Making the (Business) Case for PHM

PHM Conference 2013

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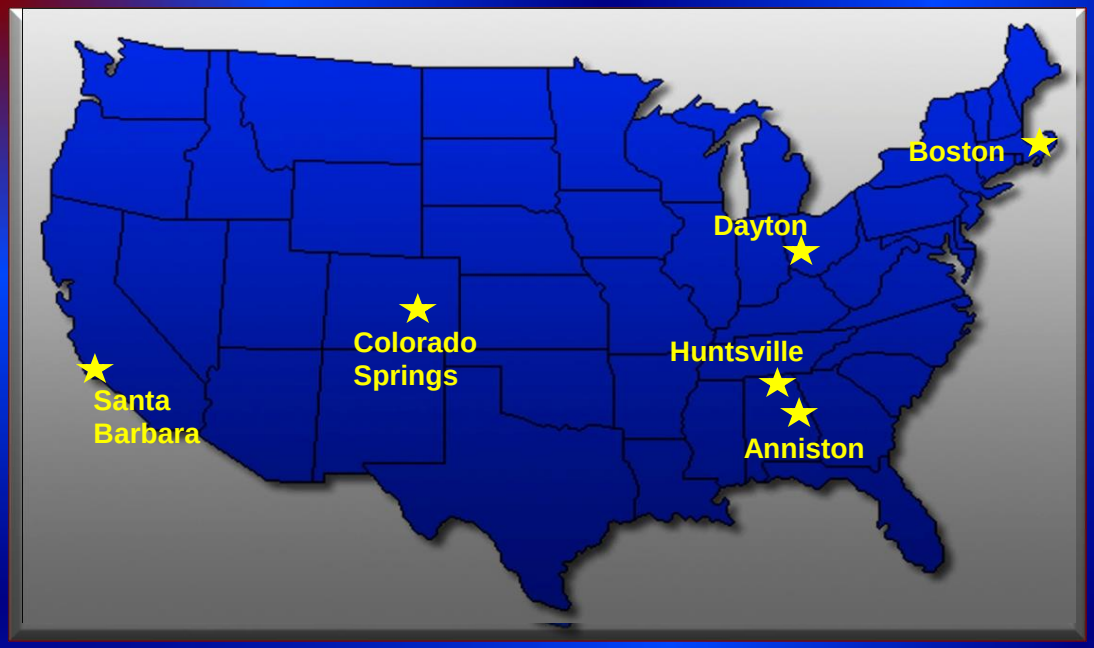
FTI Maximizes Value to our Customers



Empowering Clients Through Data Driven Decisions

by combining community-accepted decision aids and data with FTI technologies to provide effective, expert life cycle management and operational analyses and services for the DoD and Industry clients

BUSINESS UNITS

- Life Cycle Management Solutions & Applications
- Phenomenology Solutions
- Information Technology (Government & Commercial)

SOLUTIONS

- Real Time and Post Processing System Health Monitoring
- Sustainment Support
- Decision Support & Prioritization, Business Case Analyses
- Data Analysis, Calibration, & Trending

PRODUCTS

- Prioritization/Trade (I-CAIV)
- LCOM Logistics Modeling
- Integrated Cost (ICE)
- System Health Monitoring (NormNet) for CBM/PHM
- Product Assurance (PARL)
- Metrics Monitoring (PMES, MPAE)
- Integrated Sensor Analysis (I-SAT)
- Trending (TelemTrend)
- 3D spatial awareness (O-SAT)

TECHNOLOGY

- Information Technology
- Statistics
- Pattern Recognition
- Decision Theory

Managing CBM+

Platforms
Subsystems
Components

Identify High Value Critical Systems

Select Sensor Configuration and Placement

Optimize Sustainment Infrastructure

Integrate Data Sources

Analyze CBM Business Case

Implement Technology to Achieve Benefits

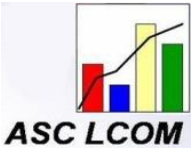
Monitor and Improve Performance

Measure progress
Analyze data
Define trends

RCM
FMECA
Sensor Coverage

NormNet

Detection &
Diagnosis
Predictive Analytics
Adaptive Reasoners



Review Infrastructure
Evaluate Supply Chain
Quantify Sustainment Impact

Quantifiable Benefits
Non-quantifiable Benefits
Metrics and Analysis Tools

I-SAT
TelemTrend

Data Source Analysis
Data Visualization Data Selection

PHM Benefits Expected

- **Increased availability**

  - » Early notification of degrading conditions and future failure
  - » Fewer unplanned failures
  - » Faster repair time associated with fixing minor problems
  - » Reduced potential for loss of service or equipment

- **Reduced cost of operations**

  - » Reduced costs of problem identification and repair
  - » Reduced probability of catastrophic failure
  - » Reduced spares inventory and redundant equipment
  - » Accurate identification of problem
  - » Reduced maintenance actions with no fault found
  - » Identification of remaining useful life and recommended remedial action
  - » Provides “condition” for support of condition-based maintenance

Challenge to Implementing PHM

The economic challenge: Describe PHM costs/benefits in terms of standard economic measures, e.g. ROI

The logistics challenge: Determine impact of PHM on higher level system logistics support measures

The technical challenge: Match technology to needs, including data sources, sensors and weight, space, and bandwidth constraints

PHM Requirements Part of the Benefit Validation Process

1. **Establish Goals/Requirements**
   - Input:
2. **Identify the High Value Needs**
   - Input:
3. **Define PHM Solutions/Alternatives**
   - Input:
   - Tools
   - Enab
   - Outp
4. **Perform Operational, Sustainment, Enterprise Analysis**
   - Inp
   - Too
   - Ena
   - Ou
5. **Perform Cost Analysis**
   - Input:
   - Tools:
   - Enabl
   - Outpu
6. **Perform Business Case Analysis**
   - Input:
   - Too
   - Ena
   - Ou
7. **Perform Validation**
   - Input:
   - Tools:
   - Enabling Knowledge/Data:
   - Output:

DoD Guidance and Related Policy

- **CBM+**
  - DoDI 4151.22, 2 Sep 2007
  - CBM+ DoD Guidebook, May 2008
- **BCA**
  - DOA Memorandum, "Performance-Based Logistics (PBL) Business Case Analysis (BCA)", 18 August 2005
  - DON Memorandum, "Department of the Navy Guide for Developing Performance Based Logistics Business Case Analyses", 6 November 2007
  - DON "Guidebook for Developing Performance Based Logistics Business Case Analyses", 1 November 2005
- **CBM+ in the Acquisition Life Cycle**
  - USAF "Systems Lifecycle Integrity Management (SLIM) Guide", 22 February 2010
- **Other**
  - Air Force Instruction 90-1301, "Implementing Military Flight Operations Quality Assurance", 1 April 2008

Literature on CBM+ and PHM Cost Benefit

- **Batteries for Ground Combat Vehicles**
  - "Cost Benefit Analysis for the Implementation of Battery Prognostics for Ground Combat Vehicles"
  - 2004 Machine Failure Prevention Technology Conference
  - Jeff Banks, et al., Penn State Applied Research Laboratory
- **Joint Strike Fighter**
  - "Writing a Convincing Cost Benefit Analysis to Substantiate Autonomic Logistics"
  - 2001 IEEE Aerospace Conference
  - Byer, Hess, and Fila, JPO/NAVAIR
- **Electronics**
  - "The Analysis of Return on Investment for PHM Applied to Electronic Systems"
  - 2008 IEEE PHM Conference
  - Feldman, Sandborn, and Jazouli, CALCE

