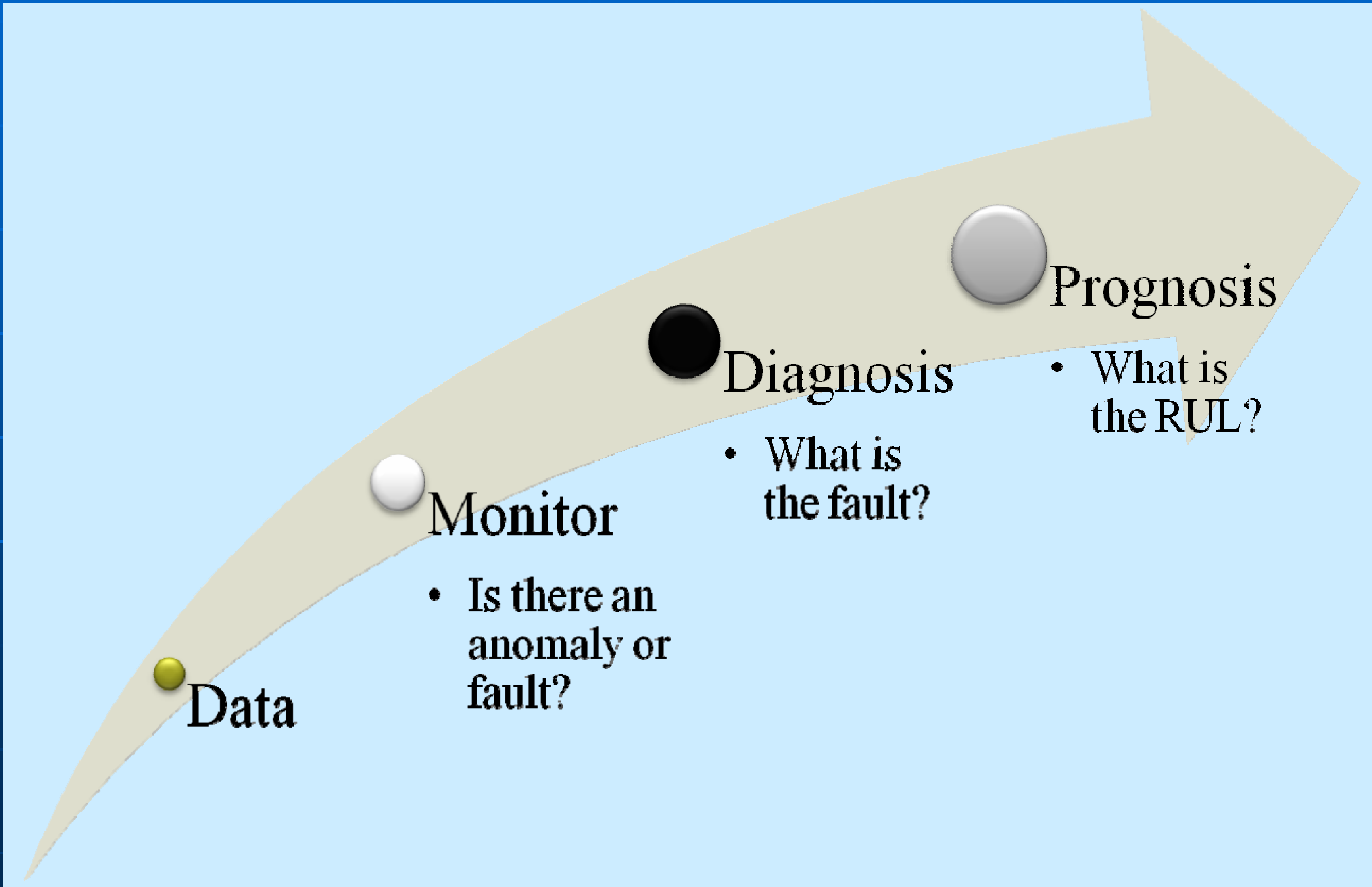
Understanding Empirical Prognostic Requirements, Planning for the Future

Dr. J. Wesley Hines
Director, Reliability and Maintainability Engineering Program
Professor, Nuclear Engineering Department
The University of Tennessee
jhines2@utk.edu

