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Wind Farm Modeling and Prognostic Opportunities

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Purpose & Overview

- **Purpose: To provide an overview of the reliability analysis approach used by SNL and encourage dialogue with industry in order to improve reliability, efficiency, and costs**
- **Overview**
  - **Objectives**
  - **Analysis approach**
  - **Reliability tools**
    - Raptor - Dynamic reliability block diagram simulation
    - Pro-Opta - Static fault tree analysis tool with improvement optimization
  - **Prognostics**
    - Where it makes sense

Program Objectives

- Establish industry benchmarks for reliability performance
- Improve system performance of wind assets through better asset management
- Identify reliability trends
- Provide high quality information to support operational and maintenance practices

Providing an independent and objective perspective

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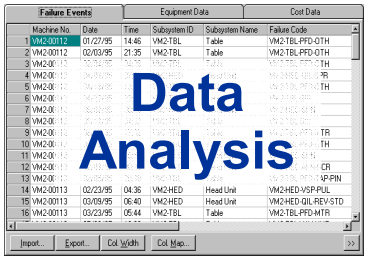
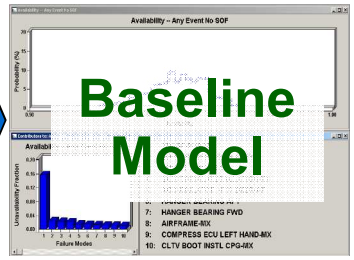
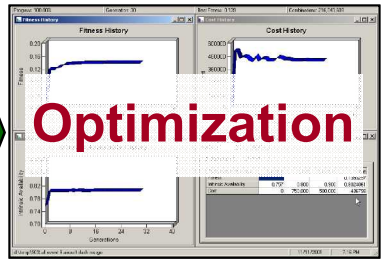
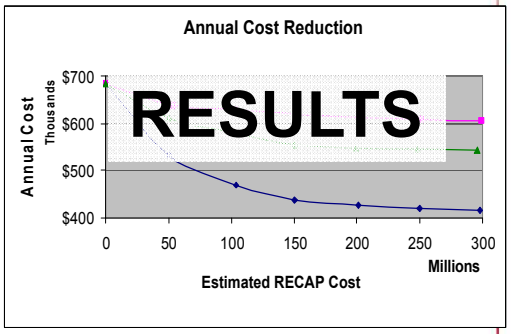
Analysis Approach

- **Data Analysis**
  - Investigate existing failure & maintenance data sources
  - Recommend reliability data elements
- **Wind Turbine System Baseline ("as is") Model**
  - Populate with existing failure & maintenance data
  - Analyze & compare against current system performance
- **Optimize Plan ("best bang for the buck")**
  - Predict impacts of component & subsystem modifications, changing maintenance practices, etc.
  - Evaluate other cost and availability drivers identified by the baseline model









Maintenance Data

- Field data
- Inspection data

MTBF Update

- Data correction
- New components

Objectives & Constraints

- Performance objectives
- Cost constraints

Maximize Availability
Minimize Cost

Reliability Toolkit

- **Numerous techniques are available**
  - Failure modes and effects analysis (FMEA)
  - Failure modes and effect and criticality analysis (FMECA)
  - Reliability block diagram (RBD)
  - Reliability, Availability, Maintainability, and Safety, (RAMS)
- **Numerous tools available**
  - Reliasoft
  - Itemsoft
  - SCADA reporting and analysis tools
  - Winsmith
  - Raptor
  - Pro-Opta

Approach

- **Data**
  - **Global Energy Concepts (GEC) Reliability and Cost Model for Generic 1 MW Wind Turbine**
    - Generic 1 MW Wind Turbine
    - Random & wearout failures modeled
  - **Modified based on wind farm owner and operator feedback**
  - **Further modified to illustrate optimization methodology**

- **Reliability software demonstration - come to our booth for in-depth information**

Raptor analysis

- **Commercially available Reliability Block diagram software package**
- **Simulation allows for “scenario testing” or “what if” analysis**

