A New Perspective on Electronic Product Reliability

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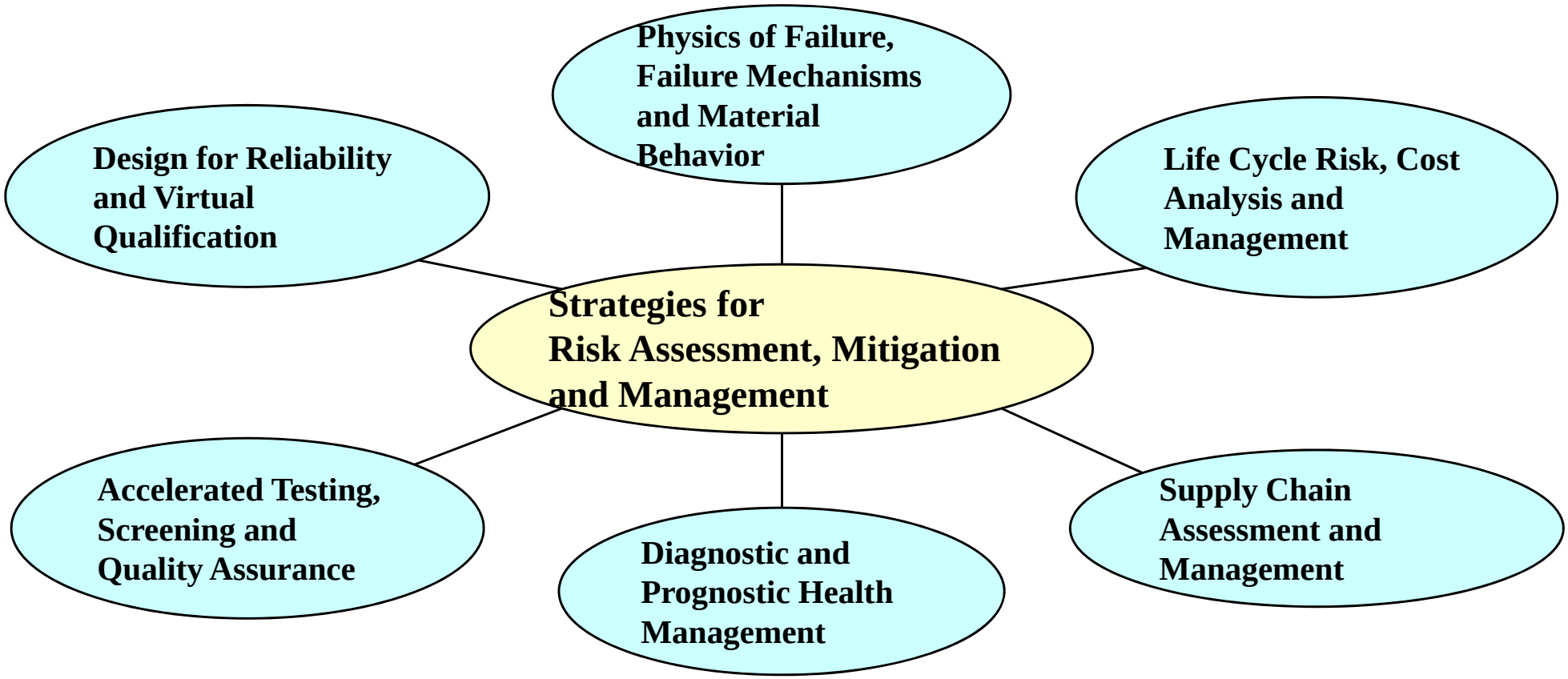
IEEE Components, Packaging and Manufacturing Technology Society

A Brief History of CALCE

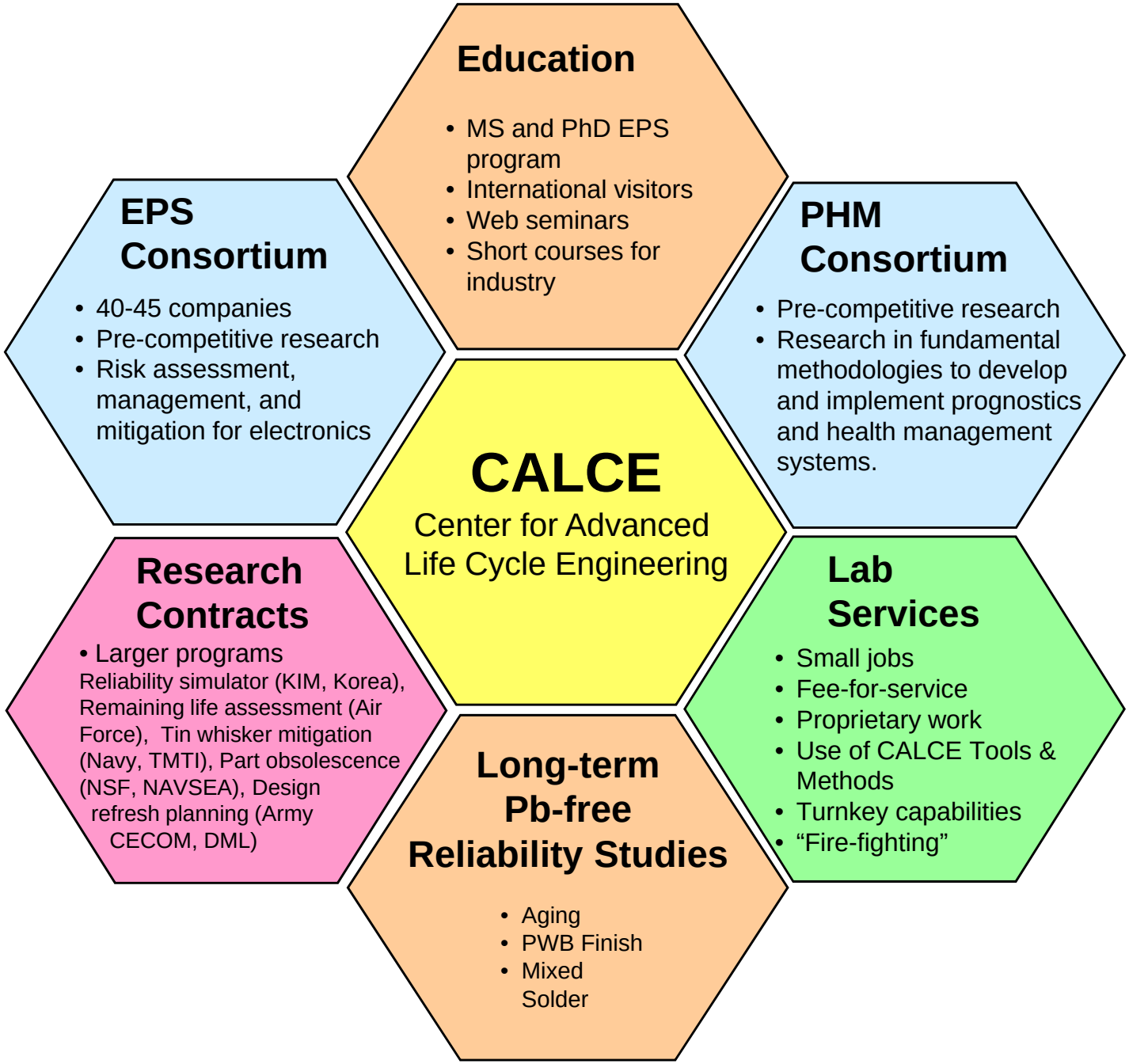
- Formally started in 1984, with support from NSF, as a US Center of Excellence in electronics products reliability
- Funded by over 150 of the world's leading electronics organizations
- Supported by 112 faculty, visiting scientists, research assistants, and 20 visiting scholars from sponsoring organizations
- Over $6.5M in research funding per year
- One of the world's most advanced and comprehensive electronics testing and failure analysis laboratories
- Developed Design-for-Reliability (DfR) methods, and physics of failure methods for electronic products

CALCE: Our Role

Provide a knowledge and resource base to support the development and sustainment of competitive electronic products and systems in a timely manner.



CALCE Organization



CALCE Electronic Products and Systems Consortium Members

- ACEL, China
- Arbitron
- BAE SYSTEMS
- Boeing Co.
- Curtiss-Wright Corporation
- Daimler
- Dell Computer Corp.
- EADS CCR, France
- Emerson
- EMC Corp.
- Ericsson AB, Sweden
- General Dynamics AIS
- GE (GE Healthcare, GE Aviation, GE Fanuc) Corp.
- General Motors
- Goodrich Engine Control Sys., UK
- Hamilton Sundstrand
- Harris Corporation
- Honeywell
- Instit. Nokia de Tecnologia, Brazil
- Lansmont Corp.
- Lockheed Martin
- NASA
- Northrop Grumman Corp.
- Naval Surface Warfare Center
- Nokia Siemens Network, Finland
- Philips CIT, the Netherlands
- Qualmark
- Raytheon Co.
- ReliaSoft Corporation
- Research in Motion, Ltd., Canada
- Rockwell Collins, Inc.
- Rolls-Royce plc, UK
- Samsung Memory, Korea
- Samsung Techwin, Korea
- Samsung Electro-Mechanics, Korea
- Samsung Mechatronics and Manuf. Technology Ctr., Korea
- Sandia National Labs
- Schlumberger Oil Field Services
- Seagate Technology Inc.
- Sun Microsystems
- Team Corp.
- Teradyne
- TRW Automotive, UK
- Toshiba, Japan
- U.K. Ministry of Defence
- U.S. AMSAA
- U.S. Army Research Lab.
- Vestas, Denmark
- Whirlpool Corp.

Super member

History
Reliability Prediction of Electronics

- 1965: US military developed Mil-Hdbk-217: a handbook for reliability prediction of electronics

- 1980s: The telecommunications industry adopted the 217 approach with various modifications

Mil-Hdbk-217 Approach

$$\lambda = \Pi_Q (C_1 \Pi_T \Pi_V + C_2 \Pi_E) \Pi_L$$

History
Reliability Prediction of Electronics

- 1988: CALCE was awarded a 3 year $2M US government contract to assess Mil-Hdbk-217 and provide guidance for the future

- Conclusion: Mil-Hdbk-217, Telecordia, Prism and other similar handbook methods have fundamental flaws built into them.

U. S. Military View of Mil-Hdbk-217

"… Mil-Hdbk-217, Reliability Prediction of Electronic Equipment, **and progeny**, is not to be used as it has been shown to be unreliable and its use can lead to erroneous and misleading reliability predictions."