Literature on CBM+ and PHM Cost Benefit

- **IVHMS**
  - **"Assessing the Impact of Health Management Approaches on System Total Cost of Ownership"**
  - **2005 IEEE Aerospace Conference**
  - **Tim Wilmering and A. Ramesh, Boeing**
- **Commercial Airline**
  - **"Cost-benefit Analysis Methodology for PHM Applied to Legacy Commercial Aircraft"**
  - **2008 IEEE Aerospace Conference**
  - **Leao, et al., Embraer**

Introduction

Talking Money – Financial Metrics

Economic Analysis Basics

- **Discount Rate**
  - Interest rate applied to series of future cash flow to adjust for risk and the uncertainty of time
  - Essentially, the time value of money
  - Use for multi-year projects (such as life cycle of system)
- **Present Value (PV)**
  - Value of future return once discount rate has been applied
  - $PV = FV_N/(1+R)^N$, where…

    FV_N = future income of period N
    R = interest or discount rate
    N = number of years or periods
  - Provides common basis for comparing multi-year projects
- **Net Present Value (NPV) = Present Value of cash outflows and inflows**
- **Return on Investment (ROI) = Net Present Value/Investment**
- **Payback period**
  - Amount of time required to recover the initial investment of the project
- **Internal Rate of Return (IRR)**
  - Discount rate that makes NPV = 0

Discount Rate and Present Value

- **Discount Rate Policy (OMB Circular A-94)**
  - **In order to compute net present value, it is necessary to discount future benefits and costs.**
  - **This discounting reflects the time value of money.**
  - **Benefits and costs are worth more if they are experienced sooner.**
  - **The higher the discount rate, the lower is the present value of future cash flows.**
  - **For typical investments, with costs concentrated in early periods and benefits following in later periods, raising the discount rate tends to reduce the net present value.**

Present Values

Years

Future Values

	1	2	3	4	5	6	7
	0.00%	0.00%	0.00%	0.20%	0.40%	0.60%	0.80%
$1.00	$1.00	$1.00	$1.00	$1.01	$1.02	$1.04	$1.06
$0.99				$1.00			
$0.98					$1.00		
$0.96						$1.00	
$0.95							$1.00

Net Present Value

- **In finance, the net present value (NPV)…of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows.**
- **In the case when all future cash flows are incoming and the only outflow of cash is the purchase price, the NPV is simply the PV of future cash flows minus the purchase price (which is its own PV).**

Source: Wikipedia

Net Present Value Example

- **Initial investment of $100K and recurring annual costs**
  - **$10K cost to implement**
  - **$30K avoided cost**
  - **Net of $20K avoided cost**

	1	2	3	4	5	6	7
$100.00	0.00%	0.00%	0.00%	0.20%	0.40%	0.60%	0.80%
$20.00	$20.00						
$20.00		$20.00					
$20.00			$20.00				
$19.84				$20.00			
$19.60					$20.00		
$19.29						$20.00	
$18.91							$20.00
$137.66							
$37.66							

Initial Investment

Present Values

Total of Present Values

Net Present Value

Return on Investment (ROI)

- **Return on Investment (ROI)**
  - **the ratio of money gained or lost (whether realized or unrealized) on an investment relative to the amount of money invested**

Source: Wikipedia

- **ROI = (Return – Investment)/Investment**
  = Avoided Cost/Investment – 1

Source: The Analysis of Return on Investment for PHM Applied to Electronic Systems", K. Feldman, P. Sandborn, T. Jazouli, 2008 International Conference on Prognostics and Health Management

- **ROI = NPV/Initial Investment**
  - **ROI < 0: NPV < 0, or, Avoided Costs < Investment**
  - **ROI = 0: NPV = 0 , or, Avoided Costs = Investment**
  - **ROI = 1: NPV = Initial Investment, or, Avoided Costs = 2*Investment**
- **From Example:**

Return	**= NPV of Avoided and Recurring Implementation Costs**
	= $137.66K
Investment	**= Initial Investment**
	= $100K
ROI	**= NPV/Initial Investment**
	= $37.66K/$100K = 0.38

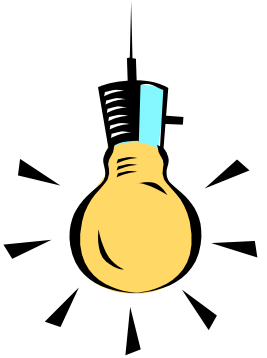
Investment Costs

- **Also known as technology cost, implementation cost**
- **Costs necessary to "develop, install, and support PHM"[1]**
  - **Non-recurring costs**
    - Algorithm development
    - Hardware, software development (requirements, design, etc.)
    - Training, documentation, data
    - Integration into system, IT system
    - Test, qualification
  - **Recurring costs (per unit)**
    - Added hardware (sensors, connectors, etc.), assembly, test, installation
  - **Annual costs (per unit time)**
    - Data management (collection, analysis, reporting, archiving), PHM maintenance, decision support, retraining
- **Investment costs are important**
  - **Larger impact for same value change than avoided costs because they are in denominator of ROI**

[1]"The Analysis of Return on Investment for PHM Applied to Electronic Systems", K. Feldman, P. Sandborn, T. Jazouli, 2008 International Conference on Prognostics and Health Management

Cost Savings and Avoided Costs

- **Cost Savings**
  - When a proposed action will clearly reduce costs, for example, planning to lower the electric bill by switching to energy saving fluorescent bulbs
- **Avoided Costs**
  - When an action prevents a future cost, if it is reasonably certain that the cost would have appeared without the action. For example, preventative maintenance for machinery
- **Lost Opportunity Costs**
  - Foregoing a gain that would appear by choosing a different course of action



http://www.business-case-analysis.com/avoided-cost.html

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Cost Benefit

- **For PHM, cost benefit is mainly from avoided costs**
  - **Measurable and Tangible**
    - Maintenance costs (cost of repair)
      - Lower average cost of repair for convenient fix
      - Fewer manhours, lower skill levels, lower manpower levels
    - Consumable costs (fuel, material)
    - Supply costs (sparing, potentially transportation costs)
    - Loss of service
  - **Measurable but Intangible (or can be difficult to quantify by cost)**
    - Availability, Mission Effectiveness
  - **Not measurable and Intangible (or difficult to measure and quantify by cost)**
    - Image, Leverage use of data, etc.
- **How to relate PHM operational and support impacts to avoided costs?**