Inputs

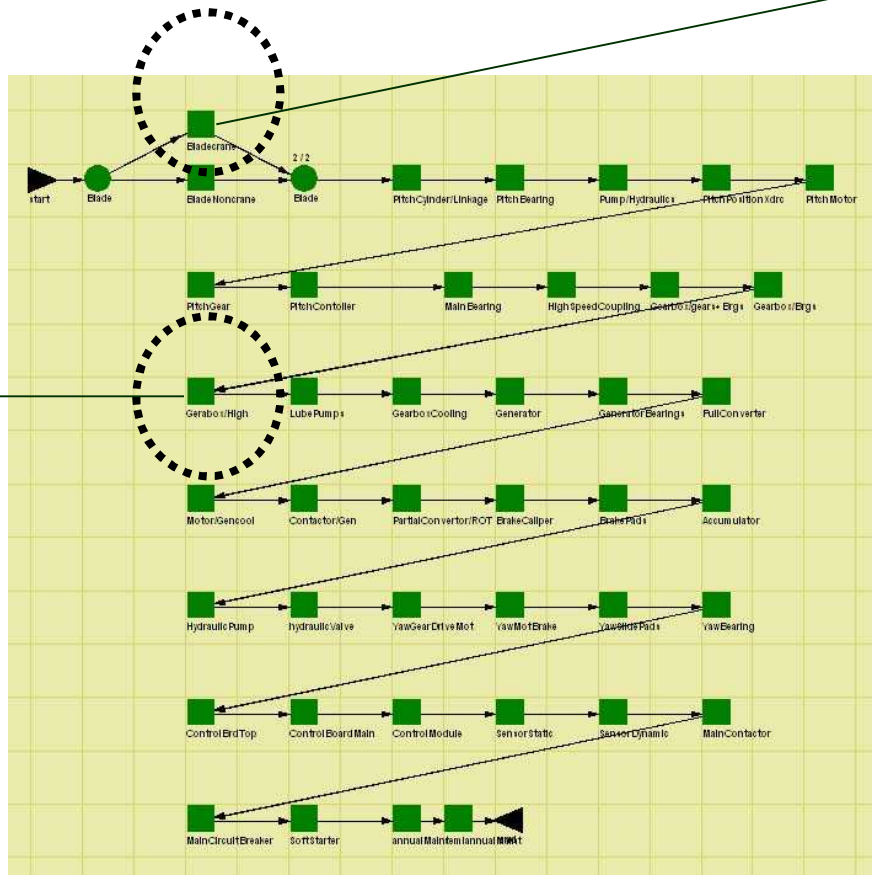
Failure, repair

Costs, resources

Spares strategy

Maintenance delays

Dependency



Inputs

Preventive maintenance

Costs, resources

Spares strategy

Maintenance delays

Dependency

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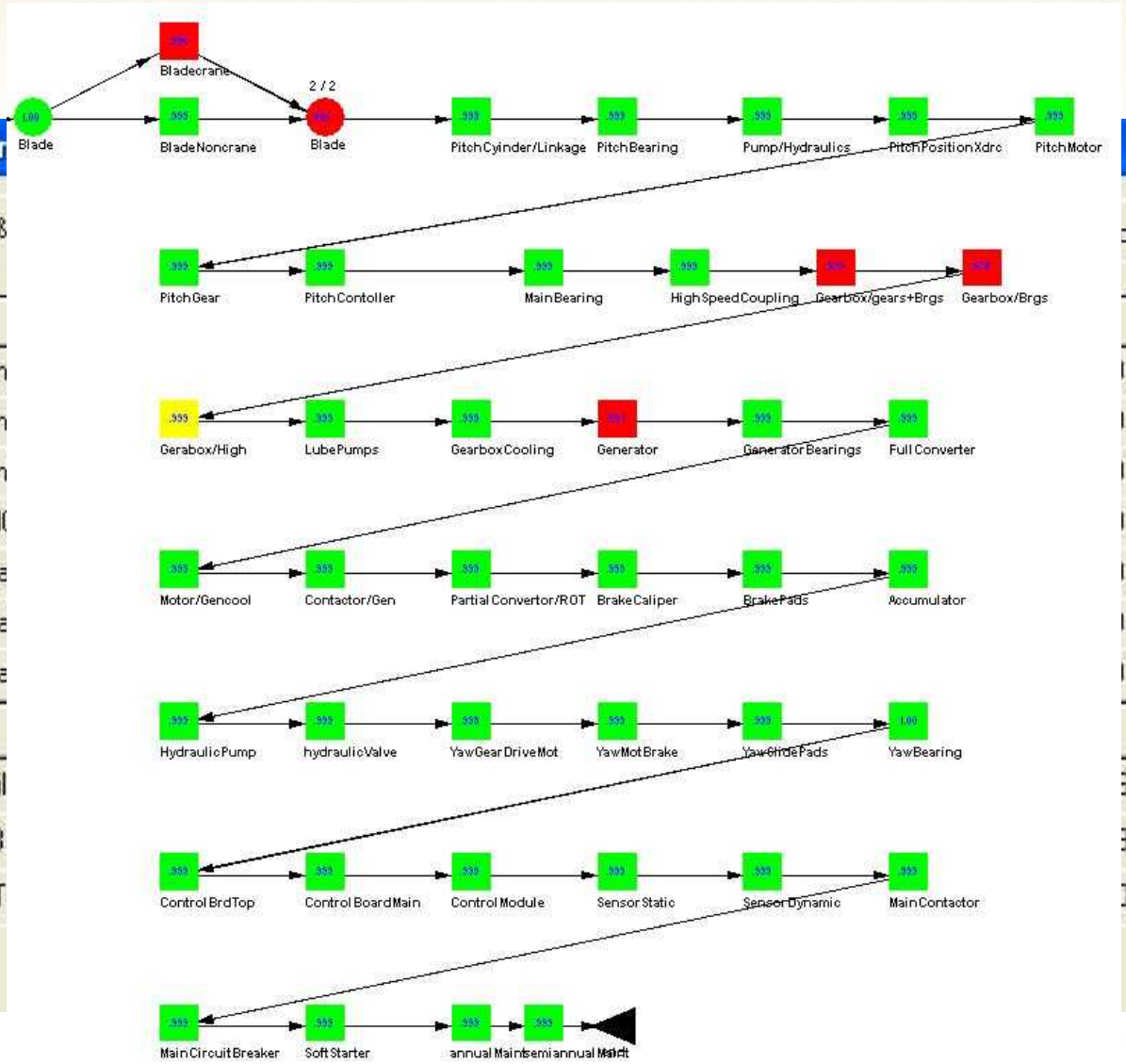
Raptor scenario analysis



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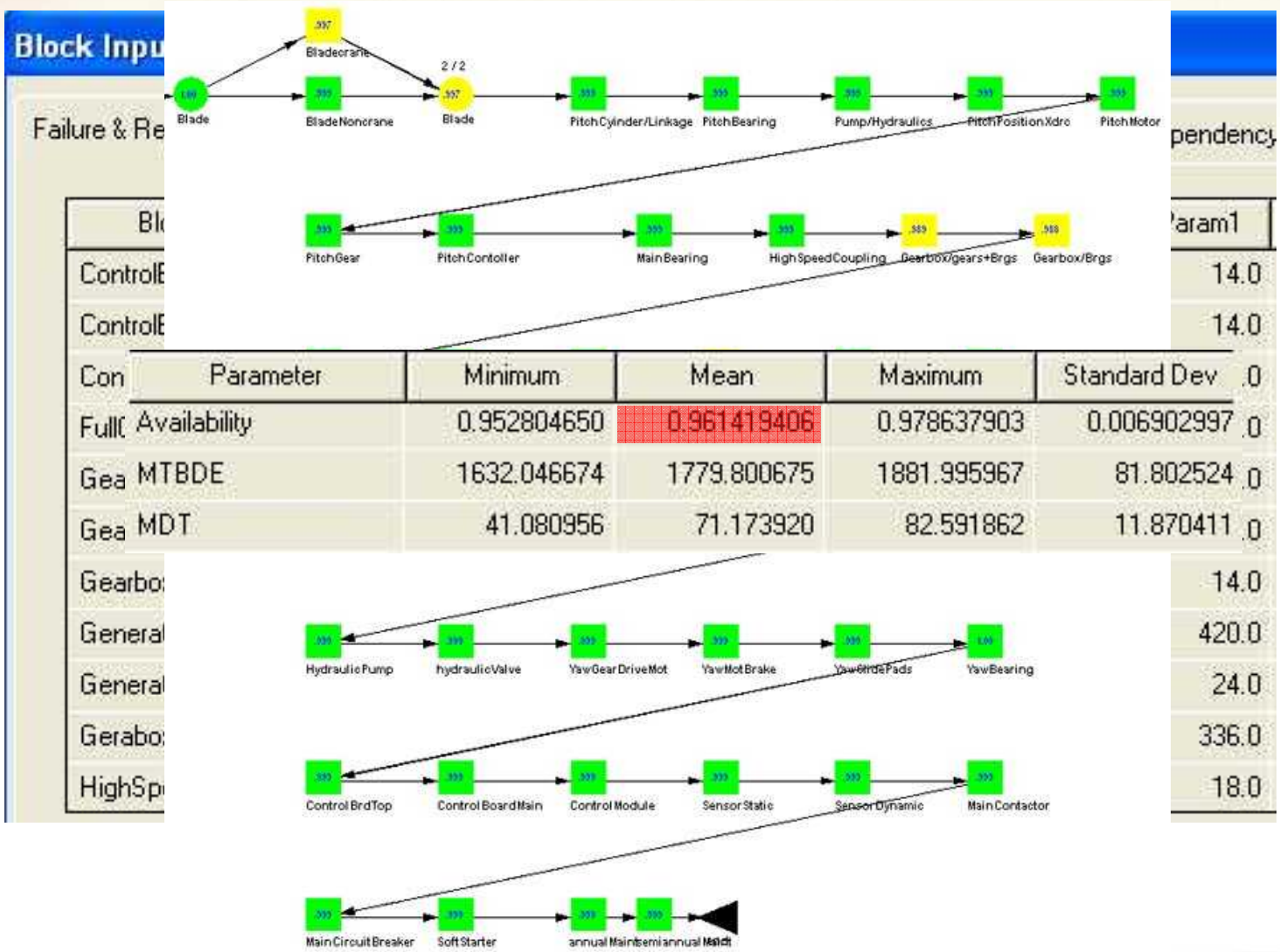
Raptor scenario building