October 1994

Decker, Assistant Secretary of the Army (Research, Development, and Acquisition), Memorandum for Commander, U.S. Army Material Command, Program Executive Officers, and Program Managers

Handbooks Start to Become Cancelled

- **British Telecom**, “Handbook of Reliability Data for Components Used in Telecommunications Systems,” (1993). {CANCELLED}
- **Italtel**, “Italtel Reliability Prediction Handbook,” (1993). {CANCELLED}
- **Siemens** Standard SN 29500, “Reliability and Quality Specification Failure Rates of Components,” (1999). {CANCELLED}
- **Nippon Telegraph and Telephone Corporation**, Standard Reliability Table for Semiconductor Devices, (1986). {CANCELLED}
- **SAE** Reliability Prediction Software PREL (1990). {CANCELLED}
- **Centre National D'Etudes des Telecommunications**, Recueil De Donnes De Fiabilite Du CNET, (2000). {CANCELLED}

History
Reliability Prediction of Electronics

- 1999: CALCE awarded 5 year $12M US government contact to develop physics of failure models (software) for electronics industry to replace 217-based methods

2003: IEEE 1413 and IEEE 1413.1

IEEE Std 1413-1998

IEEE Standard Methodology for Reliability Prediction and Assessment for Electronic Systems and Equipment

Sponsor

Standards and Definitions Committee
of the
IEEE Reliability Society

Approved 8 December 1998

IEEE-SA Standards Board

Abstract: The framework for the reliability prediction process for electronic systems and equipment, including hardware and software predictions at all levels, is covered.
Keywords: hardware prediction, reliability, reliability prediction, software prediction

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

Print: ISBN 0-7381-1551-7 SH94714
PDF: ISBN 0-7381-1552-5 SS94714

IEEE Std 1413.1™-2002

IEEE Guide for Selecting and Using Reliability Predictions Based on IEEE 1413™

Sponsor

IEEE Standards Coordinating Committee 37
on
Reliability Prediction

Approved 12 September 2002

IEEE-SA Standards Board

Abstract: A framework for reliability prediction procedures for electronic equipment at all levels is provided in this guide.
Keywords: baseline, classic reliability, constant failure rate, estimation, failure, goal, item, operating environment, reliability prediction, requirement, system life cycle

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3 Park Avenue, New York, NY 10016-5997, USA

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IEEE 1413 and 1413.1

- Shows that there is very little value in the use of Mil-Hdbk-217, 217-Plus, FIDES, and progeny prediction methods

- Physics-of-failure methods are necessary for good reliability assessment and prediction, but one also needs a good assessment of the "conditions of use"

2004: JEDEC-STD-148 Reliability Qualification of Semiconductor Devices based on Physics of Failure Risk and Opportunity Assessment

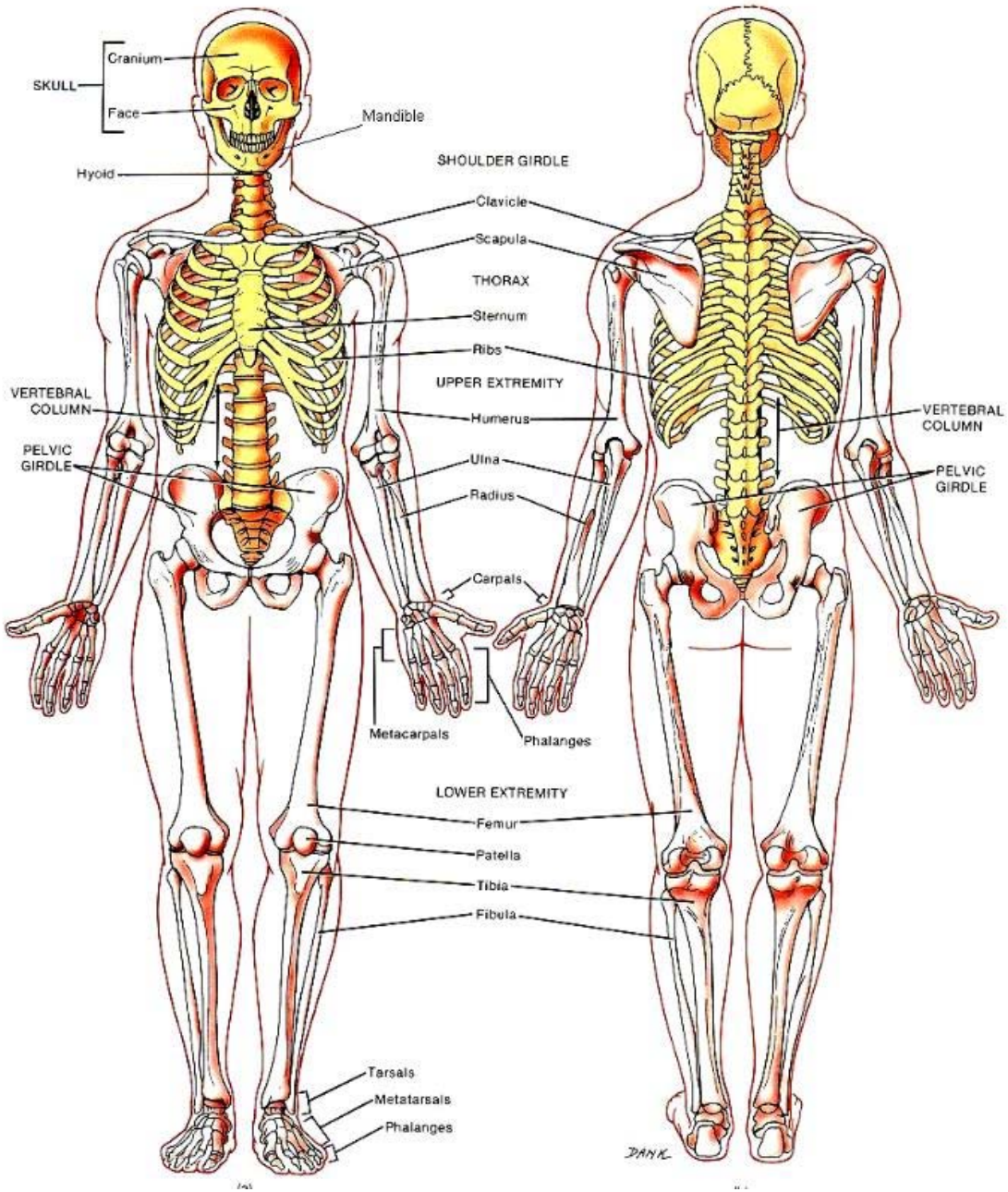
- Change from a 217-type reliability certification method to an approach based on an understanding of failure mechanisms (physics-of-failure) and the end user conditions

Health Management and Prognostics

Information for Health Assessment

- Current conditions, status
- Personal (product) history
  - Family history (design)
  - Birth conditions (production, manufacture)
  - Living style (life cycle usage conditions)
  - Environment, stress, (environment, stress)

Health is the extent of deviation or degradation from an expected normal condition.

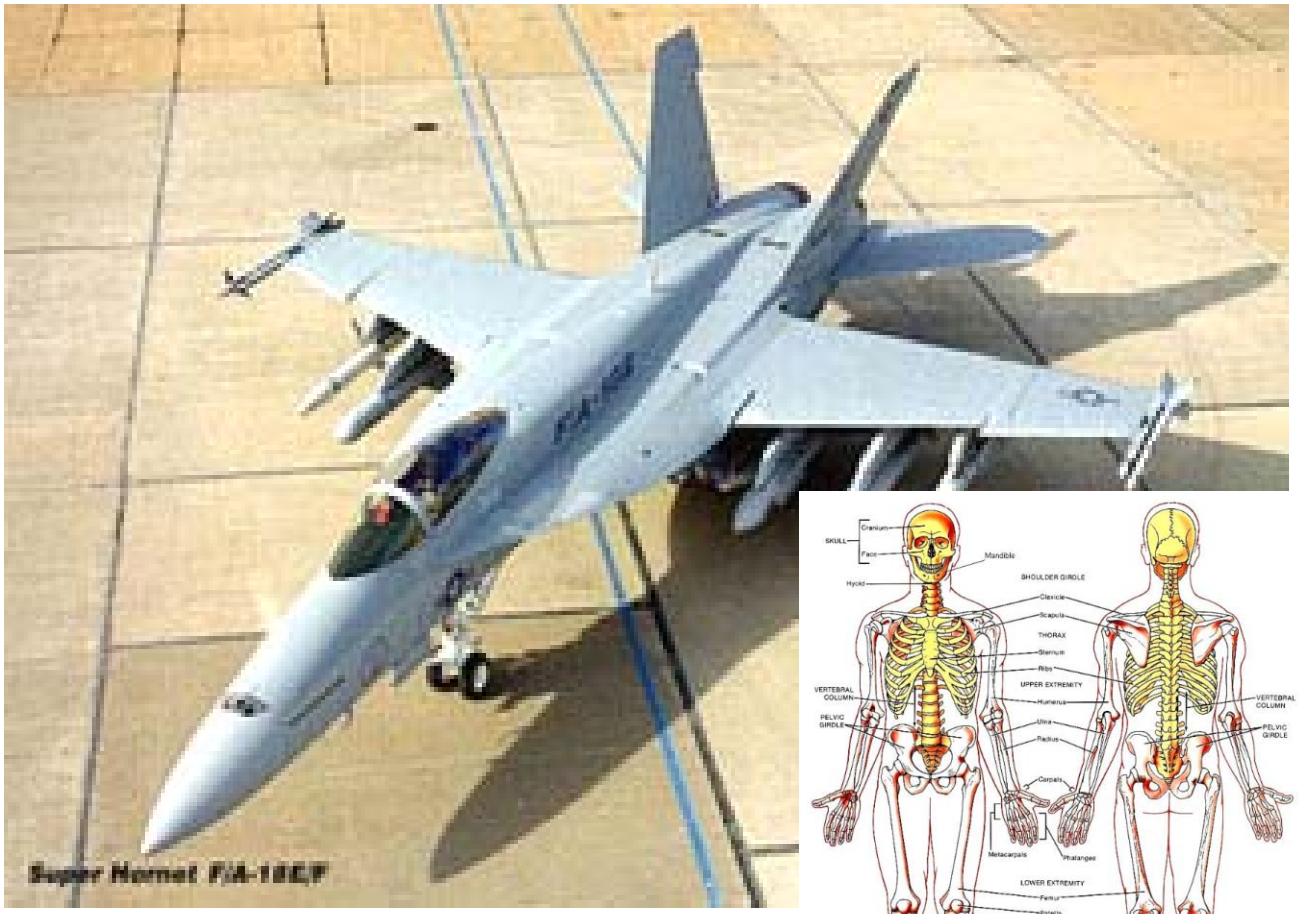


Health Management

- Health Management Systems are programs that respond in a preemptive and opportunistic manner to the anticipation of failures.
- Conducting failure analysis BEFORE the failure occurs

Prognostics

Techniques utilized to determine the remaining useful life with a defined level of confidence for a specified coverage of anticipated events



