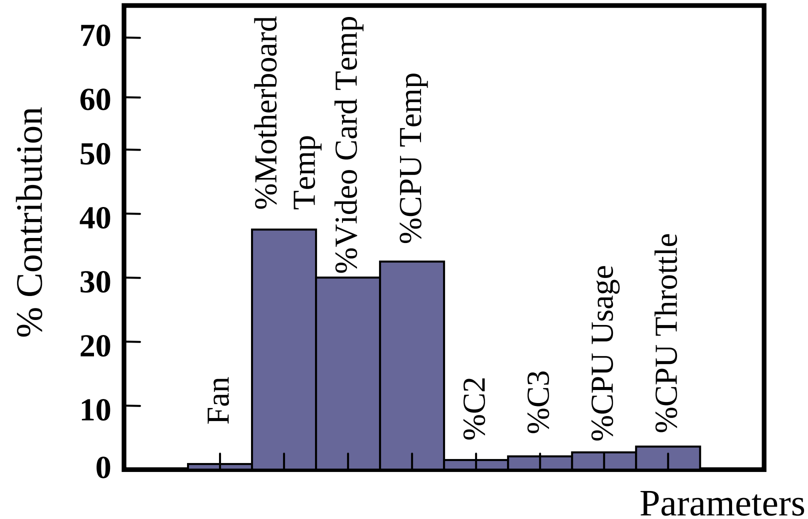




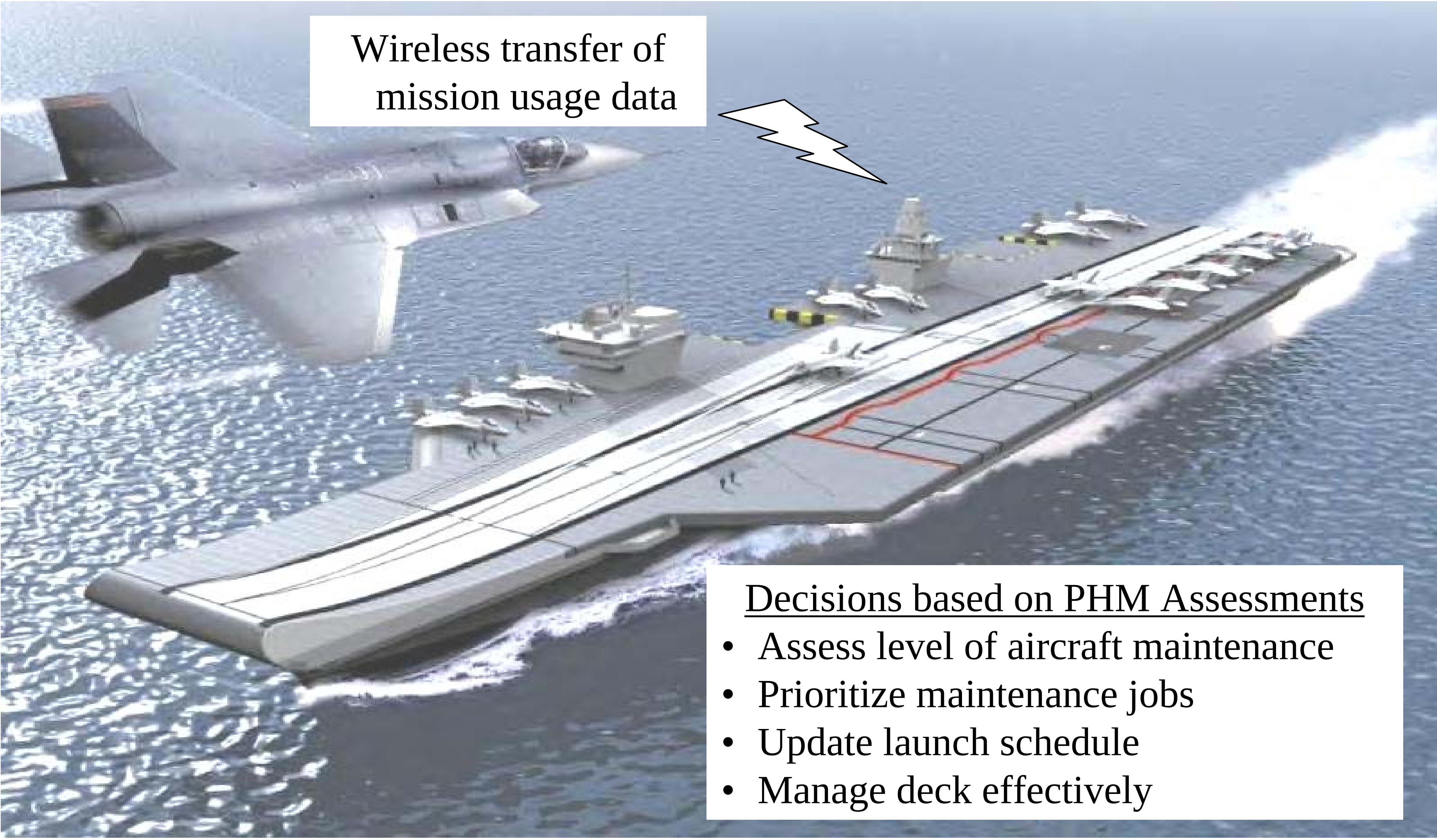
Projection Pursuit: Analysis Results - SPE