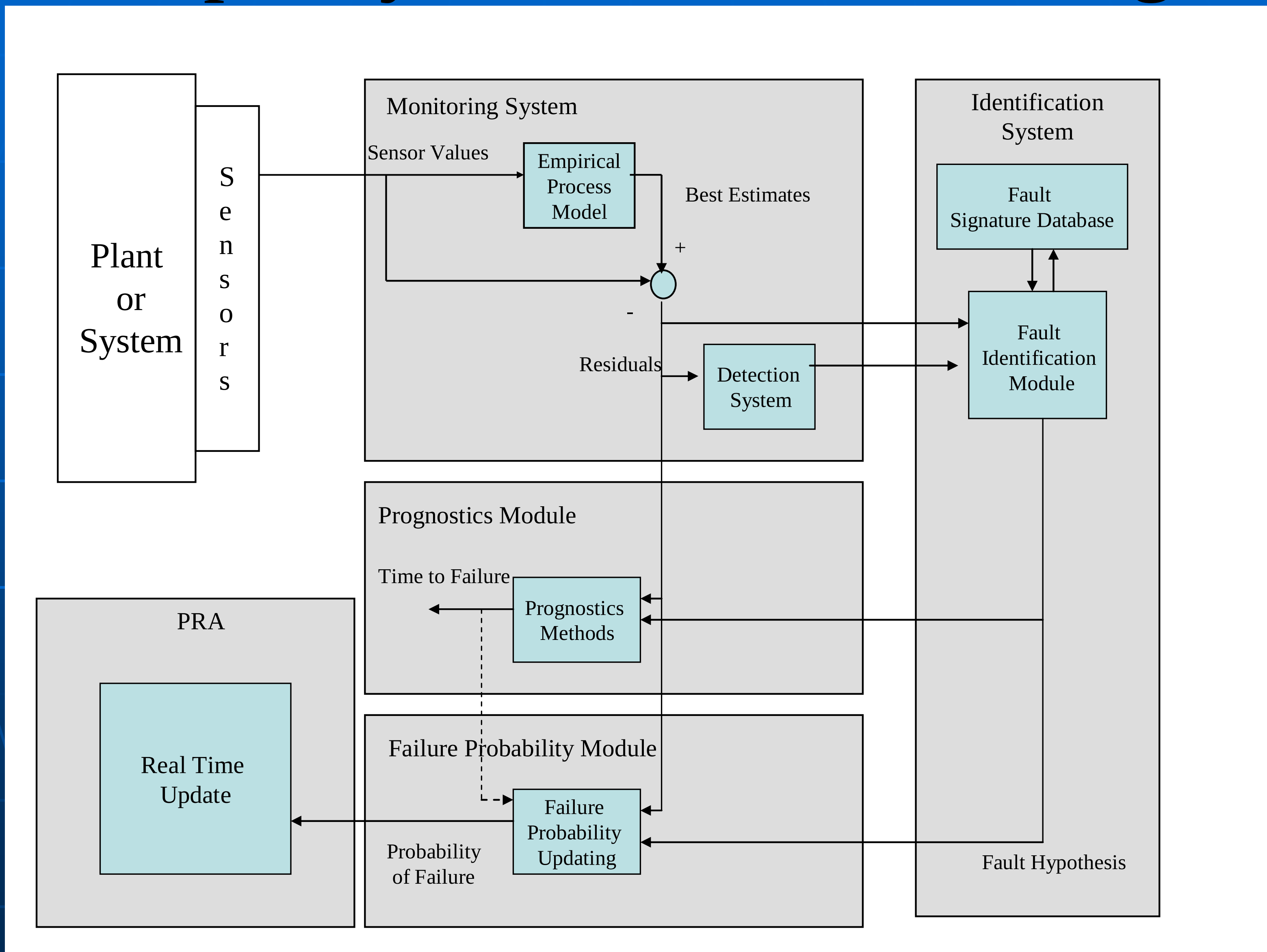
Overview

- Introduction to Equipment Prognostics
- Presentation of Prognostic Methods
- Future Steps for Improved Reliability

Typical Equipment Surveillance System

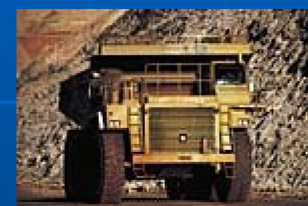


Example System Interaction Diagram



Industrial Application Areas

- Process:
  - Power Generation: nuclear, coal, gas, etc.
  - Chemical
- Aviation
- Rail
- Computing
- Heavy Machinery
- Drilling



Prognostic Term Definitions

- Methods used to predict:
  - **Remaining Useful Life (RUL):** the amount of time, in terms of operating hours, cycles, or other measures the component will continue to meets its design specification.
  - **Time to Failure (TTF):** the time a component is expected to fail (no longer meet its design specifications).
  - **Probability of Failure (POF):** the failure probability distribution of the component.
- Types
  - Physics-based
  - Empirical

Prognostics Motivation

- Improved prognostic and predictive capabilities using existing monitoring systems, data, and information will enable more accurate equipment risk assessment for improved decision-making.
  - Reduce needless maintenance through lengthened (optimized) maintenance intervals.
  - Reduce unplanned maintenance and associated costs.
  - Improve safety and reduce environmental impacts.
- Operational Decisions:
  - Should we continue to operate or immediately shutdown for maintenance?
  - Can we change operations (speed, load, stress) to make it to the next maintenance opportunity?
  - Will the equipment have high probability of safe operation for the planned mission?

Prognostics Data Hurdle

- In many fields failure data may be difficult to obtain.

WHY?

1. When components are found to be degraded they are repaired or replaced.
   - Unexpected vibration levels of a nuclear power plant reactor coolant pump will prompt an immediate response.

2. When important failure modes are discovered, they are designed out of the system.
   - When several failures of a truck's steering system are discovered, a redesign and recall may be initiated.