PHM Objectives

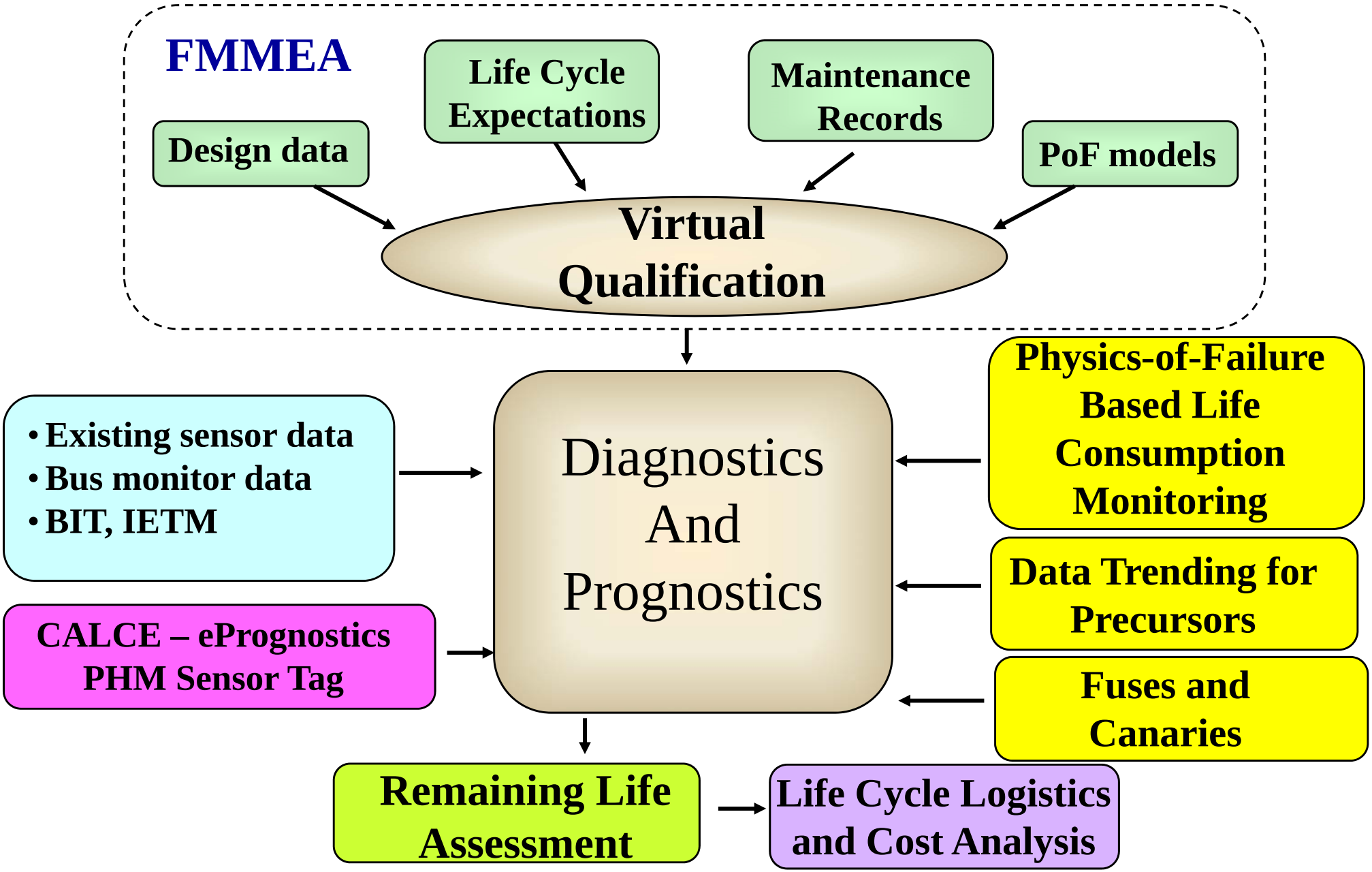
- Provide an early warning of failures
- Provide guidance to extend useful life
- Forecast maintenance as needed
- Provide efficient fault detection (CND)
- Aid in business and regulatory decisions
- Improve designs and qualification

2003: US Military Requires Prognostics to be Included in All New Weapon Systems

New Award
Reliability - Prognostics Prediction

- CALCE Prognostics for Electronics Program
- $23M over 5 years
- Purpose is to develop new methods for in-situ reliability prediction of electronics: from silicon to systems

CALCE Prognostics Methodology



Hybrid Methods

- Use FMMEA to set-up data-driven methods for early trend detection.
- Then use physics-of-failure models and environmental and operating history to predict remaining life

Prognostics of Computers

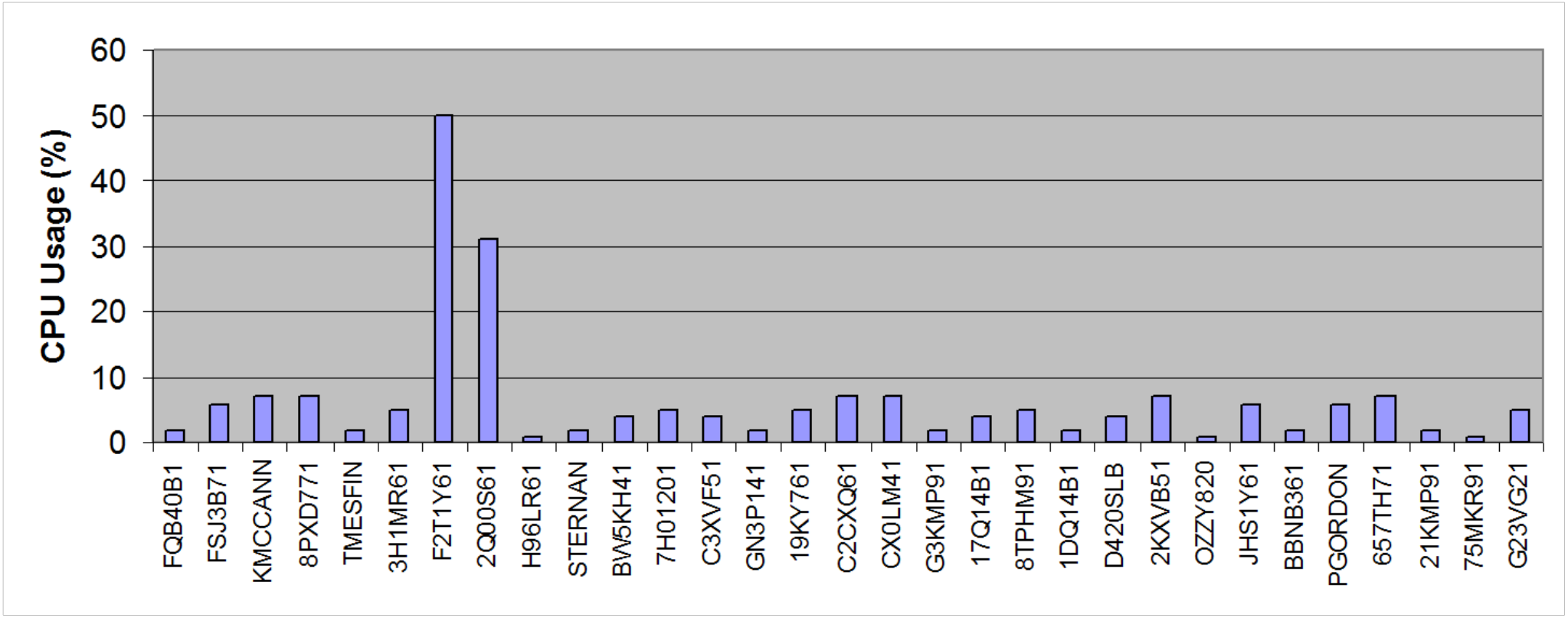
- Dell Profiler is a software tool which collects real-time environmental and usage data
- Profiler interacts with the computer's BIOS and other interfaces to retrieve system information.
- Runs in the background, without any user intervention, when operating system is running.

Categories of Parameters Monitored

- Performance parameters (Memory, CPU)
- Device information (e.g. IC, battery charge, fan speed, LCD brightness)
- Thermal (e.g. CPU, board, graphics), humidity, vibration, other load information
- Mechanical usage information (e.g. keystrokes, battery insertions)
- System hardware information