- The SPE feature also classifies the test computer as different from the baseline.
- All temperatures are dominant in the residual space and are identified as the influencing factors for the fan speed.





Prognostics Health Monitoring Enabled Logistics Decisions for Aircraft Carrier



Wireless transfer of mission usage data

<u>Decisions based on PHM Assessments</u>

- Assess level of aircraft maintenance
- Prioritize maintenance jobs
- Update launch schedule
- Manage deck effectively

Conclusions

- Prognostics using approaches including PoF based life consumption monitoring, data trending and analysis, and use of canaries can be achieved.
- Prognostics and health monitoring provides advanced warning of failure or abnormal behavior and thereby helps determine the mission readiness and availability of the product.
- Assessment of remaining life helps drive the cost effective logistics decisions.
- Condition based maintenance can be implemented with the help of health monitoring and prognostics technologies.

CALCE

CALCE founded in 1987 is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic products and systems.

Focus areas:

- Physics of failure
- Design for reliability
- Accelerated testing
- Qualification
- Supply chain management .
- Obsolescence
- Prognostics

Personnel:

- 21 research faculty
- 6 technical staff
- 60+ PhD students
- 30+ MS students
- 11 visiting scholars

Education

- MS and PhD EPS program
- International visitors
- Web seminars
- Short courses for industry

EPS Consortium

- 40-45 companies
- Pre-competitive research
- Risk assessment, management, and mitigation for electronics

PHM Consortium

- Pre-competitive research
- Research in fundamental methodologies to develop and implement prognostics and health management systems.

CALCE

Center for Advanced Life Cycle Engineering

Research Contracts

- Larger programs

Reliability simulator (KIM, Korea), Remaining life assessment (Air Force), Tin whisker mitigation (Navy, TMTI), Part obsolescence (NSF, NAVSEA), Design refresh planning (Army CECOM, DML)

Lab Services

- Small jobs
- Fee-for-service
- Proprietary work
- Use of CALCE Tools & Methods
- Turnkey capabilities
- "Fire-fighting"