Reverse Engineering Avoided Cost Example

- Assume Avoided Cost is same each year (average annual avoided cost, or ACavg/yr)
- Define values for:
  - ROI goal
  - Horizon
  - Initial and Recurring Costs
- PV of avoided costs (PVAC) is average annual avoided cost minus the recurring cost times the sum of discount rate factors over horizon
- Use ROI goal to compute PVAC
  - ROI = NPV/Initial Investment = (PVAC – Initial)/Initial
  - PVAC = ROI*Initial + Initial = Initial * (ROI + 1)
- Use PVAC to compute ACavg/yr
  - PVAC = (ACavg/yr – recurring cost) * Discount factors sum
  - ACavg/yr = PVAC/(Discount factors sum) + recurring cost
  - ACavg/yr = (Initial * (ROI + 1)) /(Discount factors sum) + recurring cost

Reverse Engineering Avoided Cost Requirement - Example

- **Define values for:**
  - **ROI goal = 1, Horizon = 7 years**
  - **Initial and Recurring Costs = $100K initial, $10K recurring**
- **Use ROI goal to compute PVAC**
  - **PVAC = Initial * (ROI + 1) = $100K * (1 + 1) = $200K**
- **Use PVAC to compute ACavg/yr**
  - **ACavg/yr = PVAC/(Discount factors sum) + recurring cost**

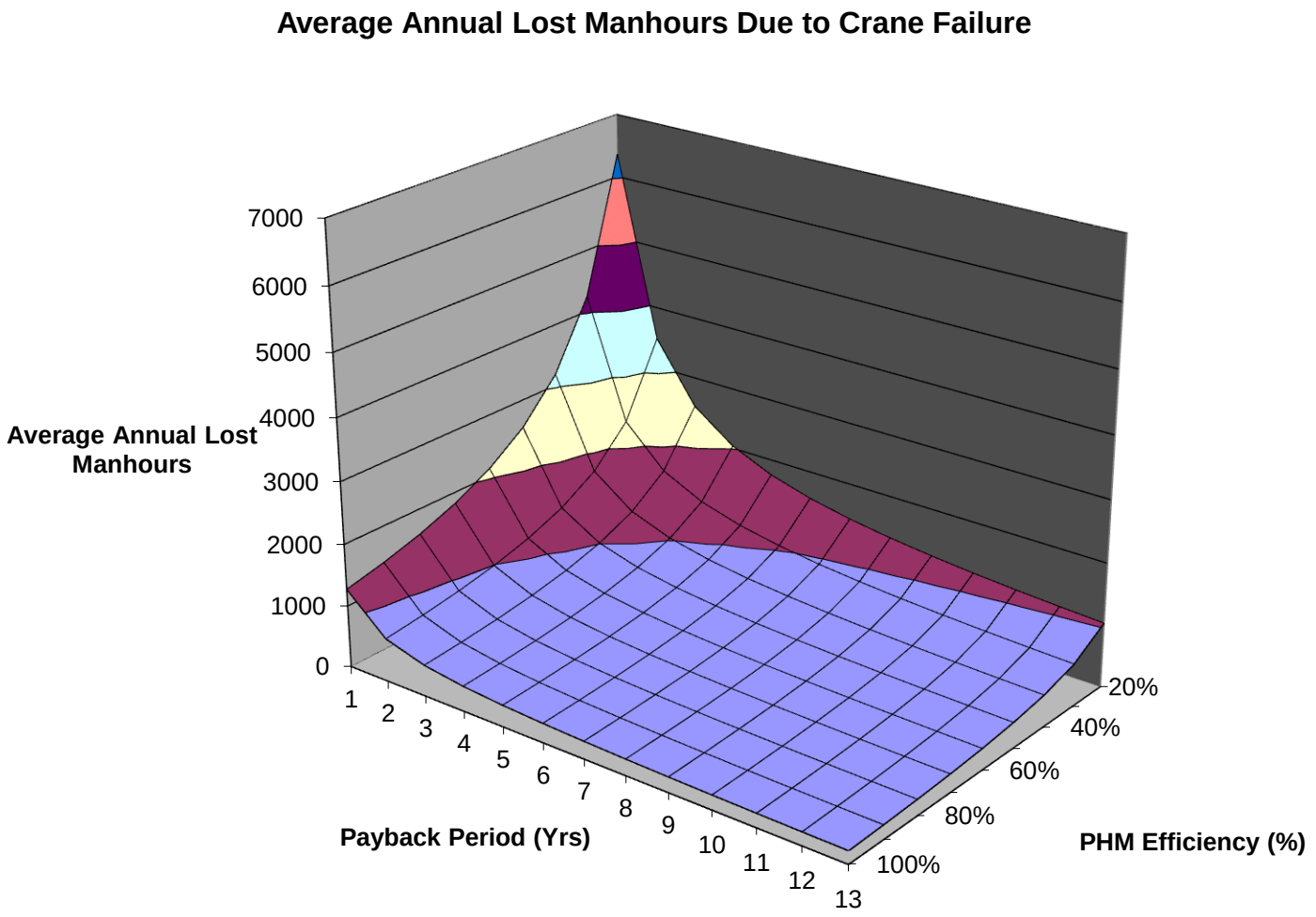
	1	2	3	4	5	6	7
	0.00%	0.00%	0.00%	0.20%	0.40%	0.60%	0.80%
1.00	1						
1.00		1					
1.00			1				
0.99				1			
0.98					1		
0.96						1	
0.95							1
6.88							

Discount Factors Sum →

  - **ACavg/yr = $200K/6.88 + $10K = $29.07K + $10K = $39.07K**

Reverse Engineering Other Requirements

- **Use plots to examine contribution of cost benefit and PHM factors on measures of interest**