Basic Prognostics Methodology

1. Collect historical failure data and related information.
2. Perform a Failure Modes Effects and Criticality Assessment (FMECA) of the system of interest.
   - A FMECA++ also identifies sensor information that changes with degradation.
3. Perform Accelerated Life Testing if Necessary
   - Collect degradation data identified in FMECA++
4. Develop Prognostic Model
   - Many types are available.
5. Validate Prognostic Model
6. Implement Prognostic Model

Note: Each failure mode may require its own prognostics model.

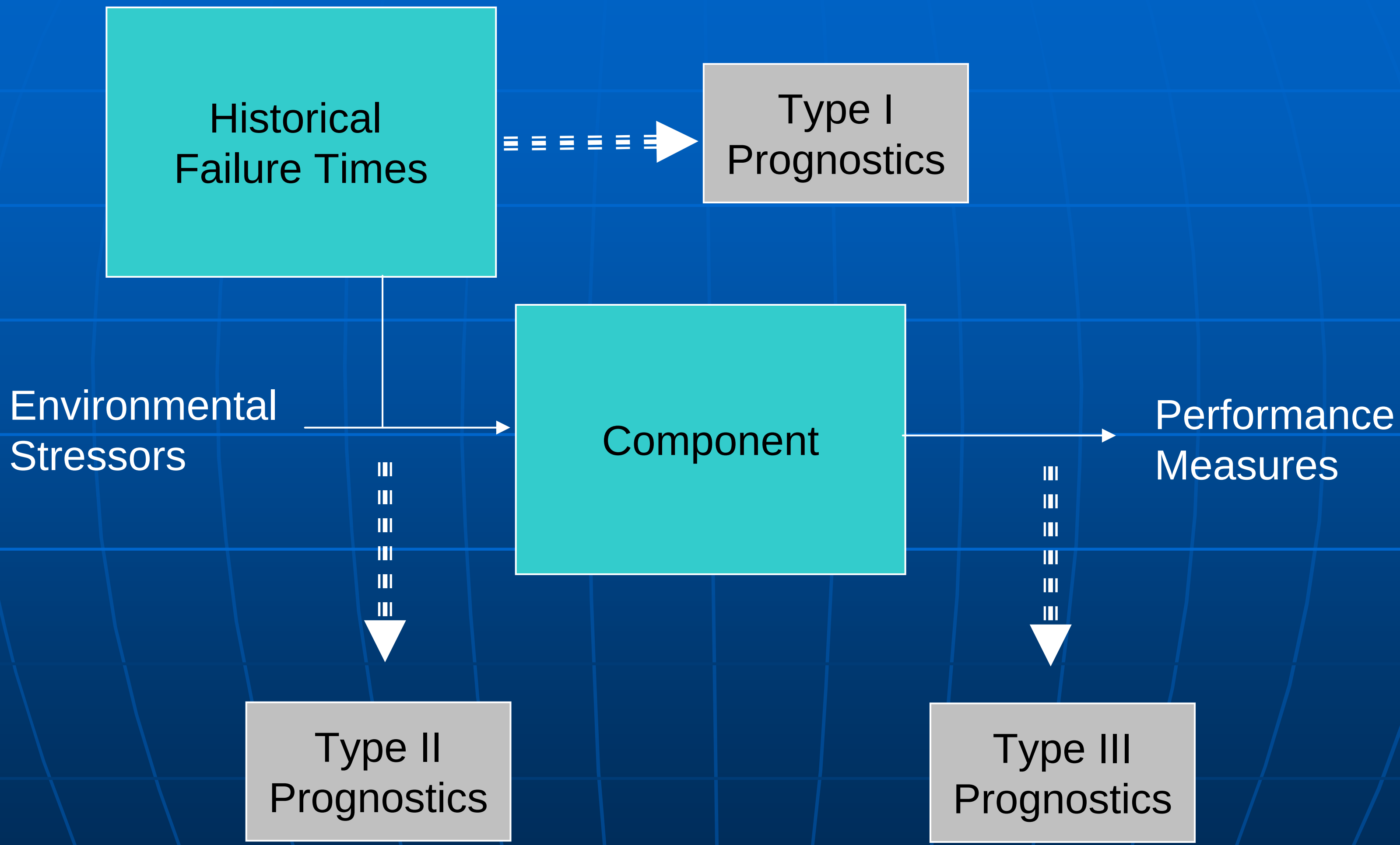
Prognostic Method Categories

- Type I: Reliability Data-based (population)
  - These methods consider historical time to failure data which are used to model the failure distribution. They estimate the life of an average component under average usage conditions.
  - Example Method: Weibull Analysis

- Type II: Stress-based (population)
  - These methods also consider the environmental stresses (temperature, load, vibration, etc.) on the component. They estimate the life of an average component under specific usage conditions.
  - Example Method: Proportional Hazards Model.