Parameter	Minimum	Mean	Maximum	Standard Dev
Availability	0.952804650	0.961419406	0.978637903	0.006902997
MTBDE	1632.046674	1779.800675	1881.995967	81.802524
MDT	41.080956	71.173920	82.591862	11.870411

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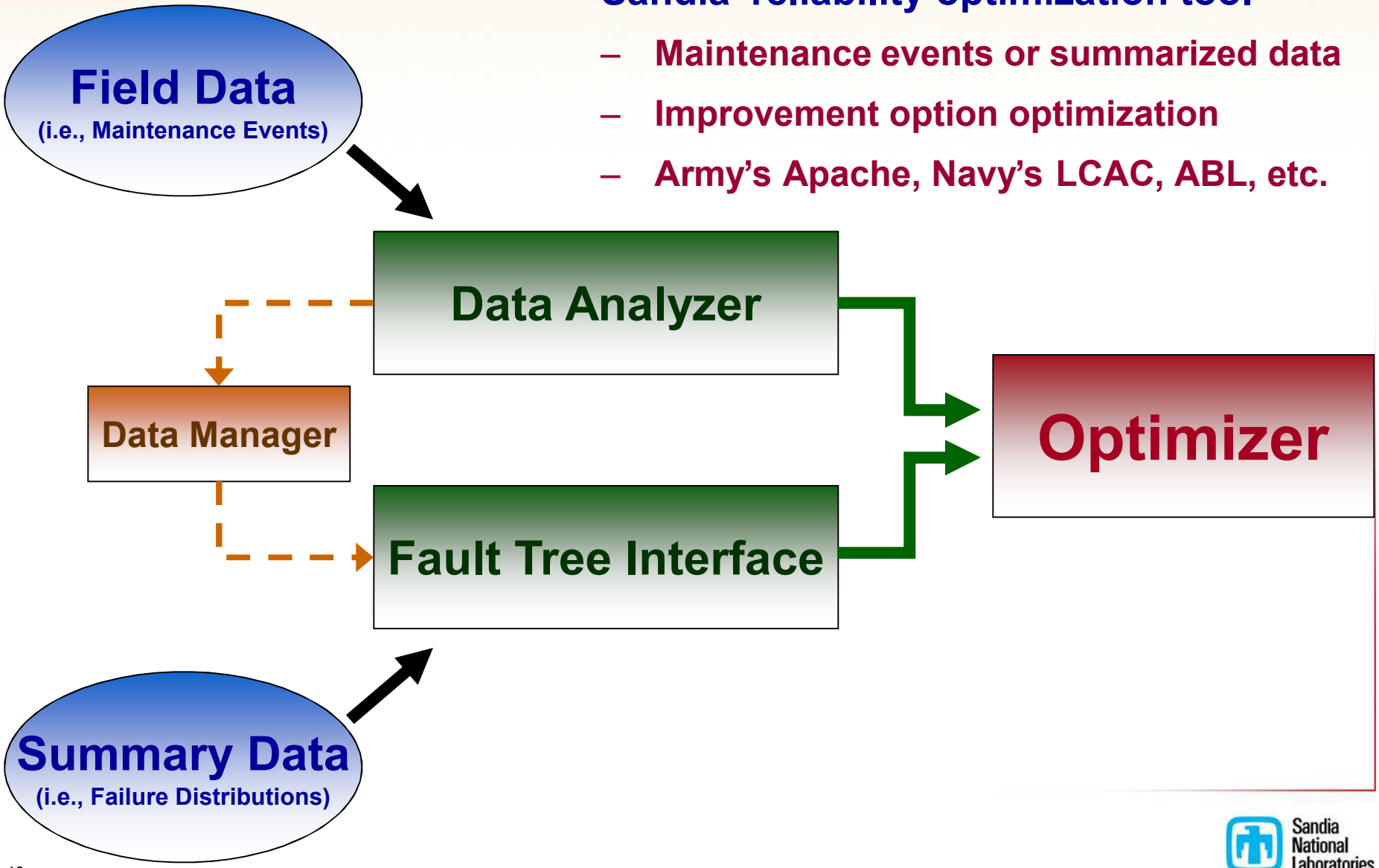
Pro-Opta Toolset

- Sandia' reliability optimization tool
  - Maintenance events or summarized data
  - Improvement option optimization
  - Army's Apache, Navy's LCAC, ABL, etc.