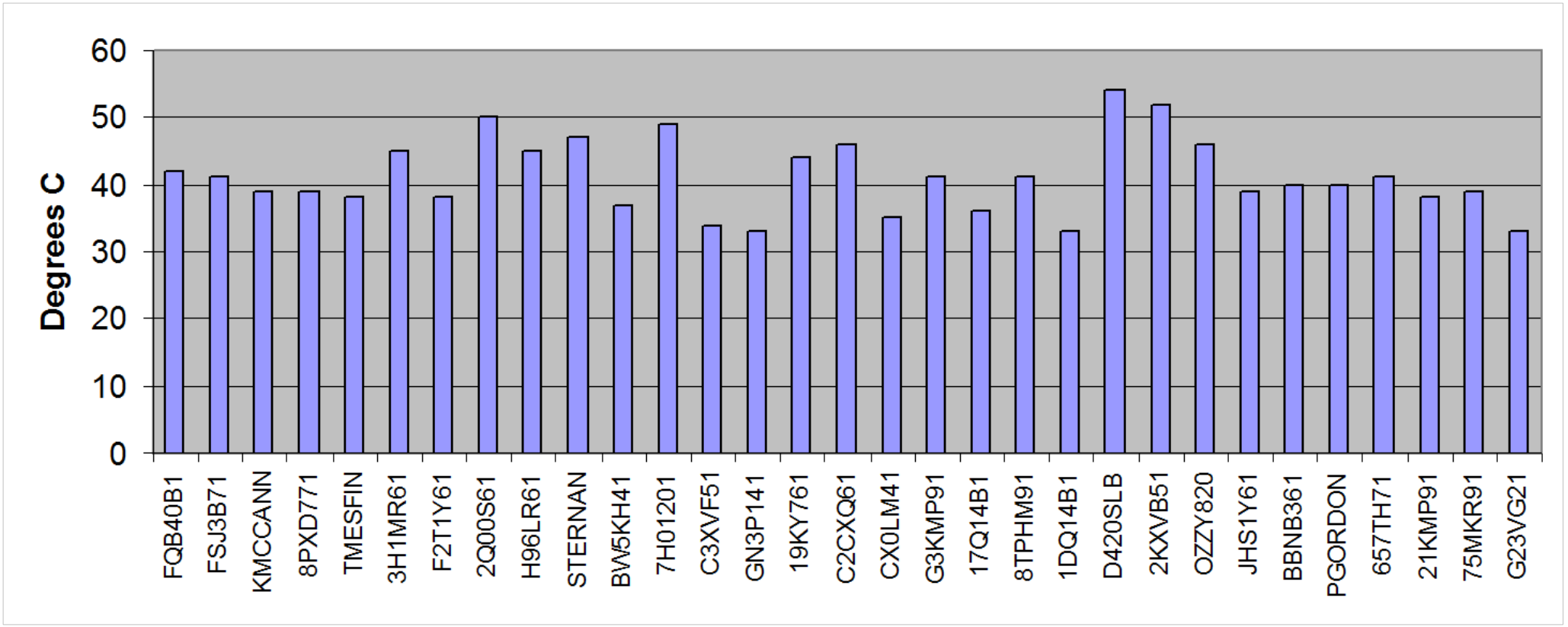
Results

Average CPU Usage



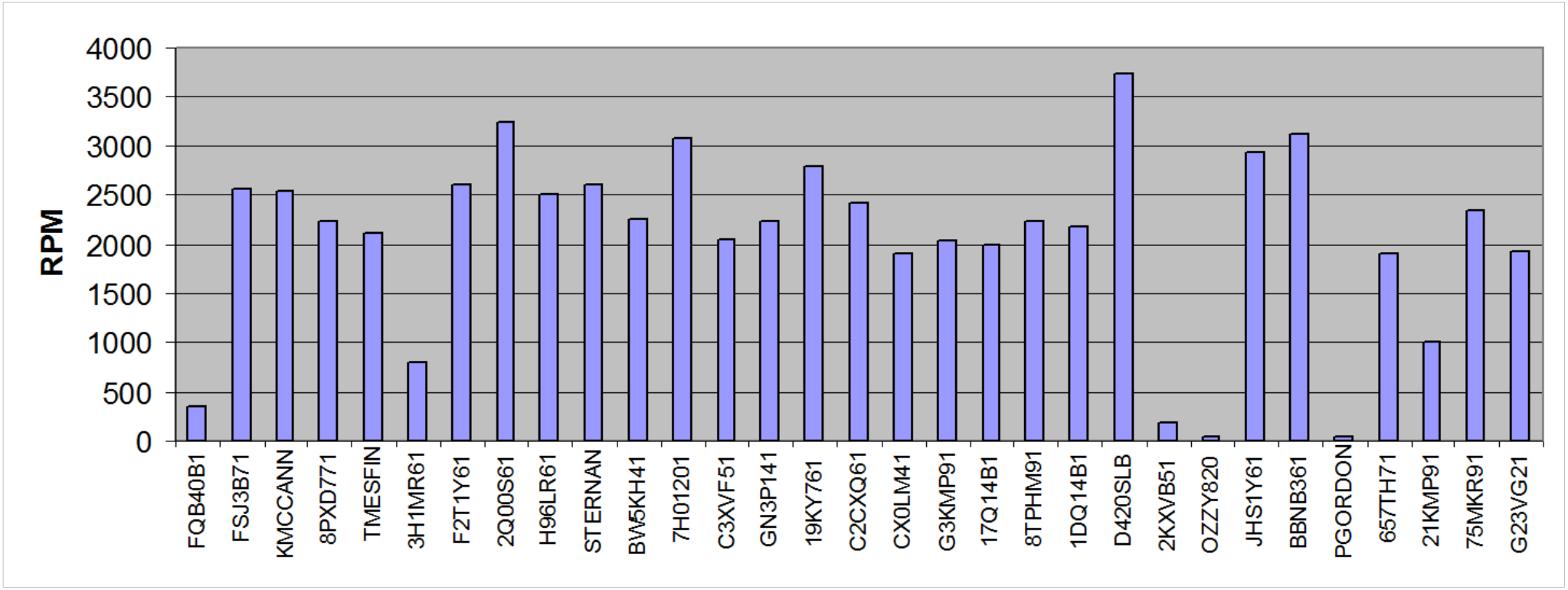
Results

Average Temperature of CPU Die



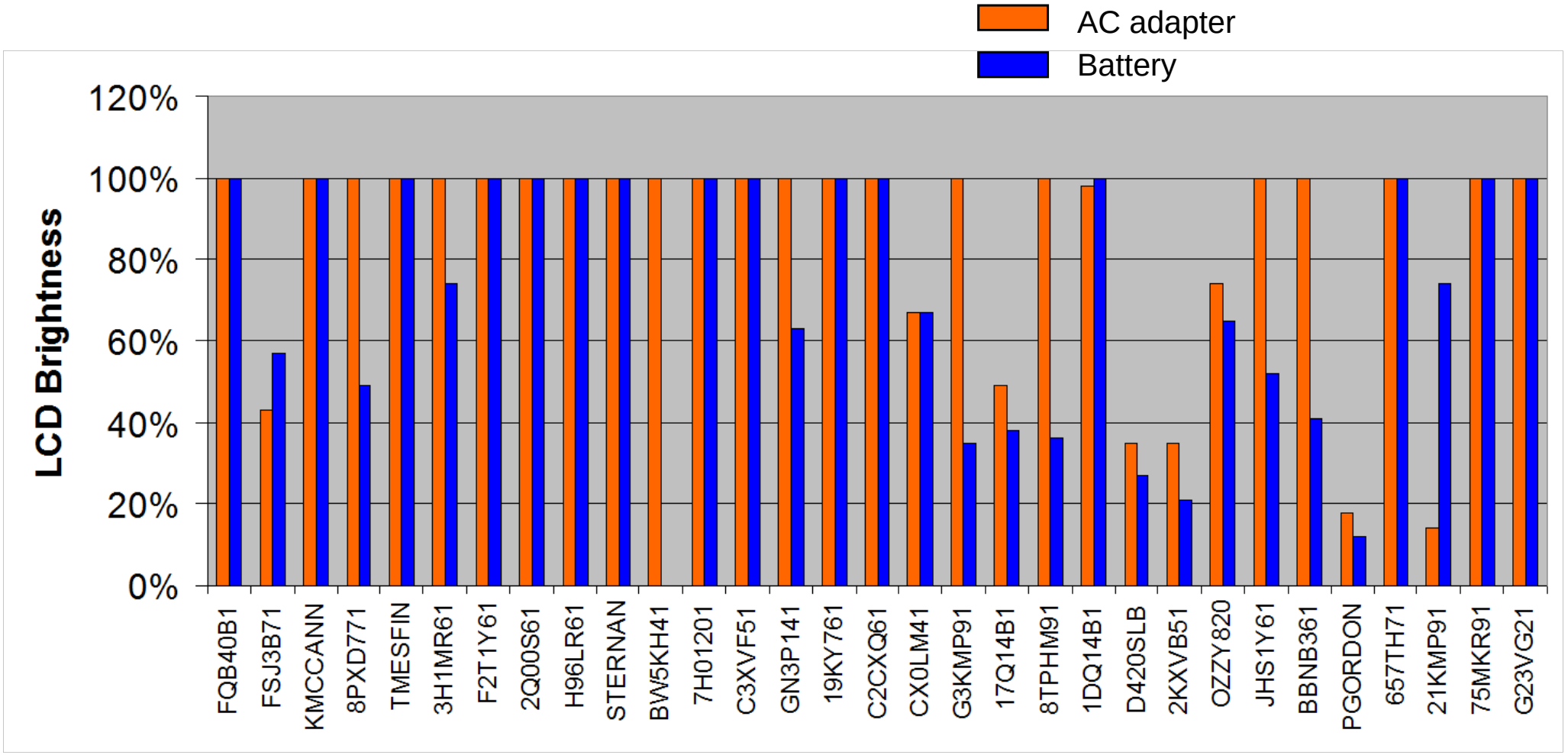
Results

Average Fan Speed



Results

Average LCD Brightness



Data-Driven Front-End

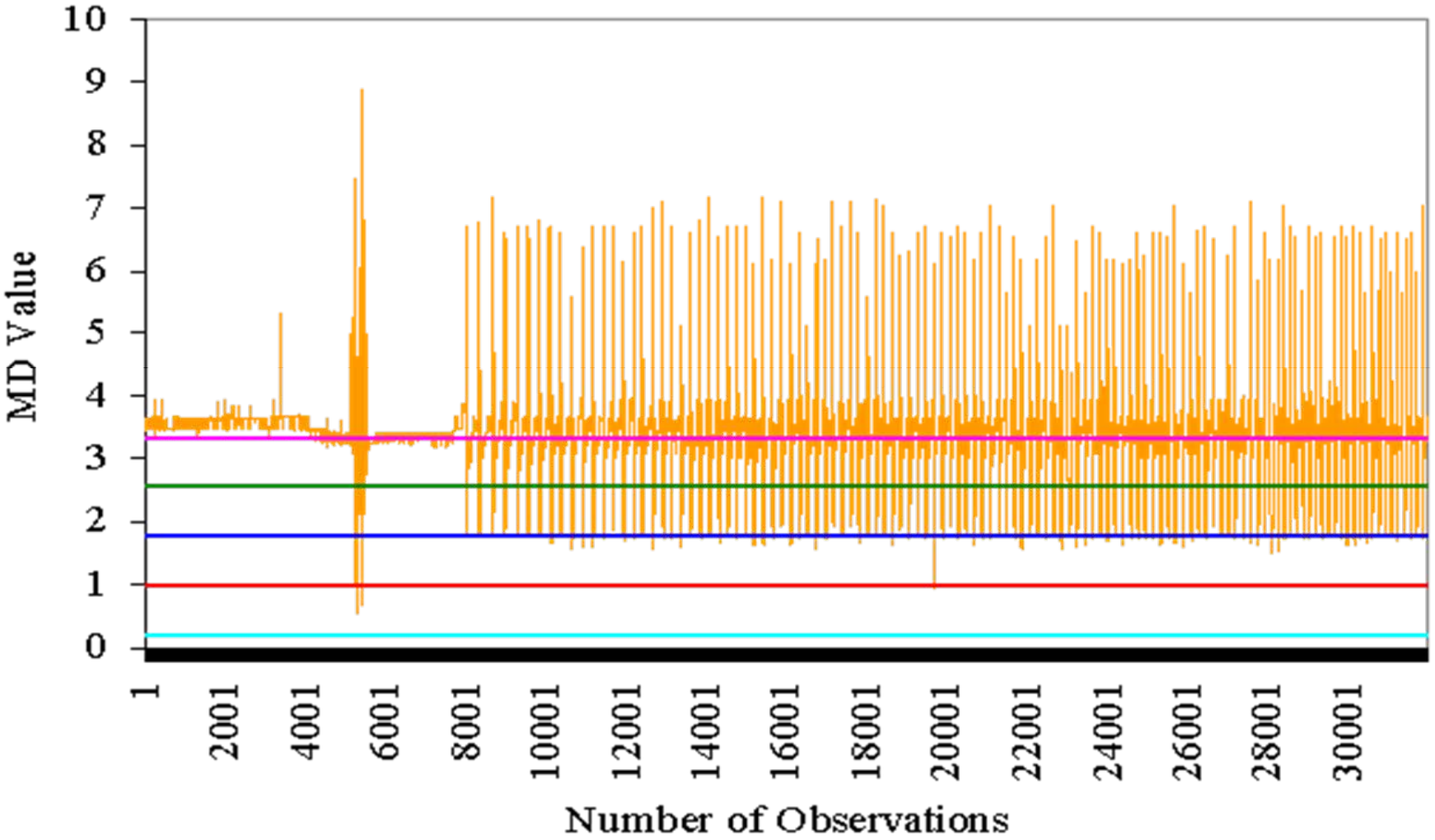
- Use Mahalanbois and Principle Component Analysis (PCA) to transform data to lower dimensional data set for rapid “anomaly” detection