- Type III: Effects-based (individual)
  - These methods also consider the measured or inferred component degradation. They estimate the life of a specific component under specific usage and degradation conditions.
  - Example Method: Cumulative Damage Model

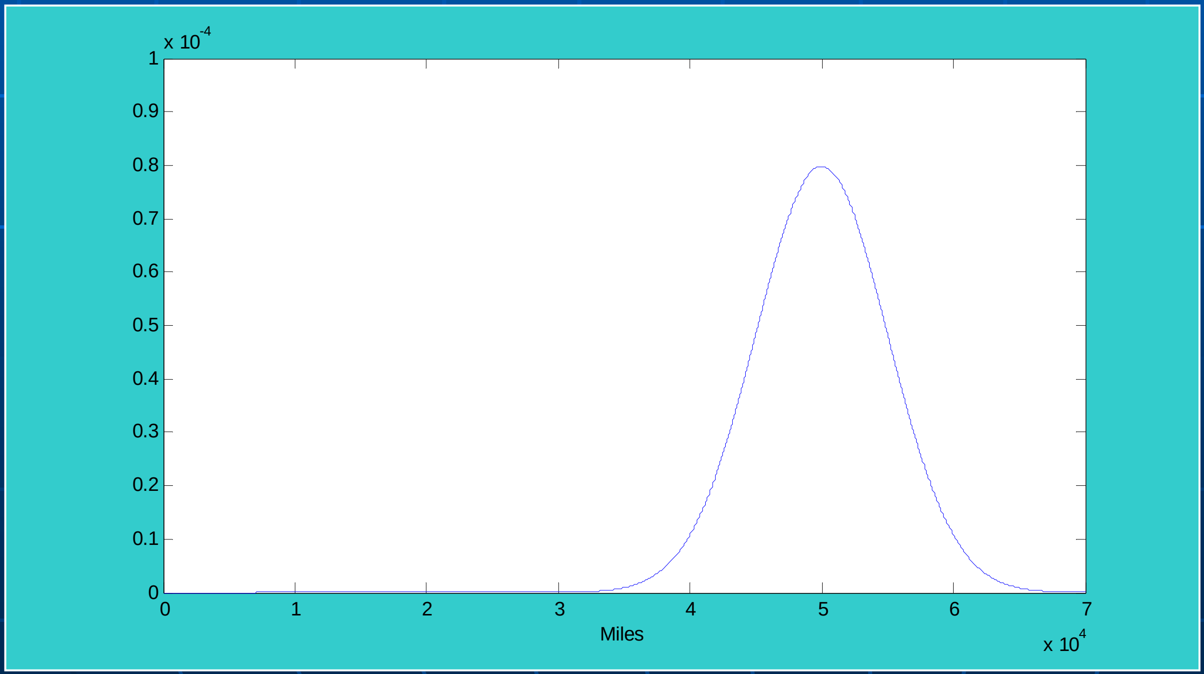
Prognostic Method Types



Tire Prognostics Example

- Type I: Tire failure distribution is normally distributed with a mean of 50,000 miles and standard deviation of 5,000 miles.

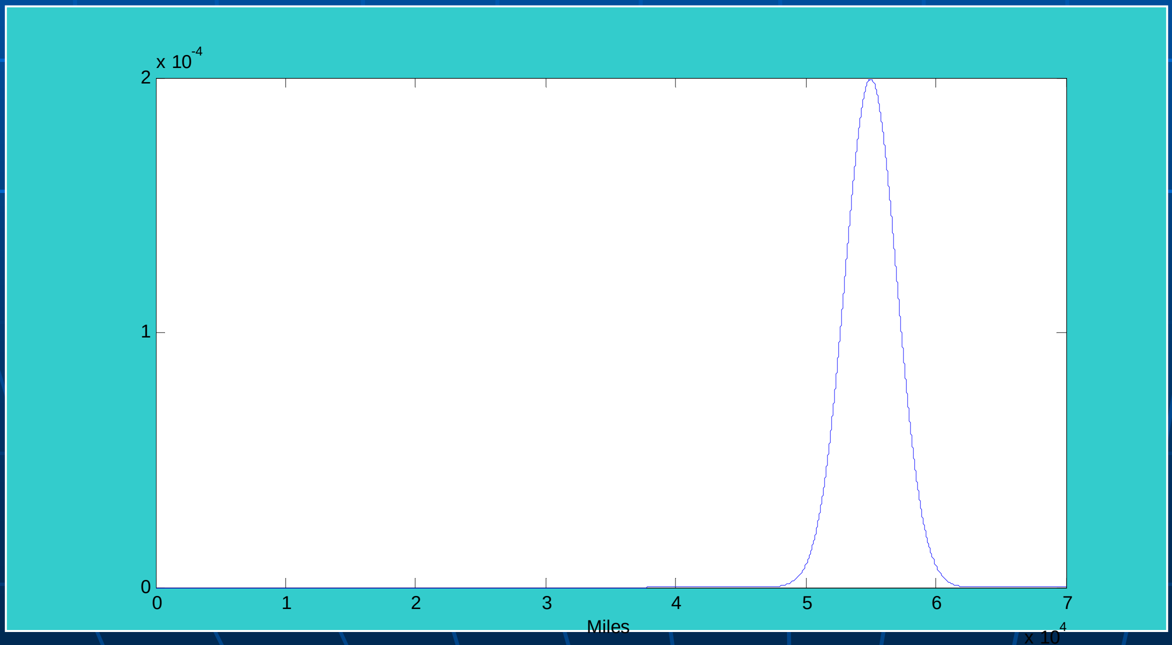
Density Function f(t)