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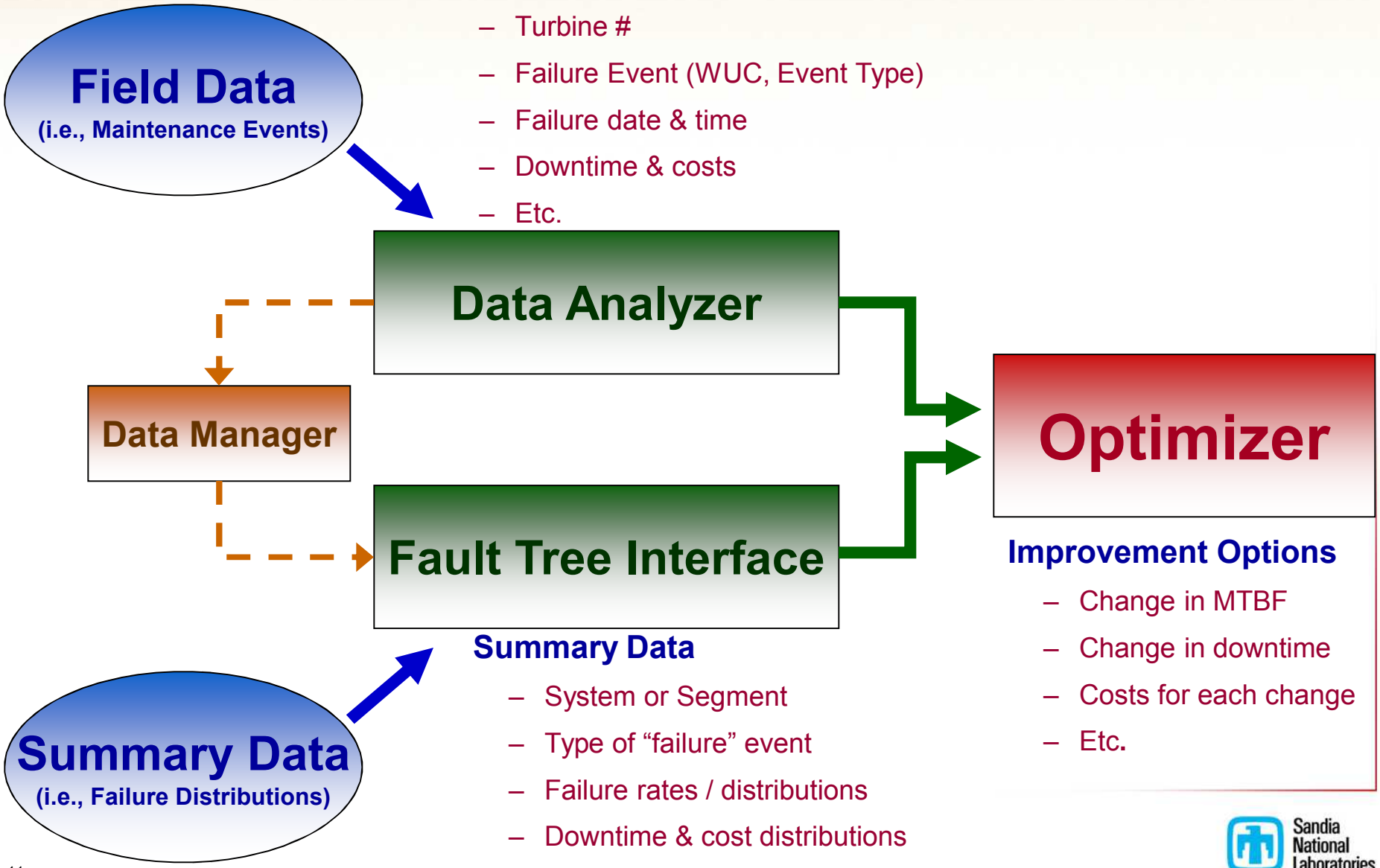
Pro-Opta Toolset



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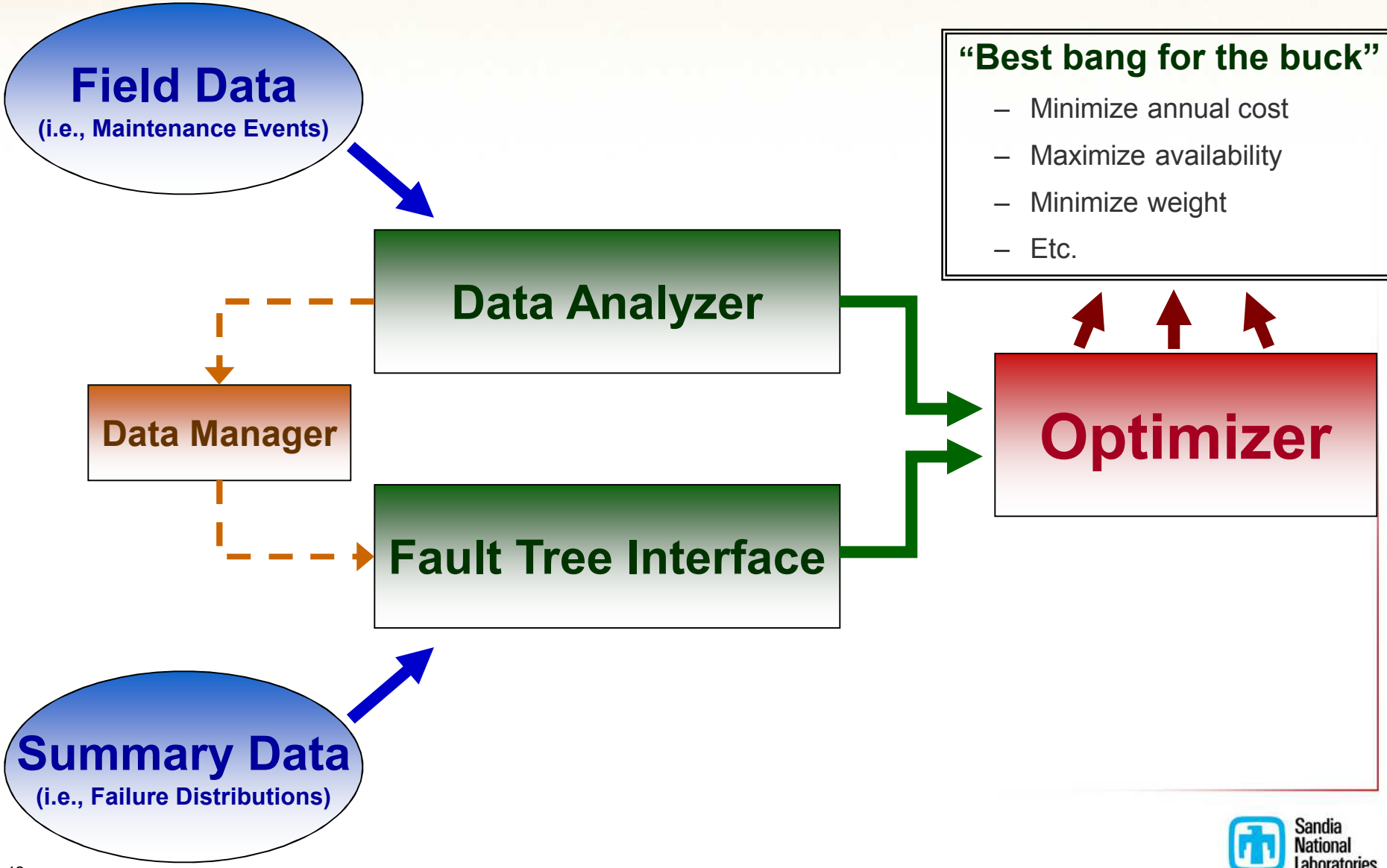
Pro-Opta Toolset