- Analysis of the squared prediction errors (SPE) of features on the residual space provides key parameters, helps identify the operational failure mechanism

Mahalanobis Distance (MD) Parameter Anomaly Detection and Trending

$$MD = \frac{1}{p} Z_i C^{-1} Z_i^T$$

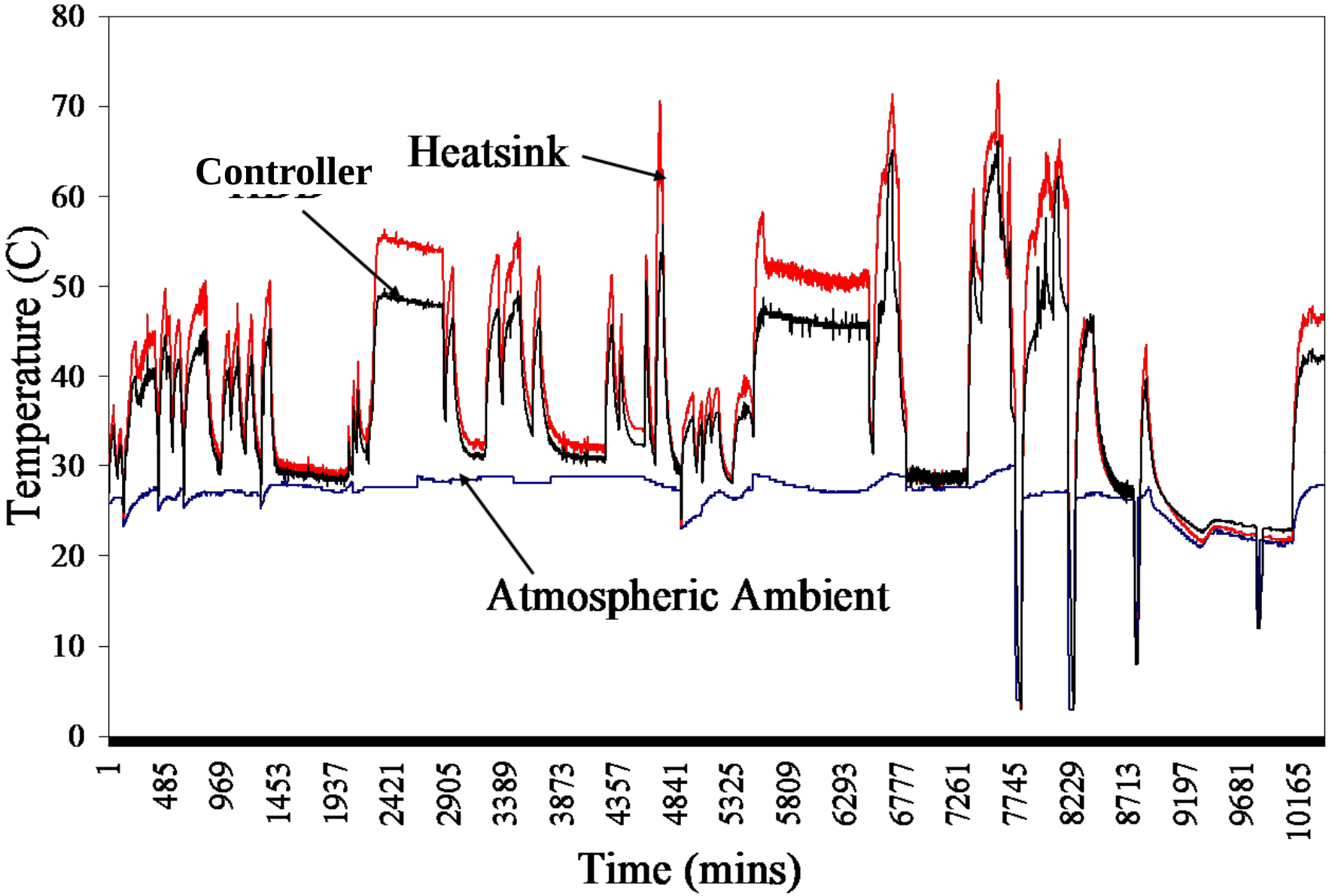
PHM Analysis



PCA Identifies Temperature as Key Parameter, But What is the Form

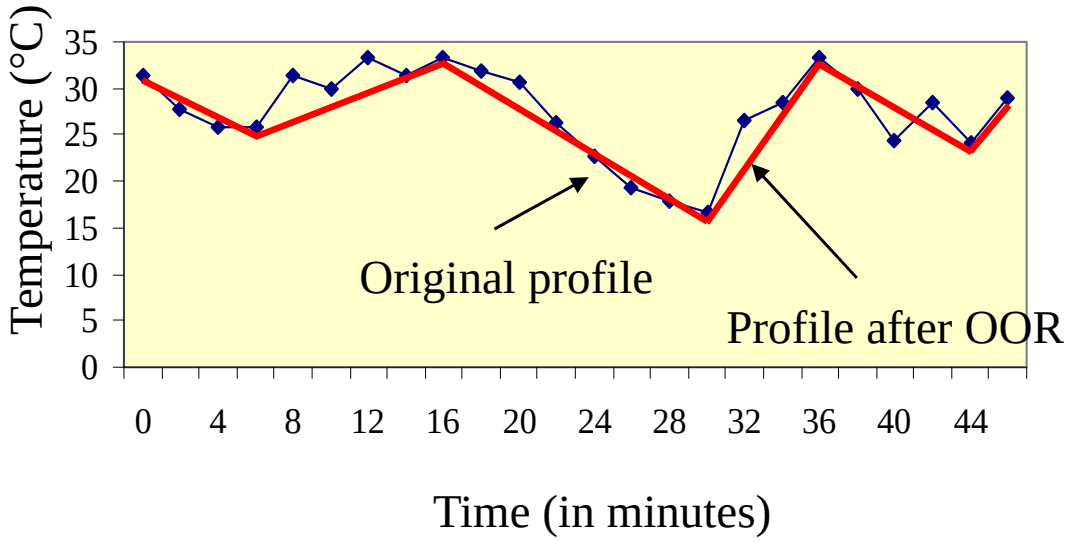
- Steady state temperatures
- Cyclic temperature ranges, means and dwell
- Temperature ramp-up and ramp-down rates
- Temperature gradients
- Power cycles

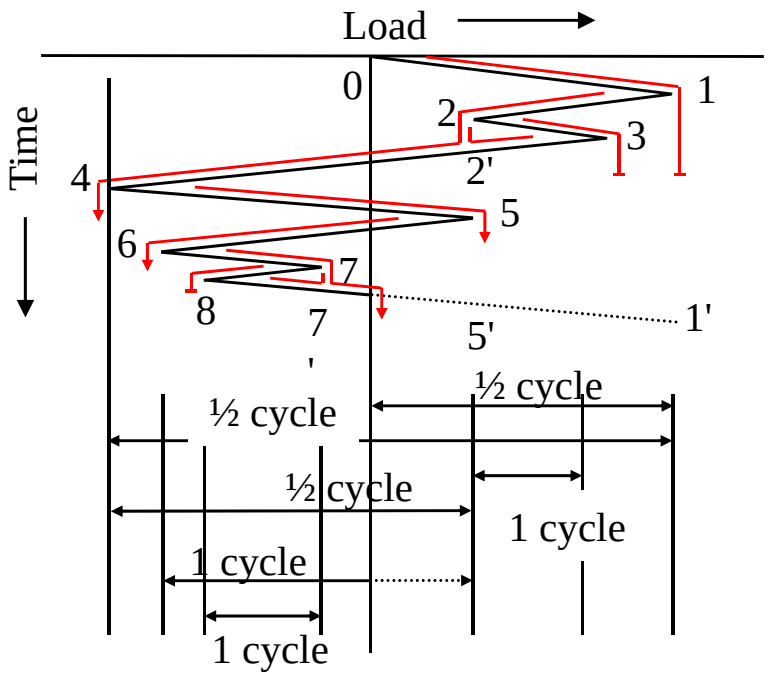
Example of Measured Temperature Data



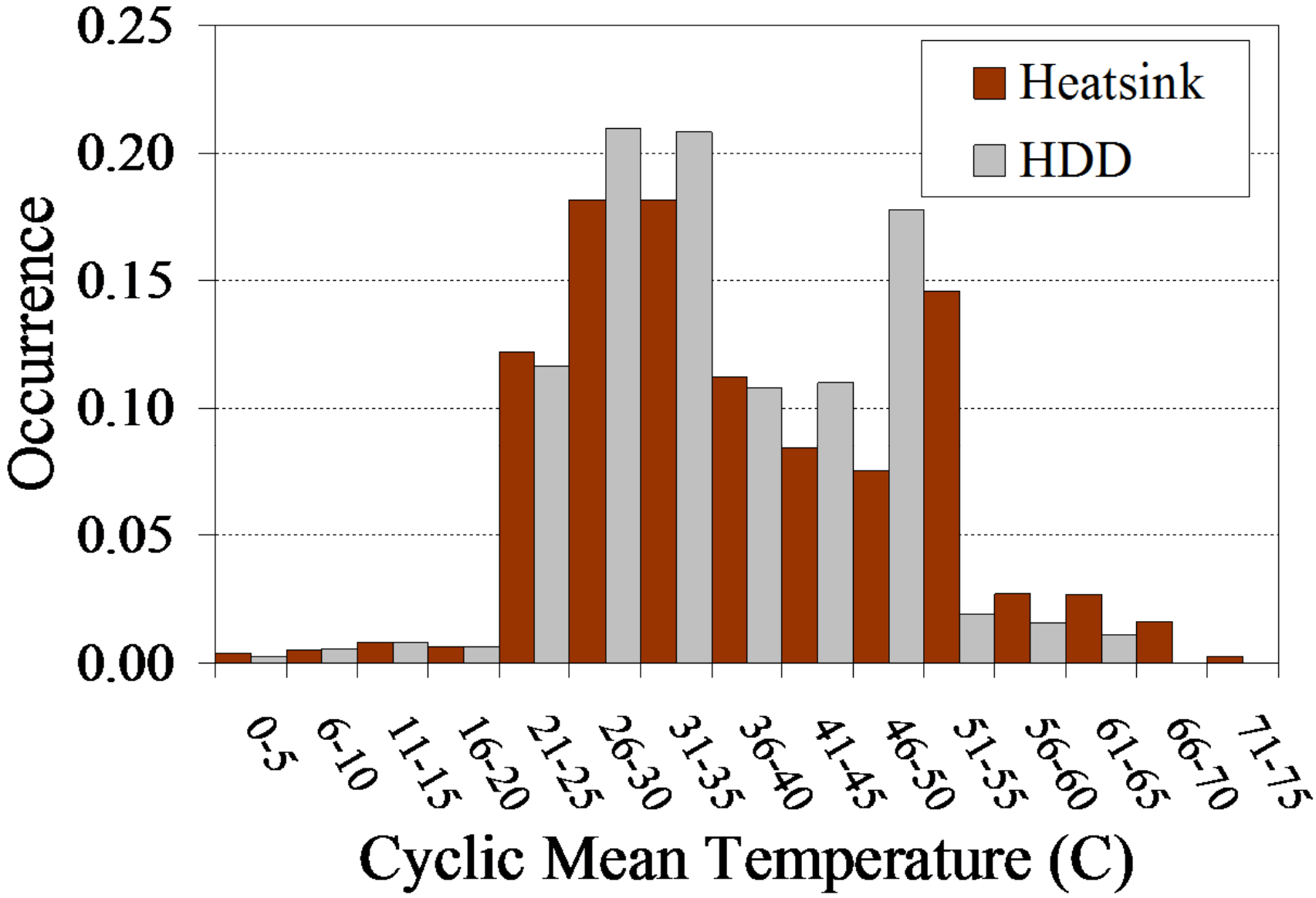
Algorithms Used for Data Processing

- The irregular time-temperature data is first converted into sequence of peaks and valleys using the Ordered Overall Range (OOR) method.
- A 3-parameter rainflow method is used to transform the time history into an equivalent cyclic history that counts the cyclic mean, ramp-up time, and the cyclic range.