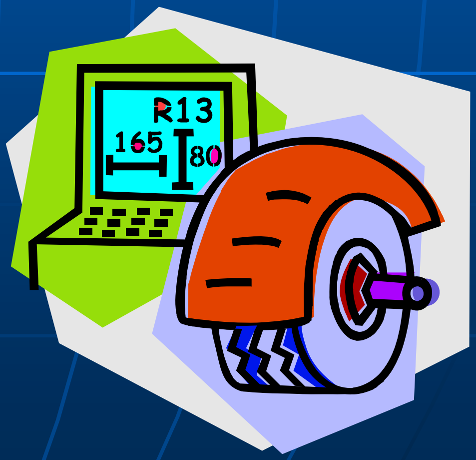


Tire Prognostics Example

- Type II: Tire failure is estimated by knowing the number of miles driven and the tire conditions for each mile driven: temperature, slippage, inflation, etc.
  - This results in a new distribution for an average tire under specific conditions.

Density Function f(t)

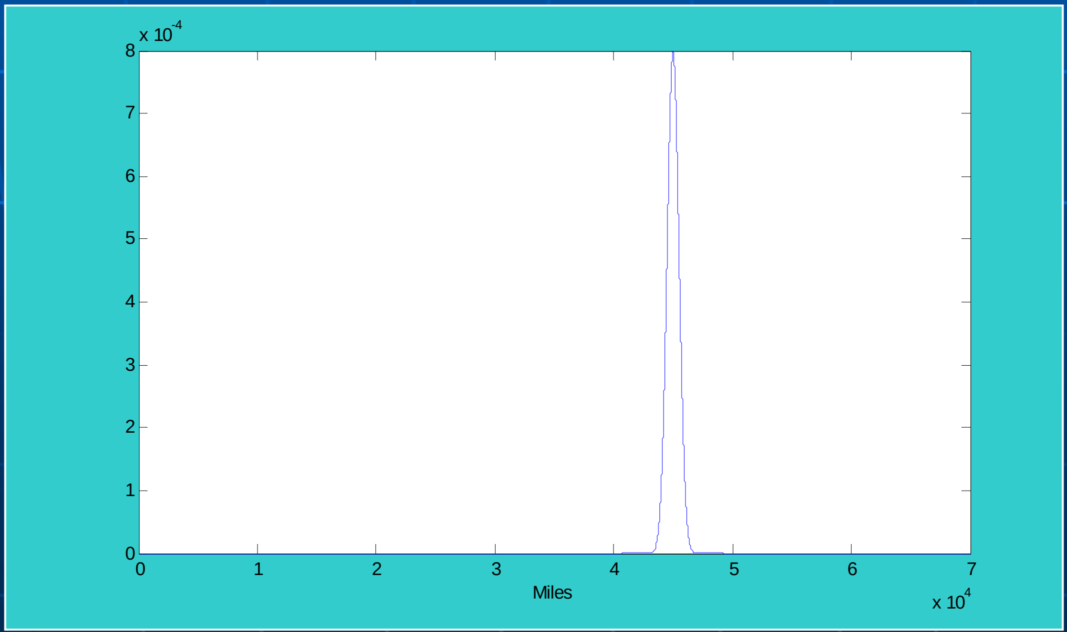




Tire Prognostics Example

- Type III: Tire failure is estimated by knowing the actual condition (tread depth, dry rot) of the tire.
  - This results in a new distribution for that particular tire.