Types of Benefits

Looking at where the benefit will come from

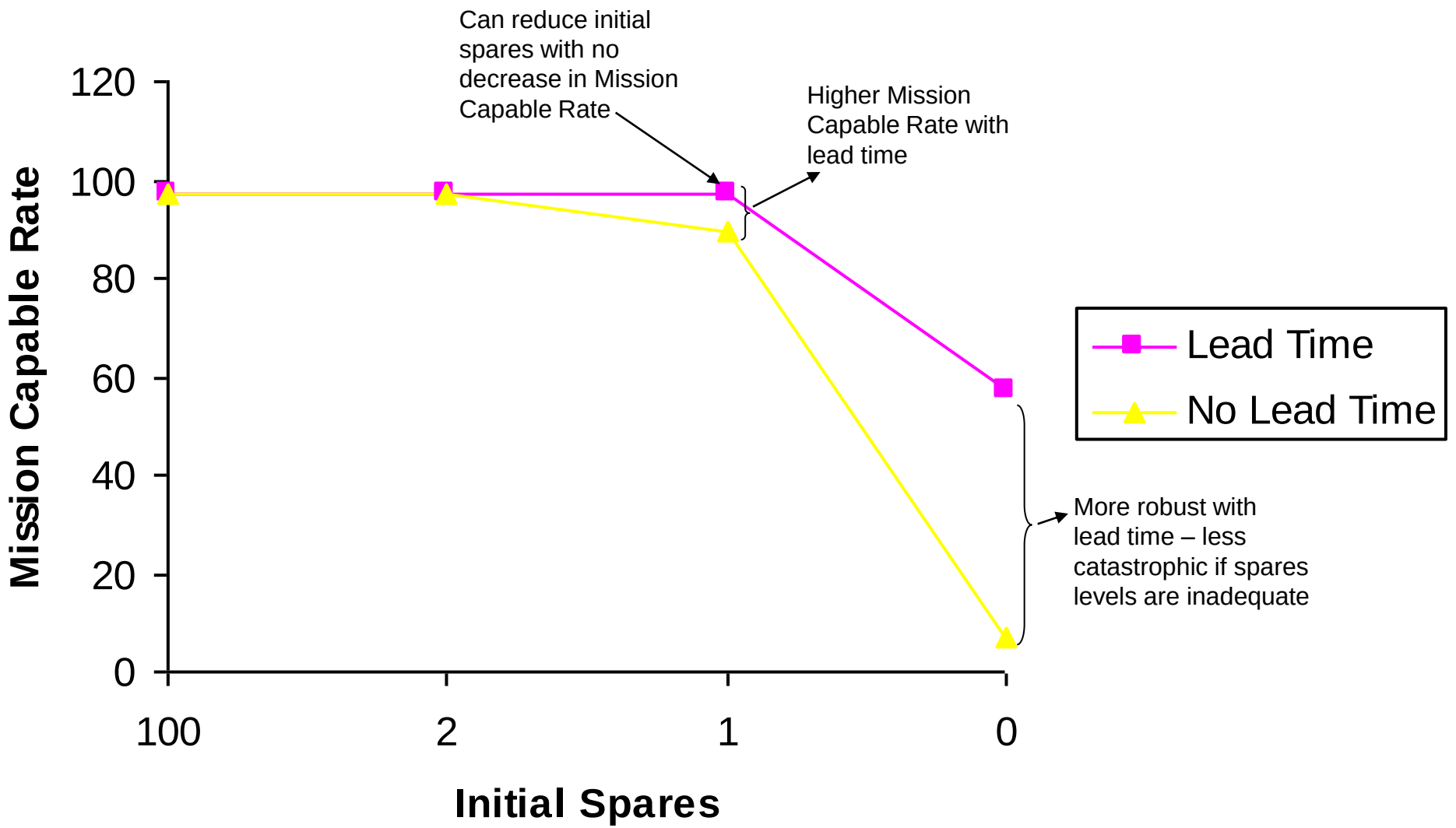
Prognostic Benefit Classes

- **Reduce Lead Times**
  - Advanced warning of failure allows for logistics planning and actions before failure occurs, reducing lead times for implementing repair/replacement
- **Avoid Consequences of Failure**
  - Advanced warning of failure allows for…
    - Repair/replacement before failure occurs, thus avoiding its potential consequences
    - Fix at convenient time, location, etc.
- **Extend Life/Reduce Maintenance Frequency**
  - Advanced warning of failure allows for transition from time-based to condition-based maintenance
- **Optimize Resource Use**
  - Advanced warning of failure allows for potential failures to be grouped to optimize use of scarce/costly resources

Reduce Lead Times

- **Description**
  - **Warning of failure results in…**
    - Ability to order parts in advance
    - Ability to order off-site resource in advance
    - Prepare for repair prior to failure
  - **Allows for run to failure**
- **Logistics Factors and Effects**
  - **Reduced resupply time – reduced pipeline spares**
  - **Reduced wait time for resources – reduced downtime**
- **Cost Factors**
  - **Lower initial spares cost**
  - **Avoided cost of replacement capacity for downtime**

Example of Lead Time on Spares Reduction



Avoid Consequences of Failures – Fix Before Failure

- **Description**
  - **Warning of failure results in repair/replacement before failure occurs, thus avoiding its potential consequences**
    - Avoid loss of system or life
    - Avoid loss of mission
    - Avoid loss of system function
    - Avoid more severe damage and collateral damage
  - **Item is repaired or replaced before it fails**
- **Logistics Factors and Effects**
  - **Reduced downtime, potentially increased availability**
  - **Reduced maintenance and supply burden of severe or collateral damage**
  - ***Increased number of maintenance/replacement actions***
- **Cost Factors**
  - **Avoided costs associated with loss of system or human life**
  - **Avoided costs of replacement capacity for loss of mission, system function, or lower availability**
  - **Avoided costs of severe or collateral damage in terms of personnel, parts, equipment, material, etc.**
  - ***Increased cost of more frequent repair/replace actions and replacement capacity for lower availability***

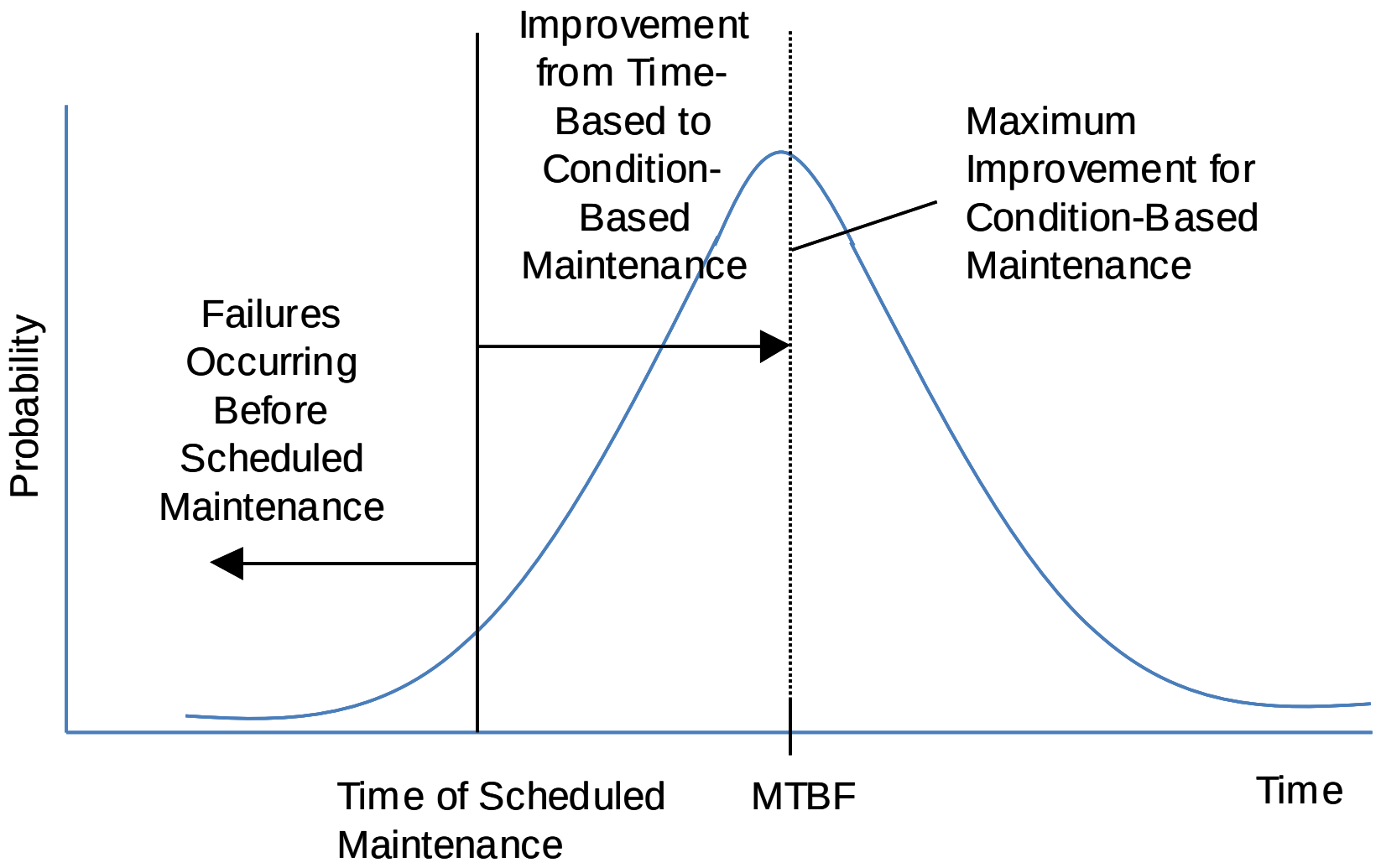
Avoid Consequences of Failures – Convenient Fix