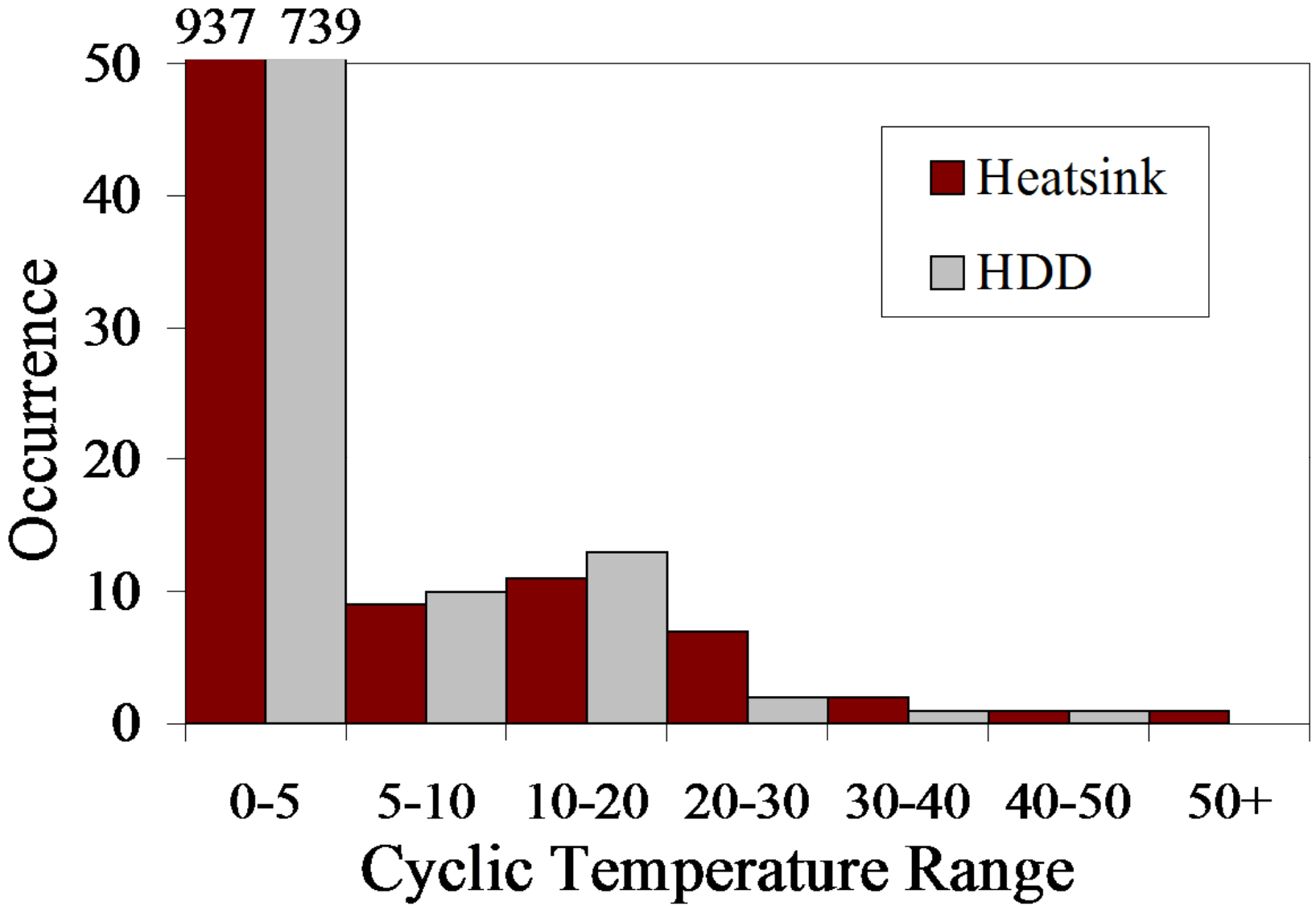




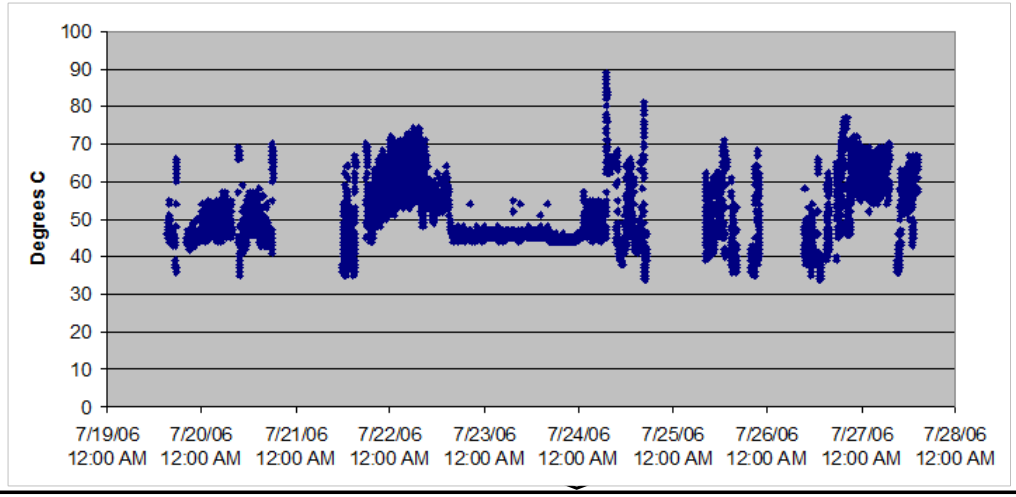
Distribution of Temperature



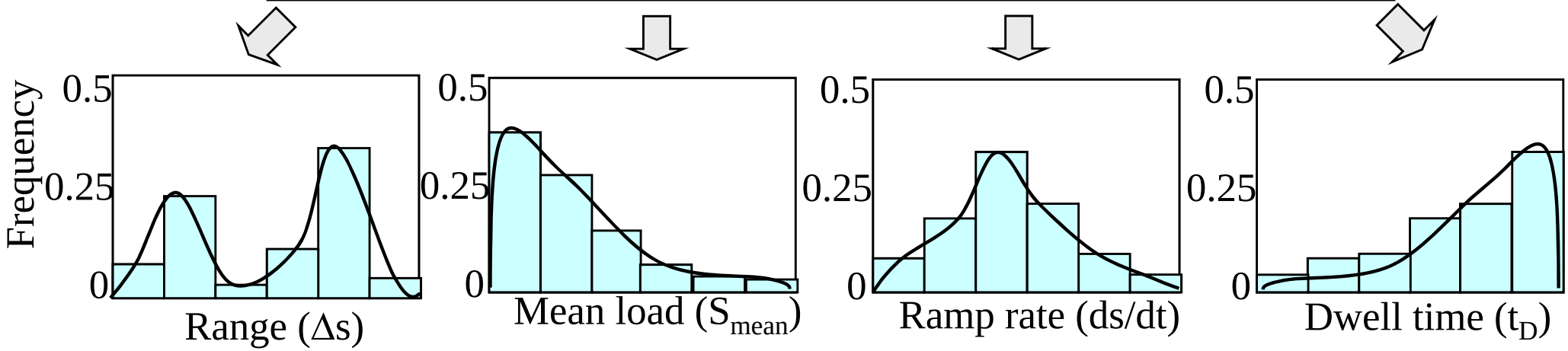
Distribution of Temperature Cycles



Remaining Life Assessment



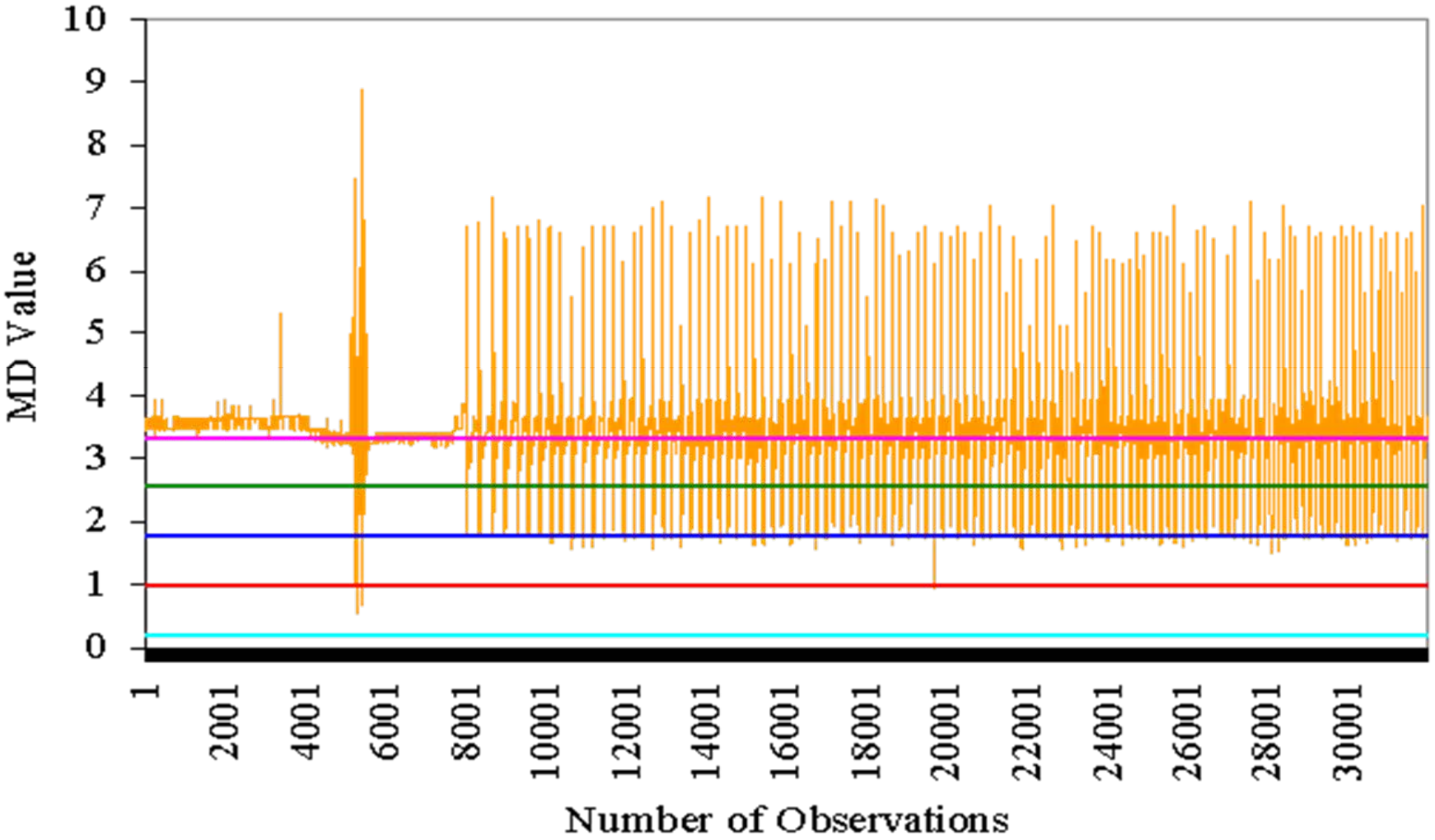
Embedded Data Reduction and Load Parameter Extraction