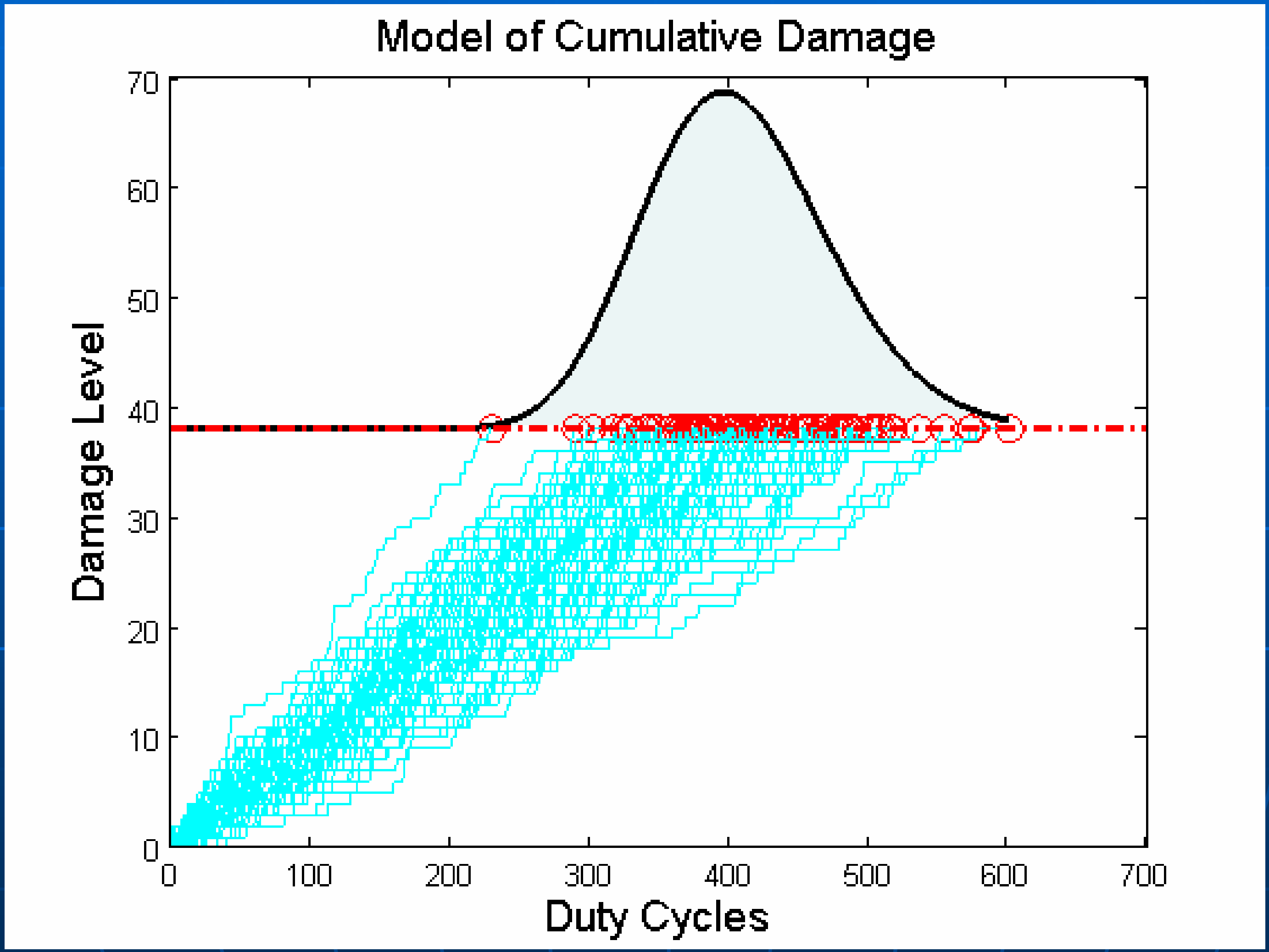
Density Function f(t)