- **Description**
  - **Warning of failure results in fix at convenient time, location, etc.**
    - Ability to schedule repair for convenient time, i.e., not during operation
    - Ability to avoid use of recovery or transport of repair resources to field/site of failed system
    - Increased safety of repair resources, especially in combat
  - **Item is repaired or replaced before it fails at a more desirable time or location**
- **Logistics Factors and Effects**
  - **Reduced downtime, potentially increased availability**
  - **Reduced transportation, use of special resources to transport resources to the system or the system to the resources**
  - ***Increased number of maintenance/replacement actions***
- **Cost Factors**
  - **Reduced repair cost (if scheduled rate < unscheduled rate)**
  - **Reduced transportation cost, cost of recovery or site visit resources**
  - **Avoided costs of replacement capacity for lower availability**
  - ***Increased cost of more frequent repair/replace actions and replacement capacity for lower availability***

Extend Life/Reduce Maintenance Frequency

- **Description**
  - **Advanced warning of failure allows for transition from time-based to condition-based maintenance**
    - Extended inspection or overhaul periods
  - **Item is repaired or replaced before it fails at a time closer to the individual failure time rather than a population statistic**
- **Logistics Factors and Effects**
  - **Fewer maintenance actions**
    - Lower demand for personnel, parts, equipment, material, etc.
    - Reduced downtime
  - ***Increased maintenance actions (if consolidation of maintenance actions at scheduled times is replaced by a greater number of maintenance actions)***
    - *Higher demand for personnel, parts, equipment, material, etc.*
    - *Increased downtime*
- **Cost Factors**
  - **Lower cost for personnel, parts, equipment, material, etc.**
  - **Avoided costs of replacement capacity for lower availability**
  - ***Increased cost of more frequent repair/replace actions and replacement capacity for lower availability***

Extending Life by Transitioning to Condition-Based Mx



Optimize Resource Use

- **Description**
  - **Advanced warning of failure allows for potential failures to be grouped to optimize use of scarce/costly resources or decrease downtime**
    - When resource is acquired for one failure, fix other pending failures
  - **Item is repaired or replaced before it fails in order to minimize use of costly resource**
- **Logistics Factors and Effects**
  - **Reduced cost of resource use**
  - **Reduced downtime**
  - ***Increased number of maintenance/replacement actions***
- **Cost Factors**
  - **Lower cost for transportation, use of scarce/costly resource**
  - **Avoided costs of replacement capacity for lower availability**
  - ***Increased cost of more frequent repair/replace actions***

Wind Farm Example

- **Crane Is Key Resource**
  - Expensive to obtain
  - Delays in getting to site
- **Turbine Component Failure**
  - Used published GE data
  - Consolidated into 5 components
- **How Can Crane Use Be Optimized?**
  - At what point should a crane be ordered?
  - How many failures should a crane fix?
  - Do impacts vary with number of turbines?

Cost and PHM Factors

Looking at their relative impact

Cost Factors

- **Cost per Unscheduled Maintenance Action**
  - Cost to repair or replace item for unscheduled failure/maintenance event
  - Labor and parts (including collateral damage)
  - Transportation to and from repair location
  - Recovery
  - Special resources
- **Cost per Scheduled Maintenance Action**
  - Cost to repair or replace item for scheduled maintenance event
  - Labor and parts (can be less in facility of choice)
  - Special resources (can be less with higher utilization)
- **Cost for Time Out of Service**
  - Service outage, or opportunity cost, for repair time, delays

Prognostic Attributes

Factor	*Symbol*	*Description*
Coverage	*f*	The fraction of failures in item failure rate (λ) which are designed to be or can be detected by prognostics
Missed failure	α	Probability or fraction of failures that occur before predicted failure
Wasted life	γ	ratio of average rate of wasted life (or inverse of mean wasted life per failure) to item failure rate (λ)
False alarm	δ_{fa}	Ratio of false alarms to 'covered' failures - i.e., of the failures that are designed to be or could have been detected by PHM (whether actually detected or not).
PHM failure	δ_{pf}	Ratio of PHM failures to 'covered' item failures - i.e., of the failures that are designed to be or could have been detected by PHM (whether actually detected or not).

Expected Effects of Prognostic Factors

- **Coverage – Shift maintenance from unscheduled to scheduled**
- **Missed failure – shift scheduled maintenance to unscheduled**
- **Wasted life – increase number of maintenance events/replacements**
- **False alarm and PHM failure – increase number of maintenance events**

Baseline Default Inputs

Cost Benefit Calculator Input	*Value*
Item Mean Time to Fail	900 operating hours
Optempo	10 operating hours per day
Horizon	360 days
Number of items in fleet	50
Coverage	0.10
Missed failure	0.05
Wasted life	0.025
False alarm	0.05
PHM failure	0.01
Time out of Service cost	$100 per operational hour
Mean unscheduled fix time	24 hours
Mean scheduled fix time	12 hours
Unscheduled maintenance	$5000 per event
Scheduled maintenance	$5000 per event

Effect of Varying Prognostic Factors

- In all cases
  - Varied factors from 1 to 10%
  - Total cost = unscheduled maintenance, new scheduled maintenance, and opportunity (time out of service avoided)
- Coverage – Total cost reduces by 2.1%
  - Time out of service reduces cost by 8.5%
  - Scheduled increases cost by 900%
- Missed failure – effect is to reduce effect of coverage
- Wasted life – Total cost increases by 0.7%
  - Scheduled increases cost by 9.5%
- False alarm – Total cost increases by 0.6%
  - Scheduled increases cost by 8.9%
- PHM failure – Total cost increases by 0.9%
  - Time out of service and unscheduled mx increases cost by 1%

Main Effects of 2^k Factorial Design

- **Main effect = change in total cost due to moving factor from '-' to '+' averaged over all other factor levels**

Prognostic Factor	*"-" Value*	*"+" Value*
Coverage	0.01	0.25
Missed failure	0.01	0.25
Wasted life	0.01	0.3
False alarm	0.01	0.25
PHM failure	0.01	0.25