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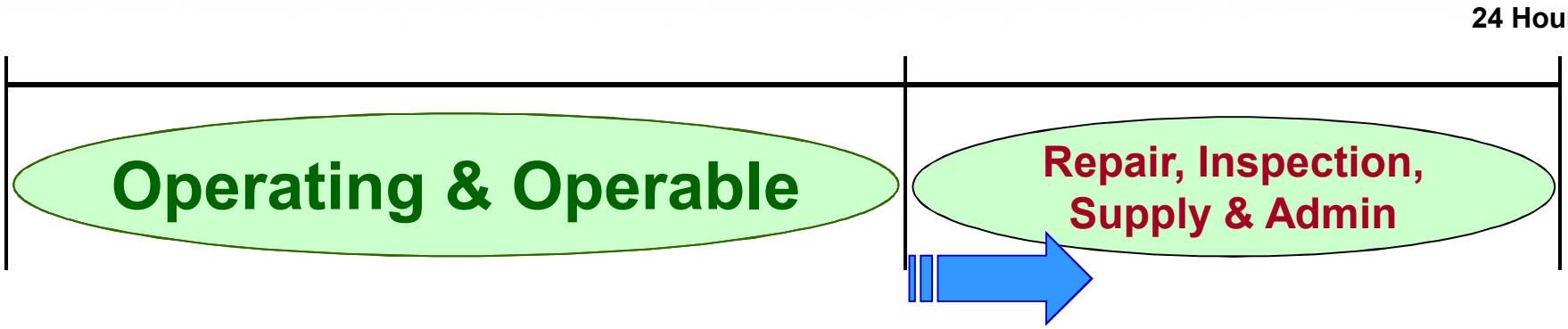
Wind Turbine Availability

"... a day in the life of a wind turbine"



Contributors to Availability:

- No suffix – parts replacement only
- "- Mx" – maintenance performed with no parts replacement
- "- Crane" – crane required to repair or replace component
- "- Can" – parts cannibalized from another turbine
- "- SchMx" – scheduled maintenance
- "- Insp" – planned inspection

A systems approach assesses key readiness drivers

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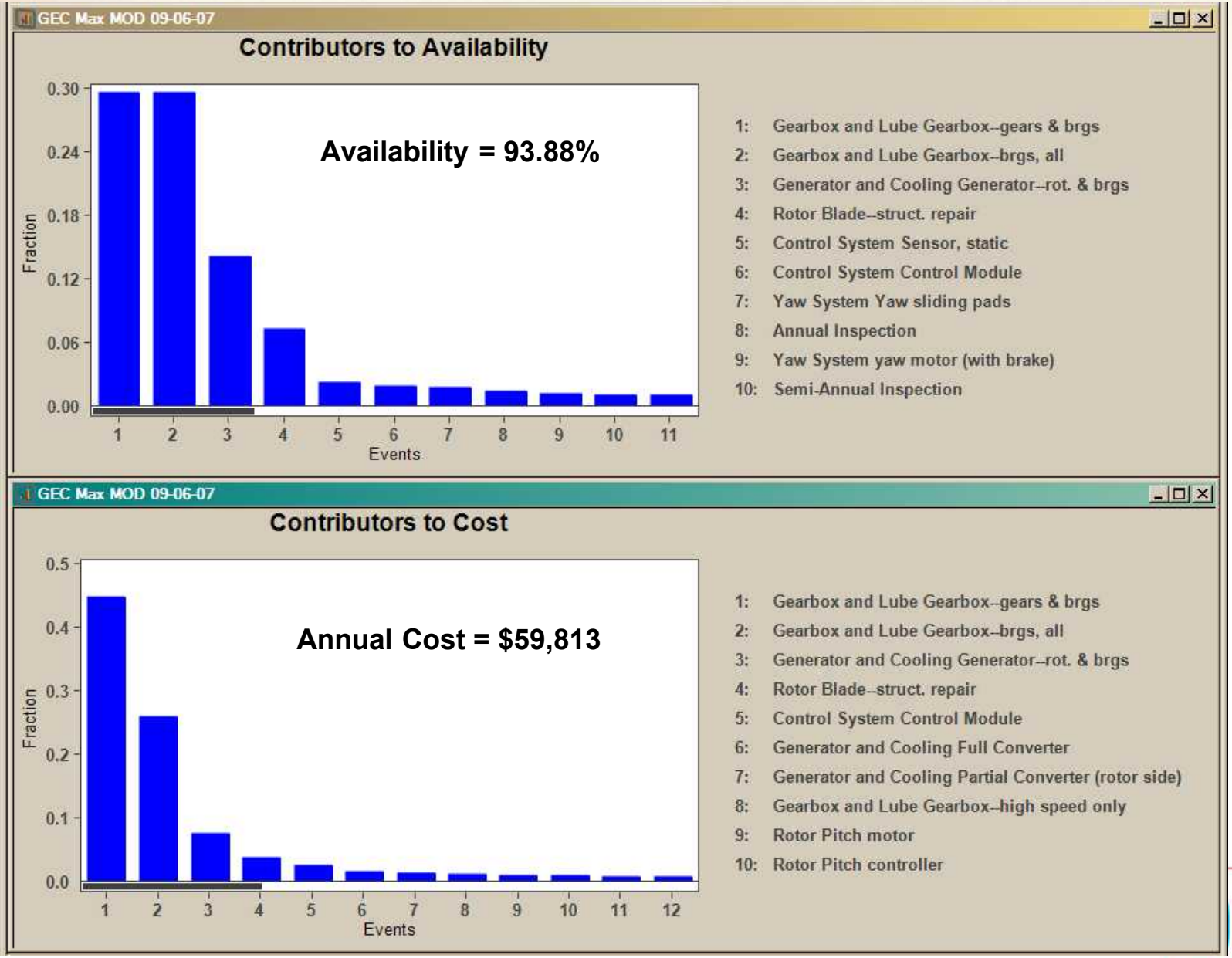
Baseline Model Results