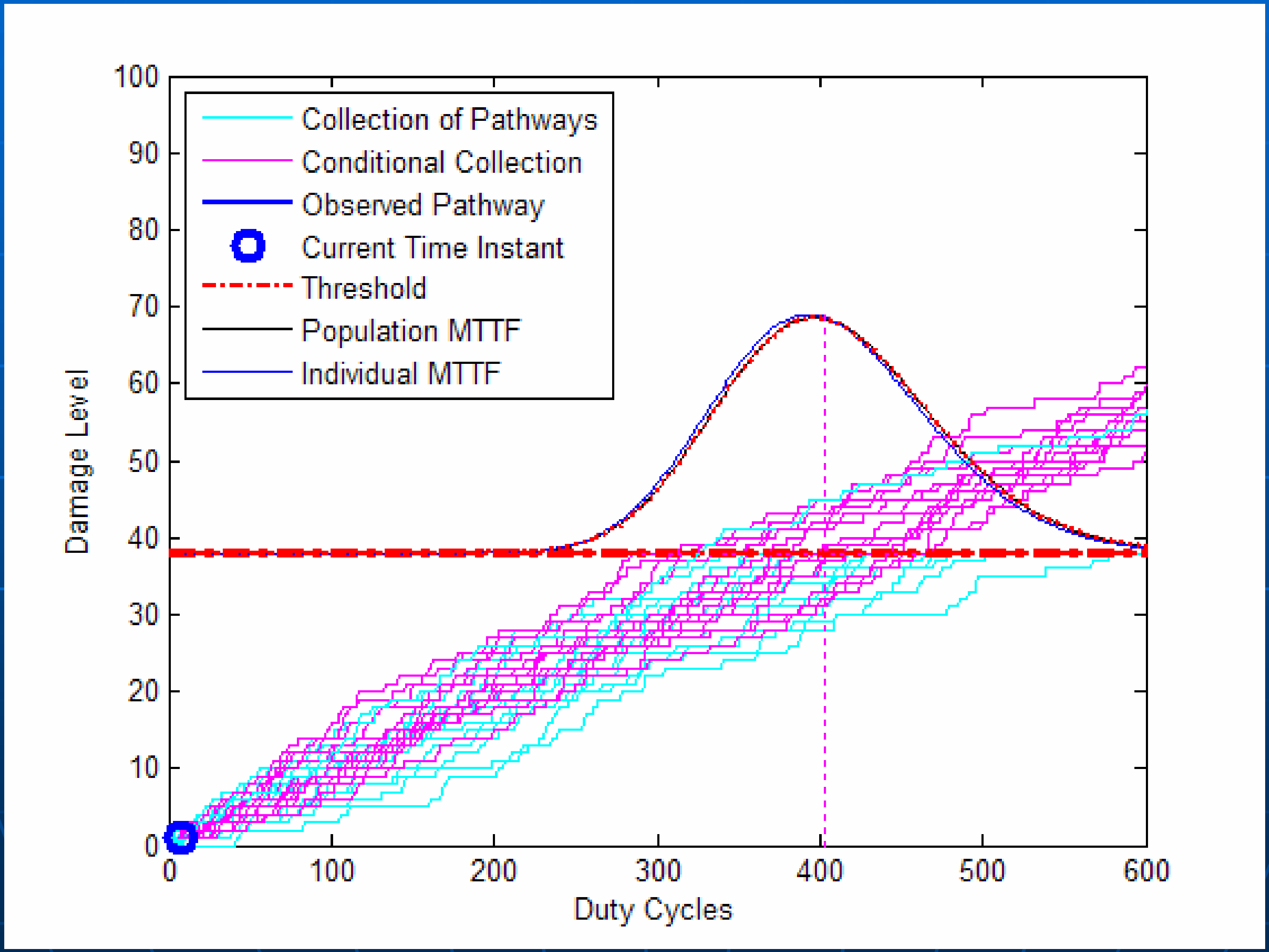
Some Basic Prognostic Data Requirements

- For Type I, failure modes must be related to usage time or number of operating cycles for historical data to be beneficial.
  - Failures cannot be random (characterized by an exponential failure model), we don't replace our tires for fear of hitting a nail.
- For Type II, environmental effects that drive the failure modes must be measurable.
  - Must measure temperature, load, cavitation, etc.
- For Type III, degradation severity must be related to a measurable degradation parameter such as tread depth, bearing vibration level, or impeller thickness.
  - Degradation growth must be slow enough for decisions to be made and actions to be taken.