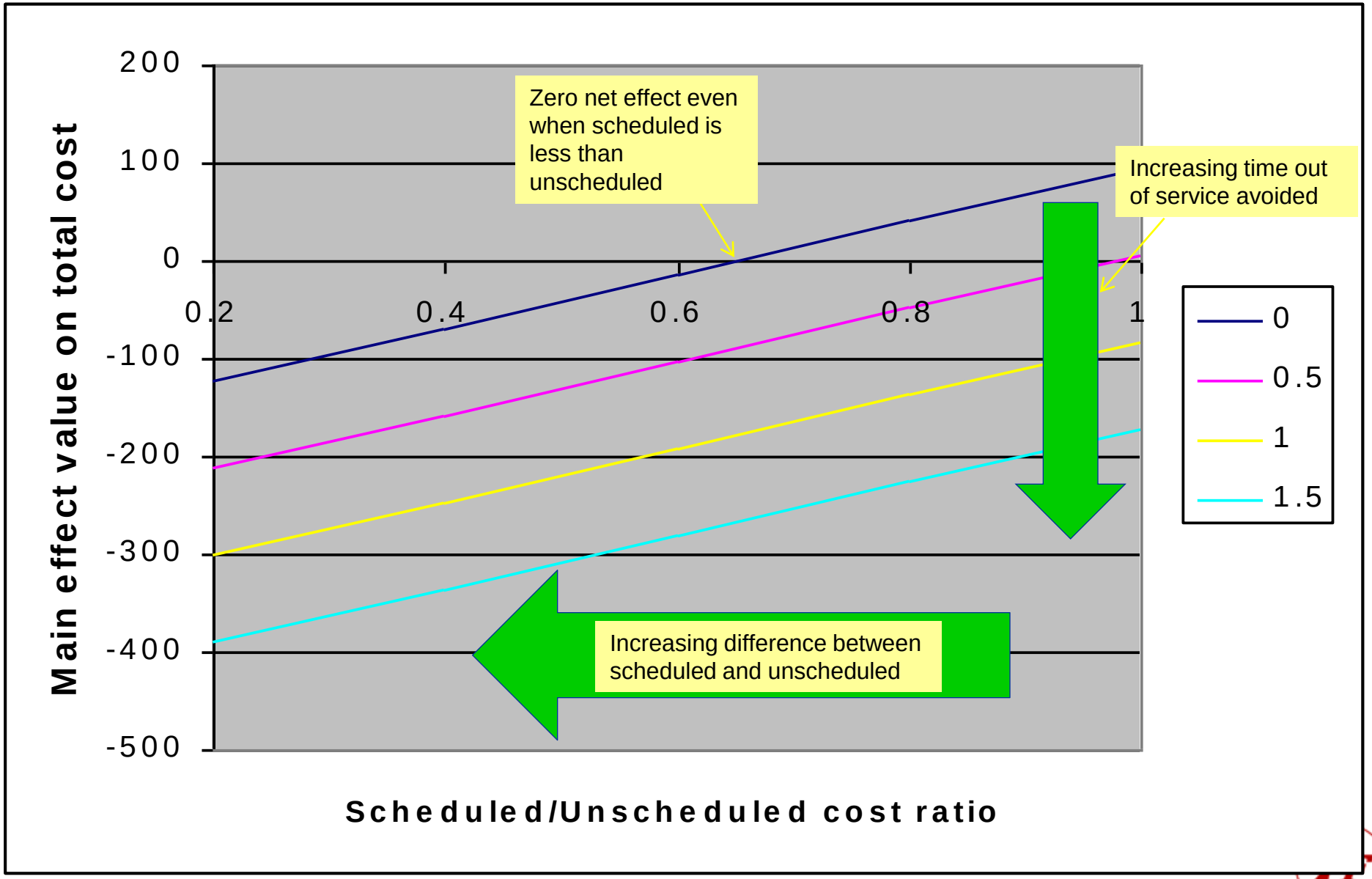
Prognostic Factor	*Main Effect Value*
Coverage	-171.636
Missed failure	41.964
Wasted life	32.799
False alarm	31.2
PHM failure	78

Two-factor Interaction Effects

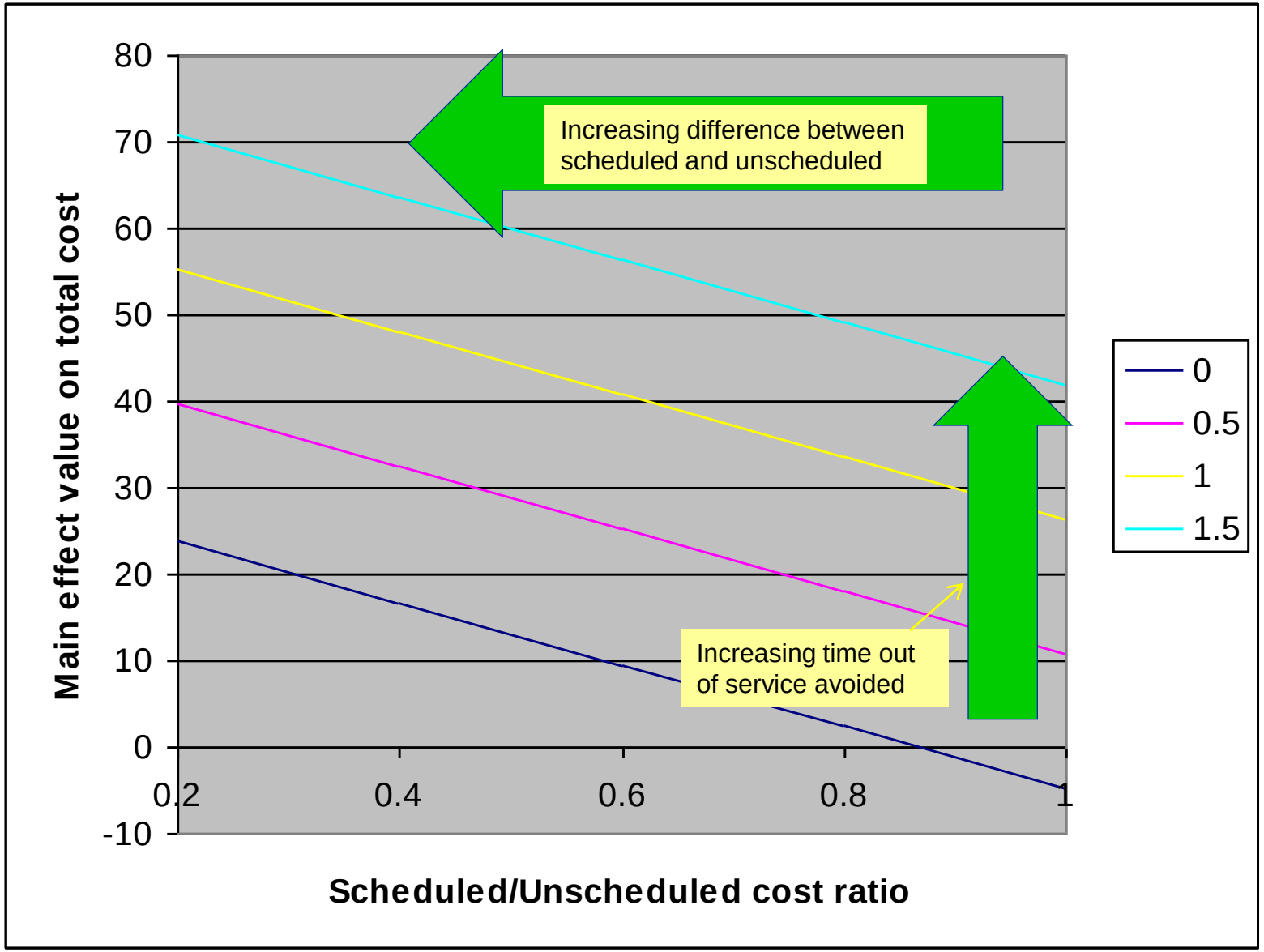
- **Increasing coverage increases factors that are a function of 'covered' failures**