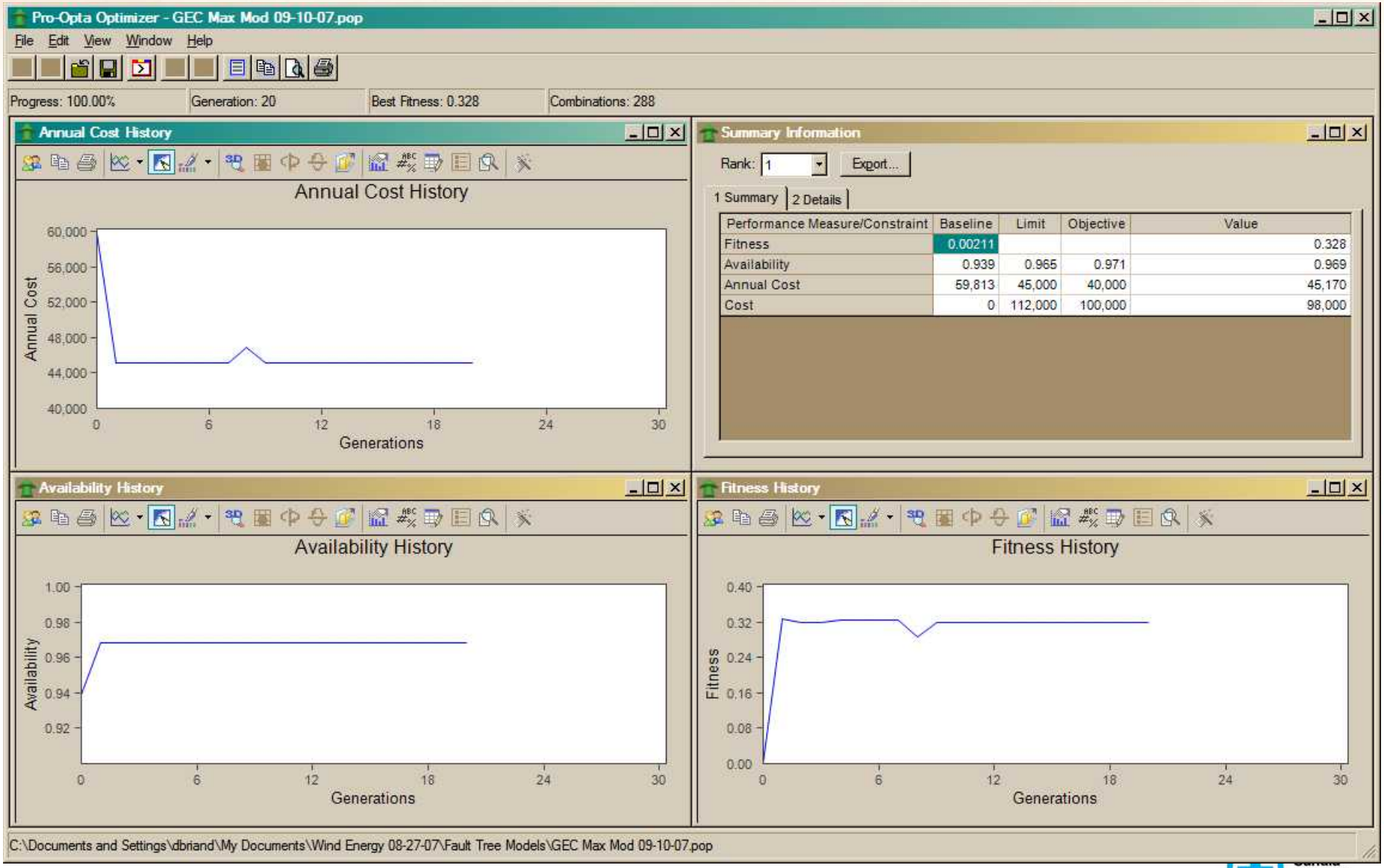


Optimization Setup

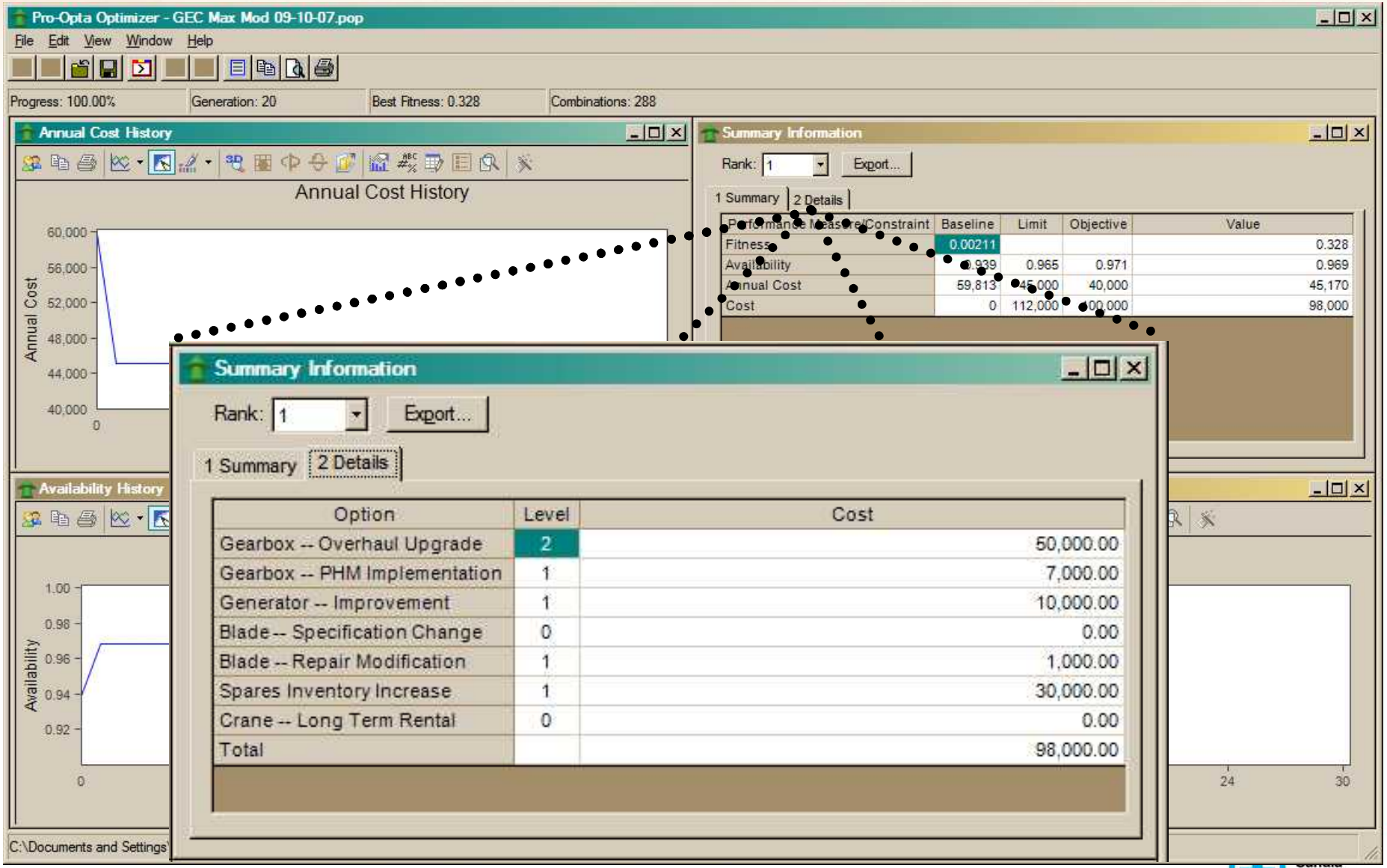
- **Optimization Setup**
  - **All TTF and downtime improvements and costs are "notional"**
  - **9 improvement options result in 288 combinations of possible solutions**
    - *Genetic algorithm helps find the optimal or near optimal solution*
    - *Multiple top solutions available*
  - **Approximately $100K to spend in improvement options**

Improvement Option Name	% TTF Improvement	% Downtime Improvement	Implementation Cost	Level
Gearbox -- Overhaul Upgrade	15	0	$20,000	1
Gearbox -- Overhaul Upgrade	30	0	$50,000	2
Gearbox -- PHM Implementation	0	50	$7,000	1
Generator Improvement	30	0	$10,000	1
Blade -- Specification Change	25	0	$15,000	1