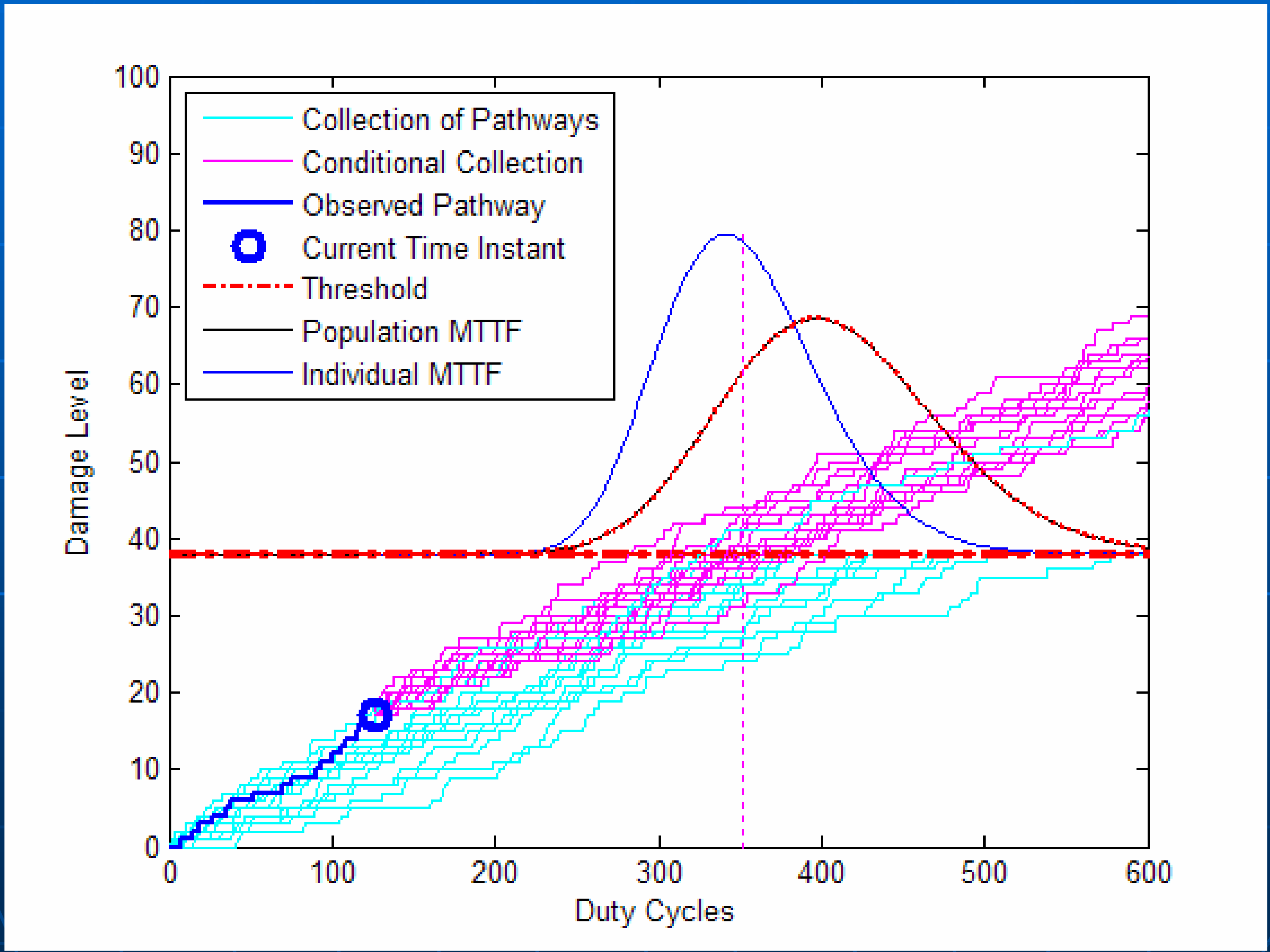
Stochastic Cumulative Damage Model



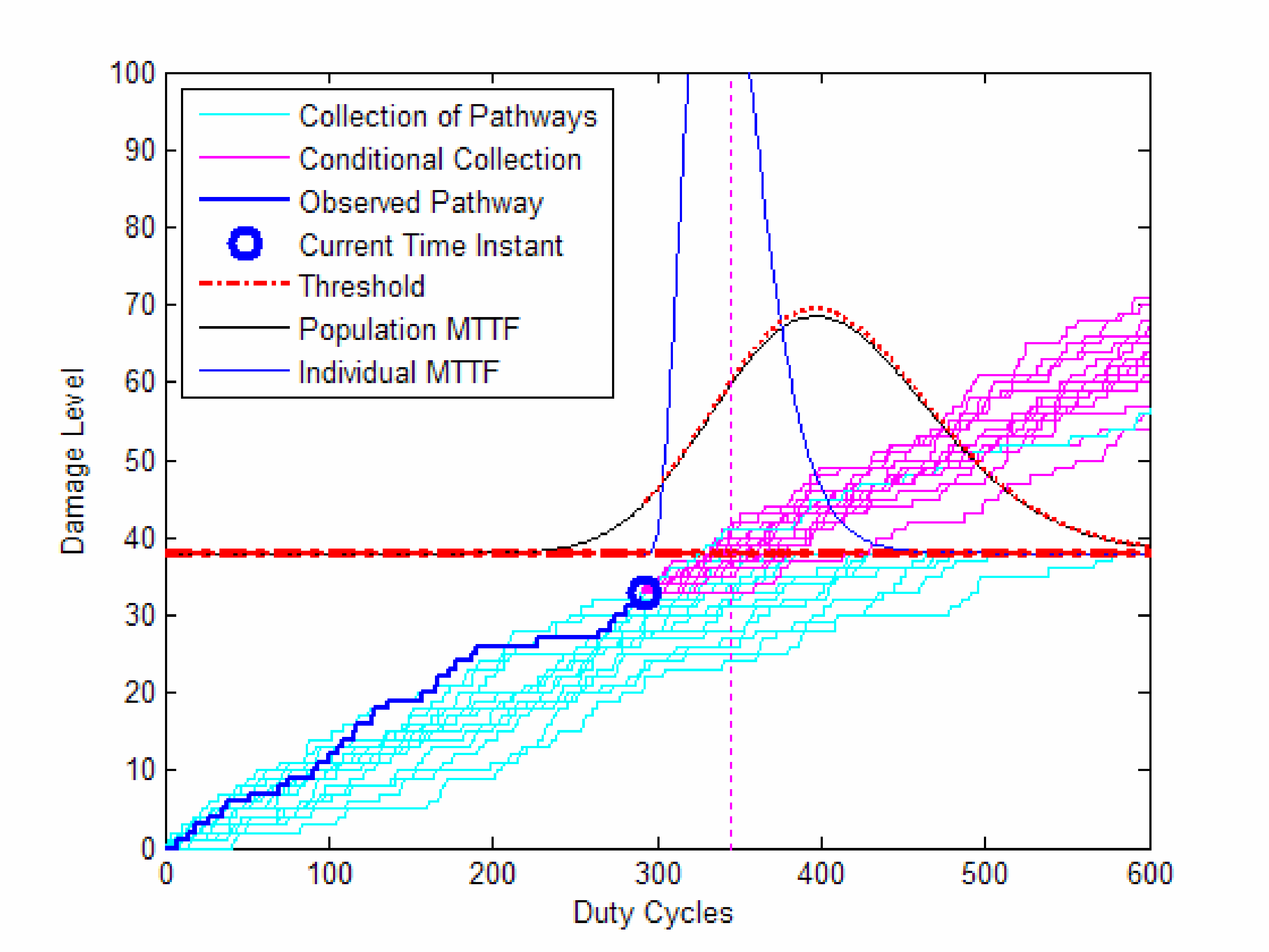
Cumulative Damage Model



Cumulative Damage Model



Cumulative Damage Model



Hybrid Prognostics Approach

- Historical failure data will be used to estimate the population POF.
- Covariates (e.g. speeds, currents, pressures, vibration, etc.), or covariate residuals with the use of empirical models, will be used to develop a degradation parameter and used to augment population POF to provide individual POF.
- A Bayesian framework has been developed to update RUL or POF predictions based on new data.

Next Steps

- Survey equipment to determine where prognostics brings the best benefits.
  - It is not applicable to all failures.
- Perform pilot applications and optimize methods.
- Determine where additional instrumentation would be beneficial.
- Collect data for future applications.