Prognostic Factor Pairs	*Interactive Effect Value*
Coverage and Missed failure	38.736
Coverage and Wasted life	30.276
Coverage and False alarm	28.8
Coverage and PHM failure	72
Missed failure and Wasted life	-4.524
Missed failure and False alarm	0
Missed failure and PHM failure	0
False Alarm and PHM failure	0
False Alarm and Wasted life	0
PHM failure and Wasted life	0

Coverage Main Effects – Varying Cost Factors



Missed Failure Main Effects – Varying Cost Factors



Computing Critical Unscheduled Maintenance

- **Computing failures that occur during the maintenance free operating period**
  - **Missed failures**

$$\lambda_{ucrit\_missed} = \lambda_{ucrit} * f * \alpha$$

  - **PHM failures (assuming not self detected)**

$$\lambda_{ucrit\_phm\_fail} = \lambda_{ucrit} * f * \delta_{pf}$$

  - **False alarms**

$$\lambda_{ucrit\_false\_alarm} = \lambda_{ucrit} * f * \delta_{fa}$$

  - **Failures not 'covered'**

$$\lambda_{ucrit\_not\_covered} = \lambda_{ucrit} * (1-f)$$

Computing Critical Unscheduled Maintenance

- **Sum of failures that occur during the maintenance free operating period**