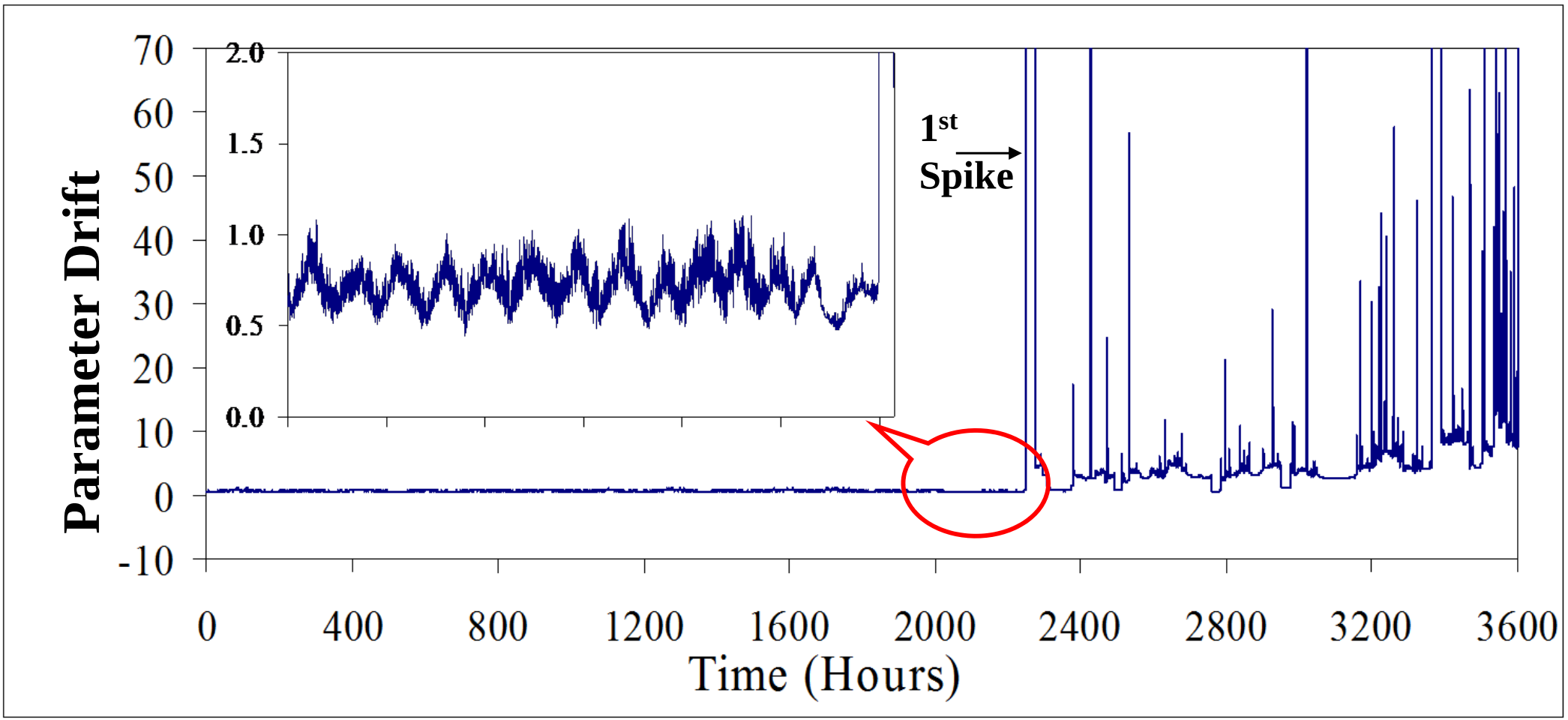
$$\text{Damage, } \Delta w = f(\Delta s, S_{mean}, \frac{ds}{dt}, t_D, ...)$$