Blade -- Repair Modification	5	5	$1,000	1
Blade -- Repair Modification	10	10	$5,000	2
Spares Inventory Increase	0	35	$30,000	1
Crane -- Long Term Rental	0	50	$46,600	1

Optimization Results

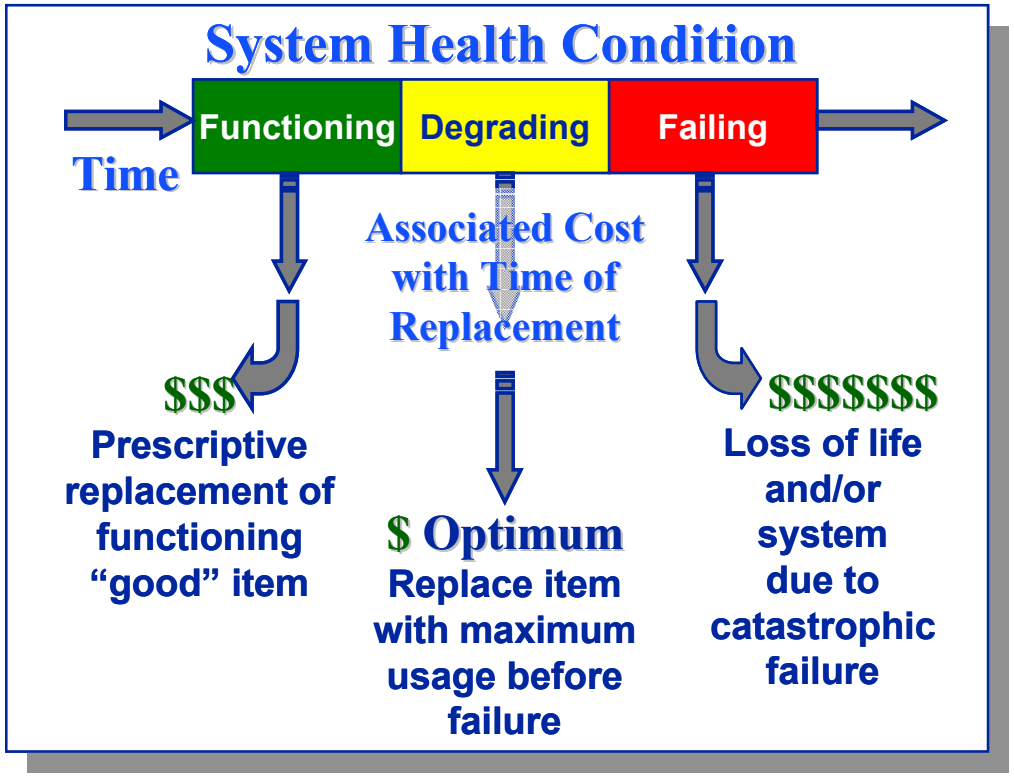


Optimization Results



Prognostics & Health Management (PHM)

- **Prognostics & Health Management:**
  - A technology to accurately predict the remaining useful life of a system or component
  - Produces time-to-failure (TTF) estimates which could be projected for long periods of time to assist in maintenance planning.
  - Requirement of every major new military hardware acquisition: FCS, JSF, etc.



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Sandia PHM System Architecture

PROGNOSTICS & HEALTH MGMT.