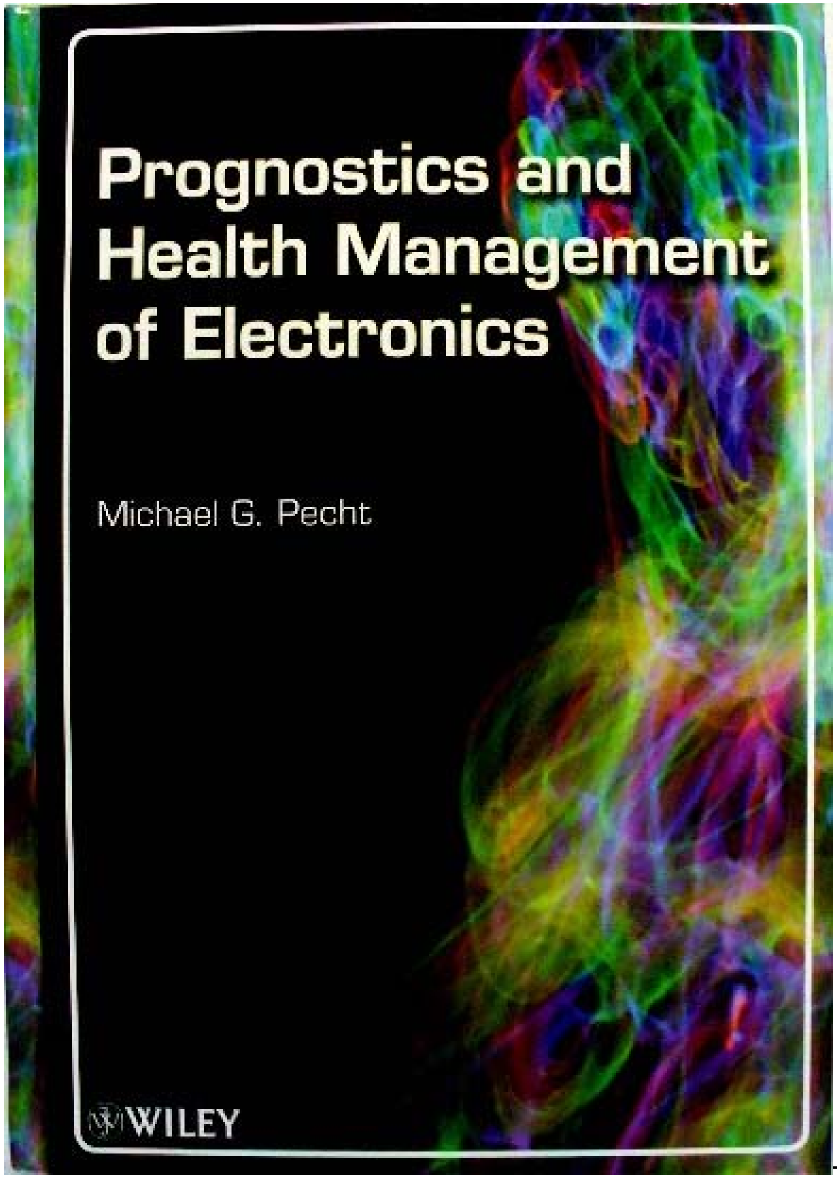
Standards

- IEEE 1332
- IEEE 1413
- IEEE P1624
- GEIA
- IPC

CALCE Research Focus in PHM

- Developing the capability to learn from data, detect changes in real-time and predict the future performance of electronic systems.
- Integrating the center’s expertise in reliability and physics of failure (PoF) of electronic components into hybrid data driven models for autonomous system prognostics and diagnostics.
- Researching and developing prognostic and health management technologies that will enable autonomous fault diagnostics and prognostics in electronic systems such that reliability mitigations can be implemented.

PHM Book



- Overviews the **concepts of PHM** and the techniques being developed.
- Discusses the **state-of-the-art** in sensor systems.
- Discusses the various data driven/ statistical **models and algorithms**.
- Discusses the **physics-of-failure** based prognostics approaches.
- Overview of the implementation costs and **return on investment** (ROI).
- Provides a **roadmap** based on the current challenges and opportunities for research and development of PHM, and
- Discusses the activities of the major players in the prognostics research field, including **companies**, **academia** and **government** organizations.