$$\text{Remaining life} = f(\Sigma\, \Delta w)$$

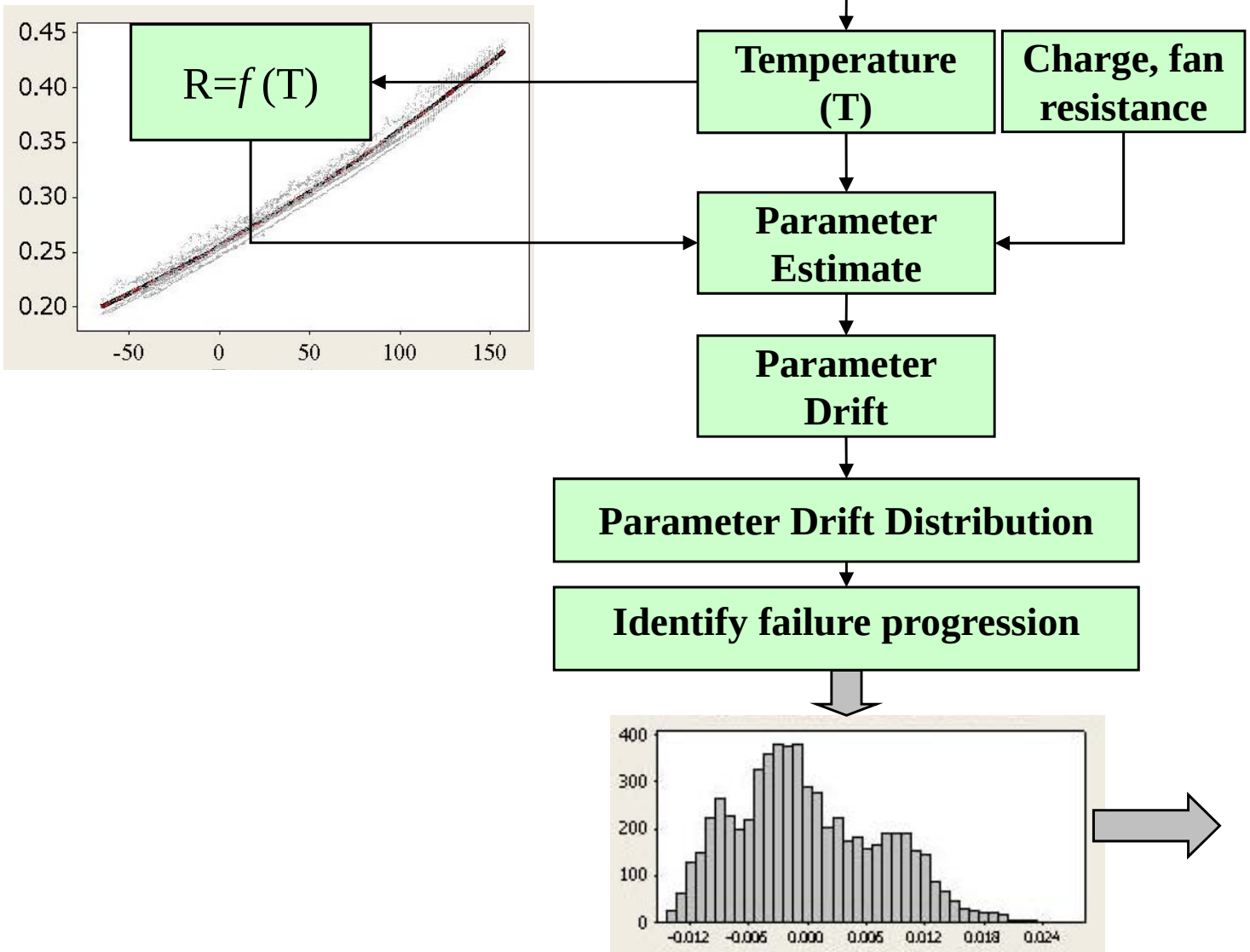
PHM Analysis



Prognostic Approaches



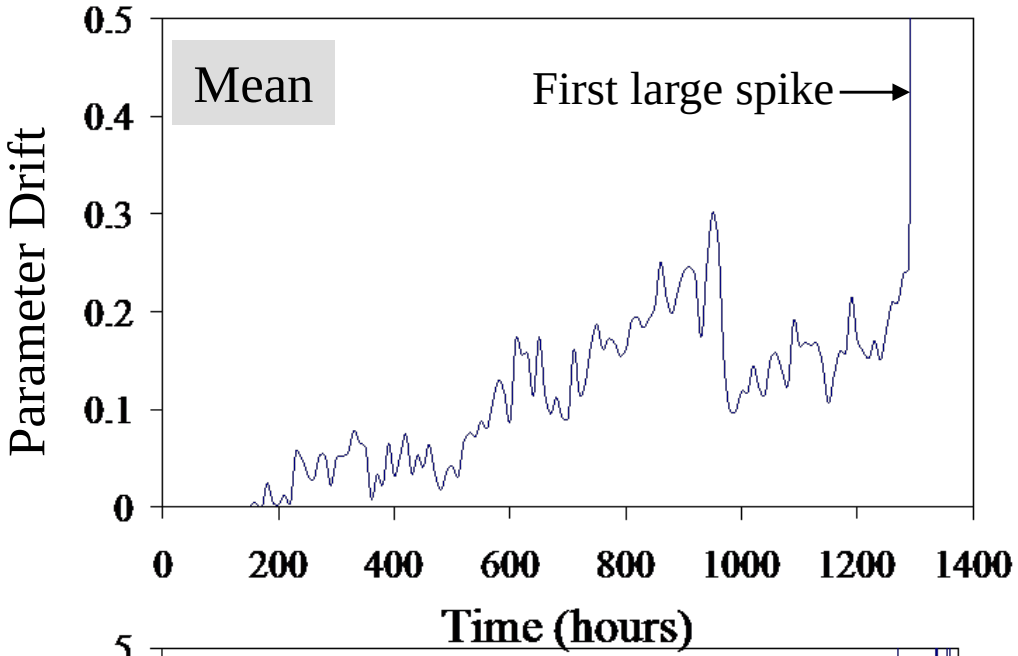
PHM Data Analysis

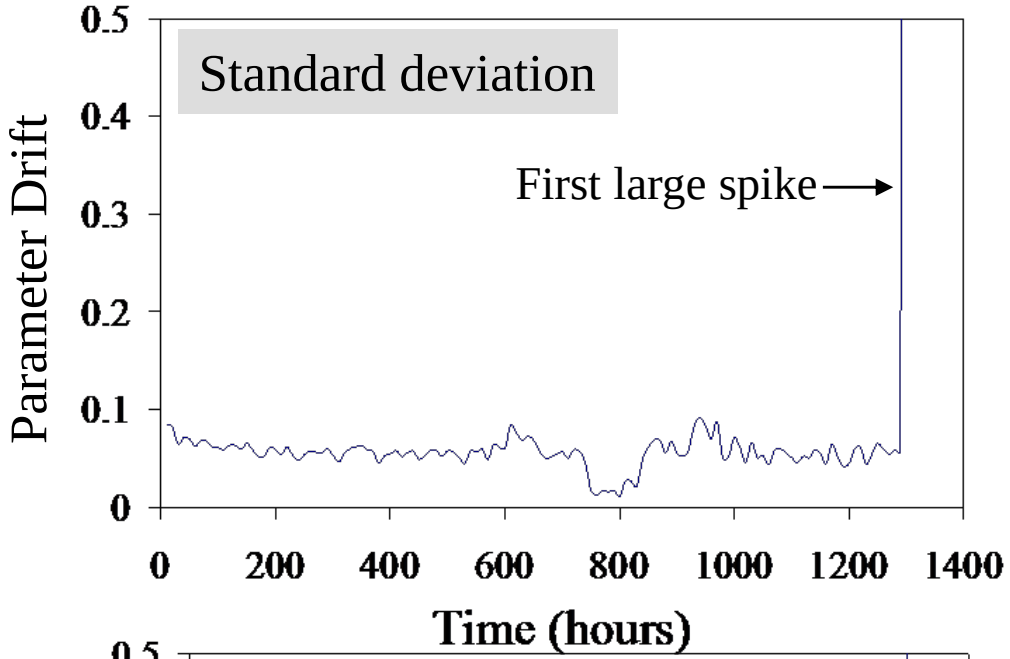


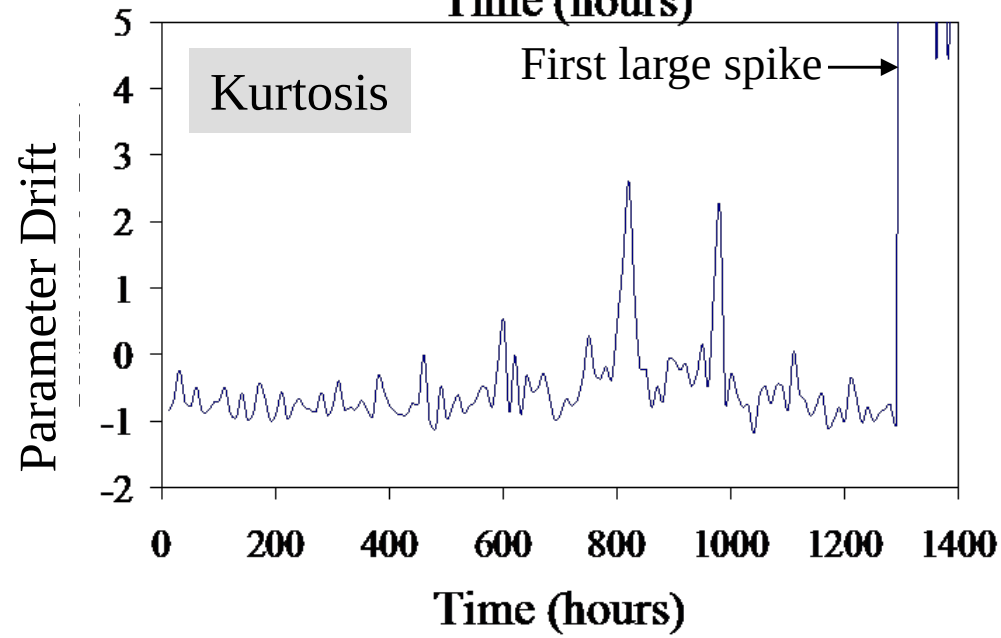
Features Investigated

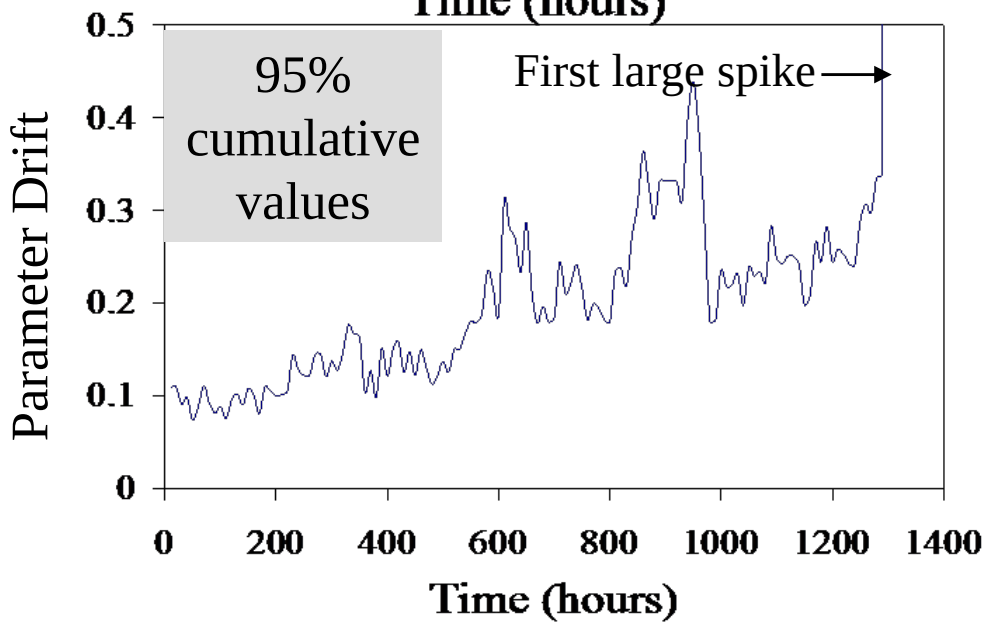
- Charge, fan, temp drift
- Mean drift values
- Mean peaks
- Standard deviation
- 95% cumulative distribution values
- 95% cumulative peaks
- Skewness
- Skewness peaks
- Kurtosis
- Kurtosis peaks

Trending Features

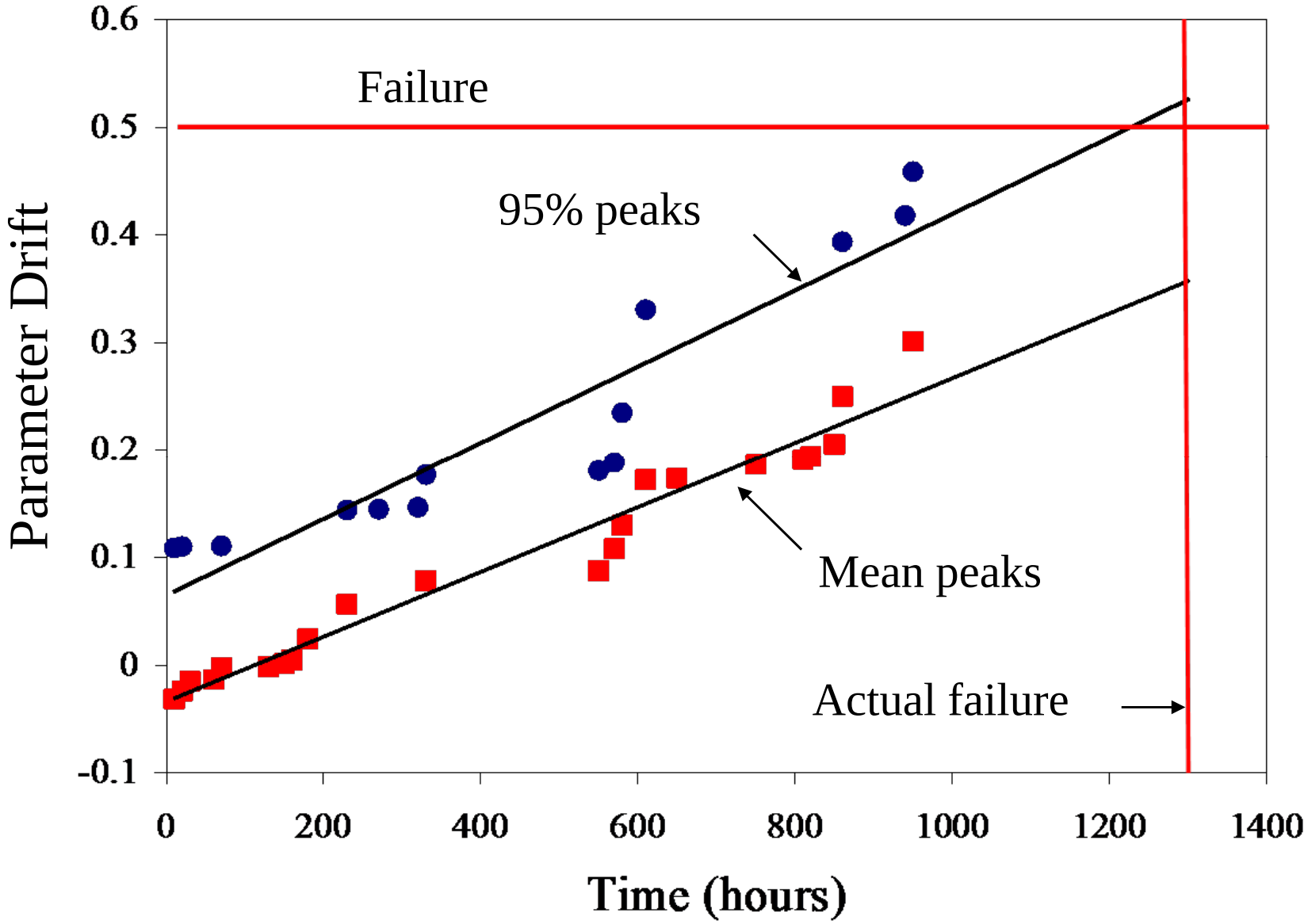








Qualification Life Prediction



Summary

- The use of handbook methods such as Mil-Hdbk-217, 217-Plus, FIDES are inaccurate, misleading and not useful
- Hybrid approaches using data driven and physics-of-failure techniques are effective in prognostics
- Prognostics will be embedded in most critical electronics within the next 10 years