Updated TTF Distributions

Estimates of Remaining Useful Life

Evidence Engine (System Health)

System

Subsystem

Component

Data Fusion: Bayesian Belief Networks

- Environmental Conditions
- Maintenance History
- Physics of failure
- Aging and Time-to-Failure

Consequence Engine

Maintenance Scenarios

Consequence Analysis

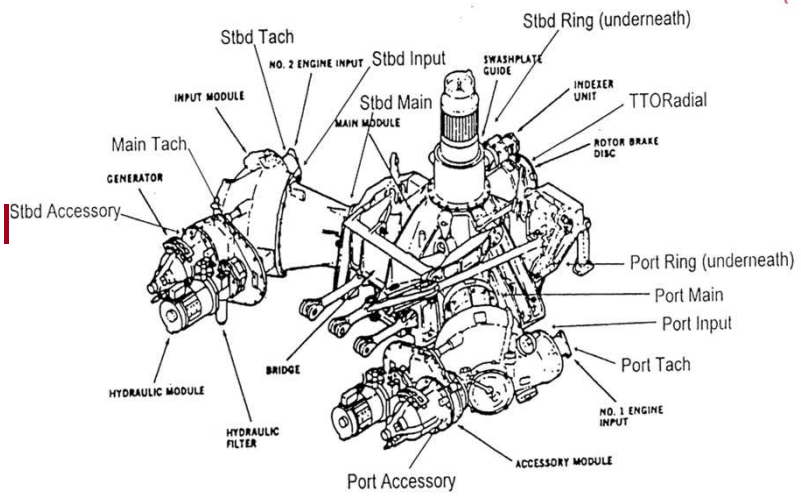
Optimal Maintenance Recommendations

Data Analysis

Sensor Feature Interpretation (NN, SHT, SET)

Sensor Feature Extraction

Raw Sensor Data



Sandia PHM Research

- **Nuclear Power Plant "Smart" Equipment**
  - DOE Nuclear Energy Research Initiative (NERI) with MIT, etc.
  - Introduce PHM to selected power plant equipment
- **Manufacturing Facility PHM**
  - DOE funded program
  - Implement PHM in manufacturing facility
- **Machine Tool PHM**
  - DOE funded program
  - Implement PHM on SNL machine tools
- **F-16 Accessory Drive Gearbox (ADG)**
  - Joint Shared Vision program with LM Aero
  - Extend replacement intervals
- **Airborne Laser (ABL)**
  - Program with MDA and Industry
  - Implement PHM on fluid flow systems (COIL)
- **MEMS-Based PHM for Internal Combustion Engines**
  - Predict failures in internal combustion engines and other rotating machinery
  - Low footprint PHM hardware & software solution

Power Plant PHM


Manufacturing Facility PHM


Machine Tool PHM


F-16 ADG PHM


Airborne Laser (ABL) PHM

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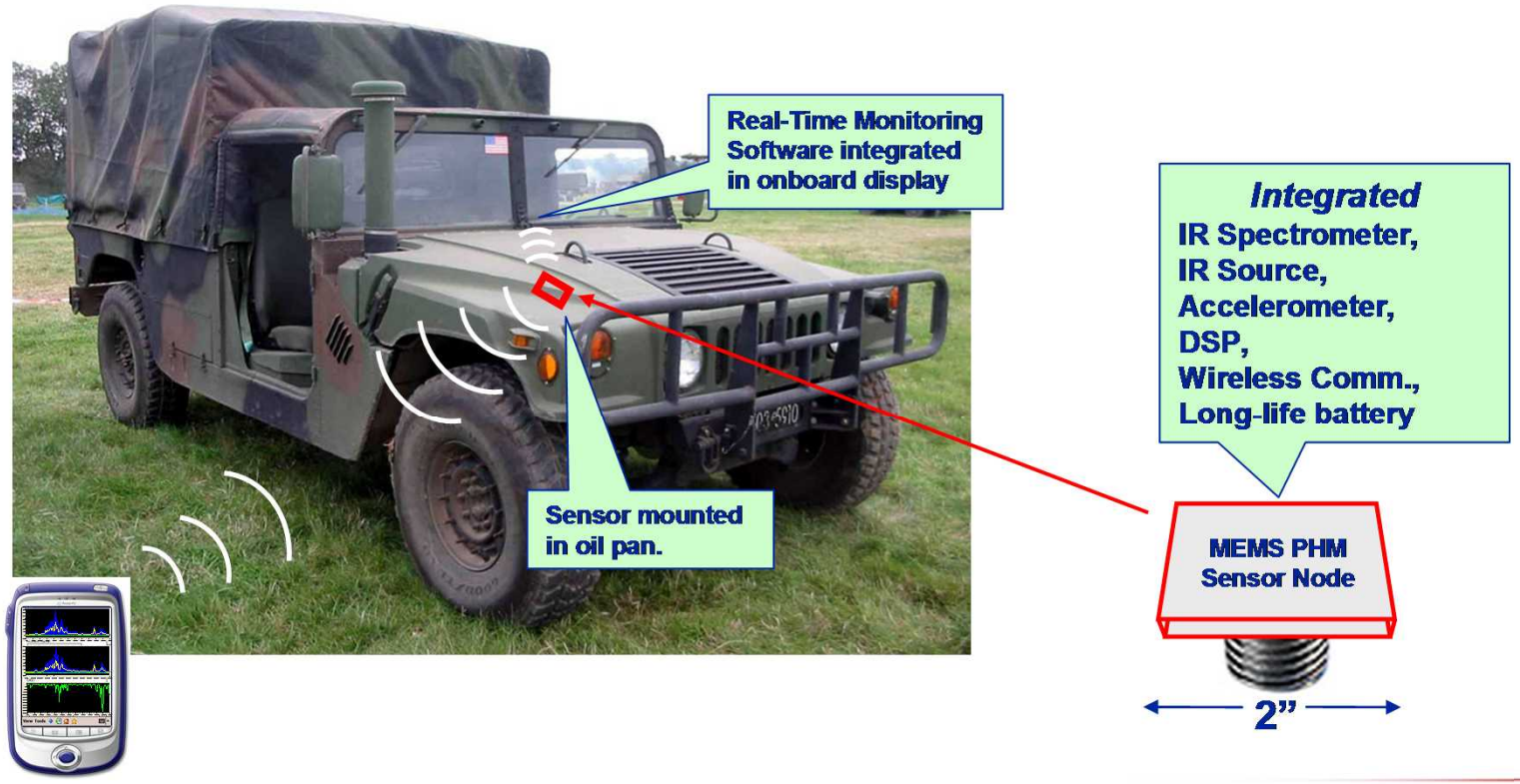
Sandia PHM Research

- **Develop a low-footprint PHM solution for rotating machinery**
  - **Sandia 3-year internally funded research (finishing 1st year)**
  - **Predict failure through vibration analysis & oil properties**



Wind Turbine Gearbox Application

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Summary

- Multiple reliability analyses tools available
  - Assess wind turbine top contributors to availability
  - Determine optimal component improvement options
- Migrate towards a PHM system
  - Cost effective