$$\lambda_{ucrit\_phm} = \lambda_{ucrit} * (1 - f * (1 - \varepsilon))$$

Decreases failures in maintenance free operating period

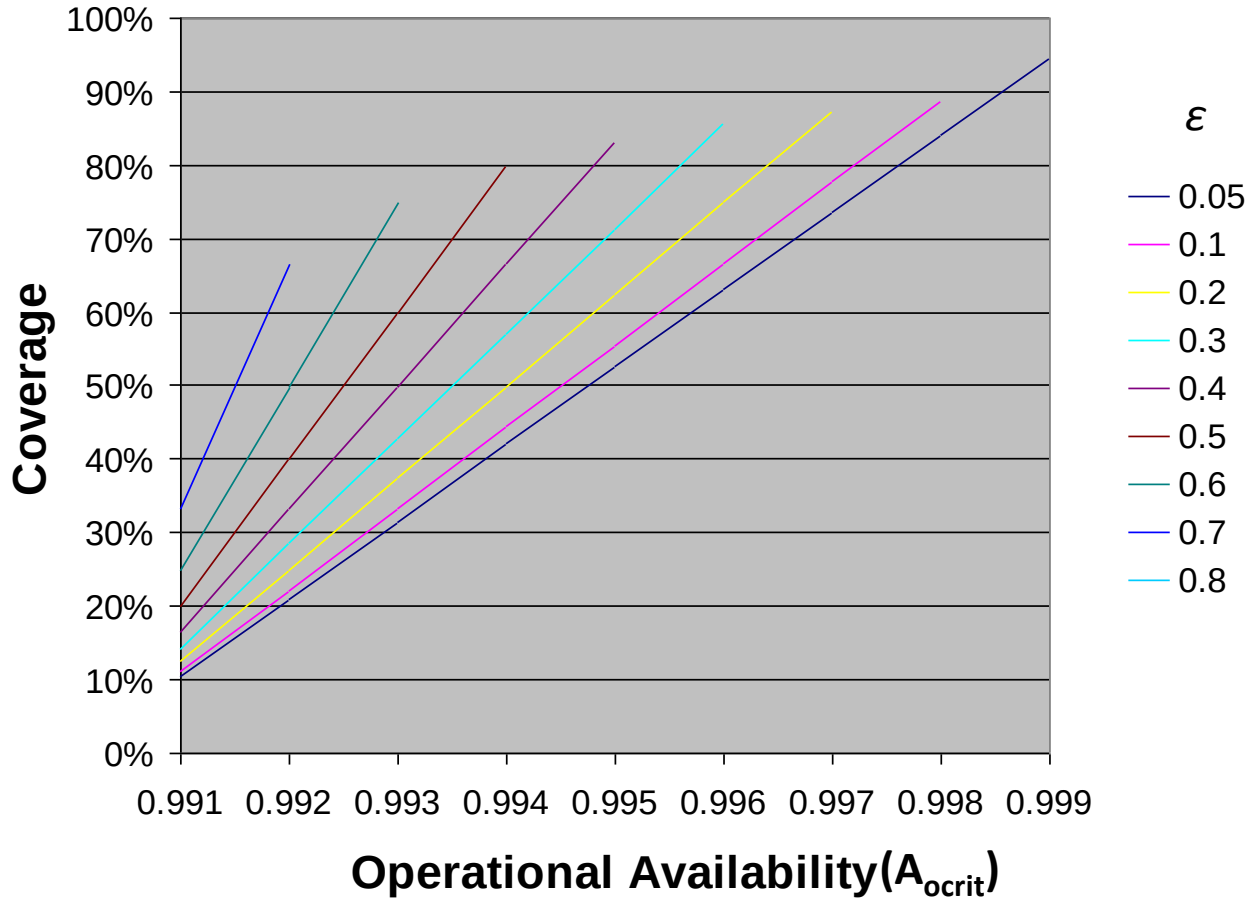
where

$$\varepsilon = \alpha + \delta_{pf} + \delta_{fa}$$

Reduces the decrease

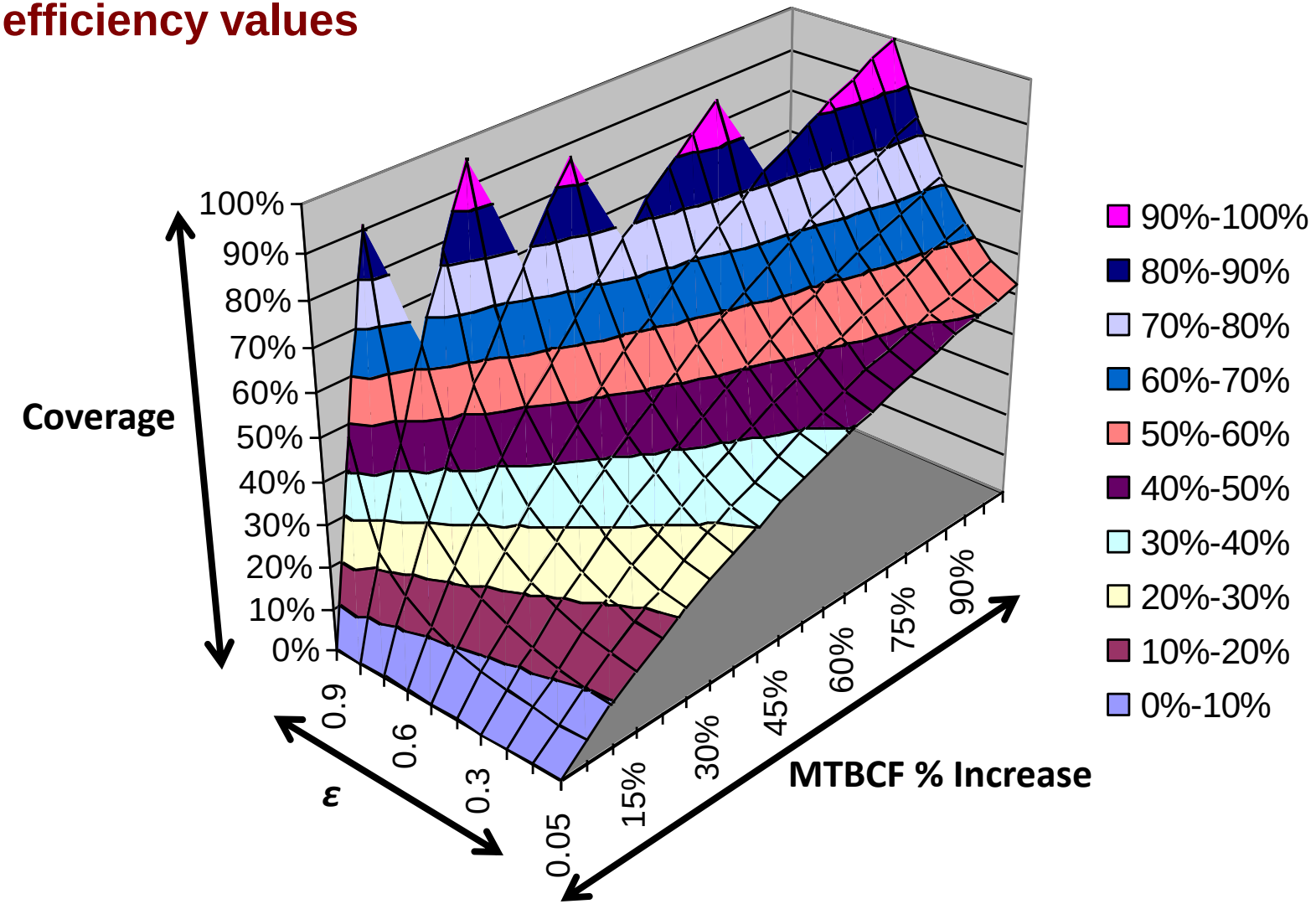
Deriving System Coverage Requirements

- **From system level, increases in inefficiency (ε):**
  - **Increase coverage requirement**
  - **Reduce achievable A_{ocrit}**



Relating Performance and PHM Requirements

- **Links coverage and inefficiency to MTBCF increases**
  - **For desired MTBCF increase, shows range of coverage and inefficiency values**



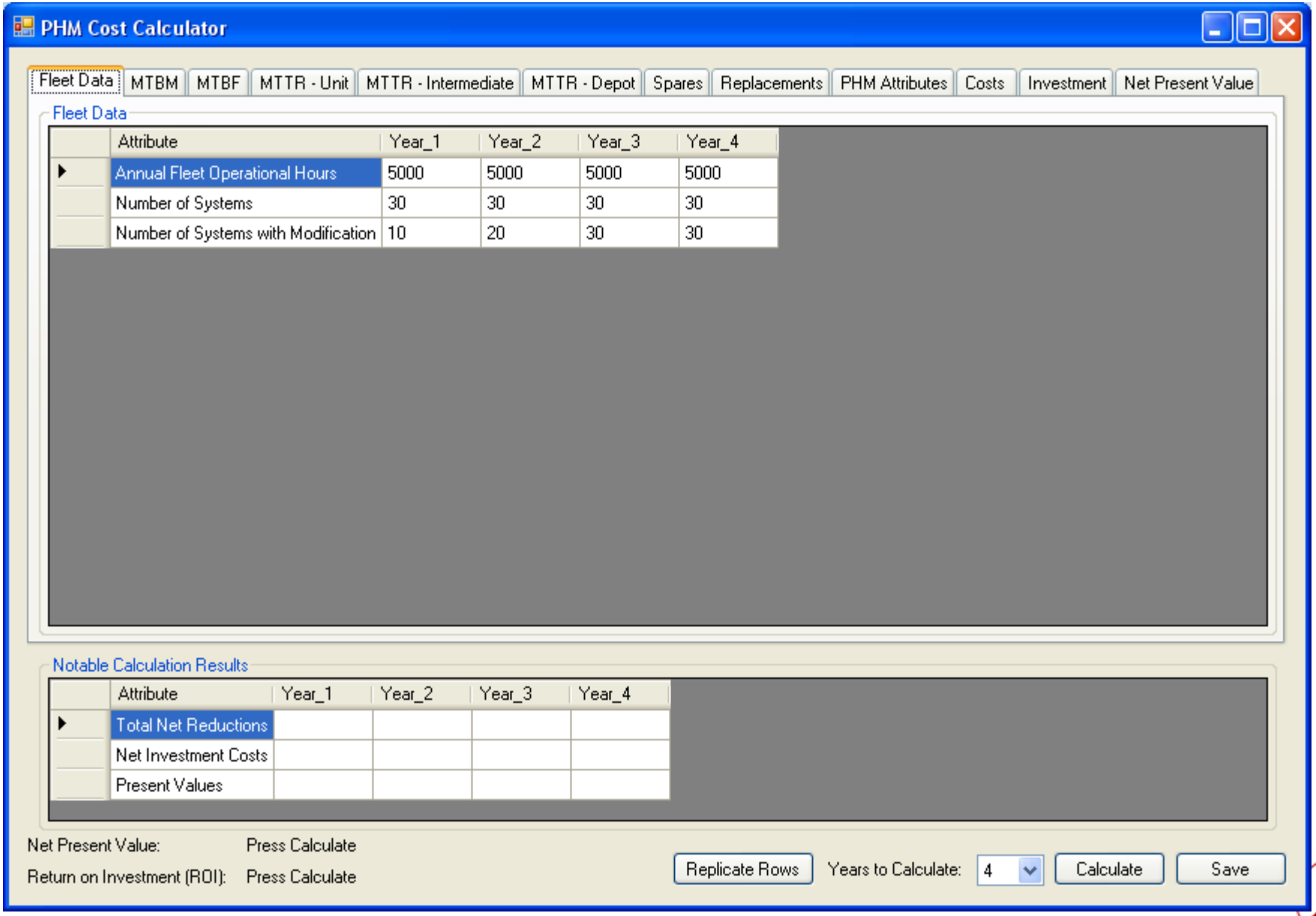
PHM Cost Calculator

Bringing it all together

Cost Calculator Overview

- **Looks at net reduction in costs**
  - **Time out of service**
  - **Maintenance**
  - **Component replacement**
  - **Other**
    - Collateral damage
    - Recovery
    - Special resources
- **Computes Present Value of costs based on drivers**
- **Investment costs due to technology and associated with implementation of technology**
- **Combines delta and investment costs in Net Present Value and ROI**

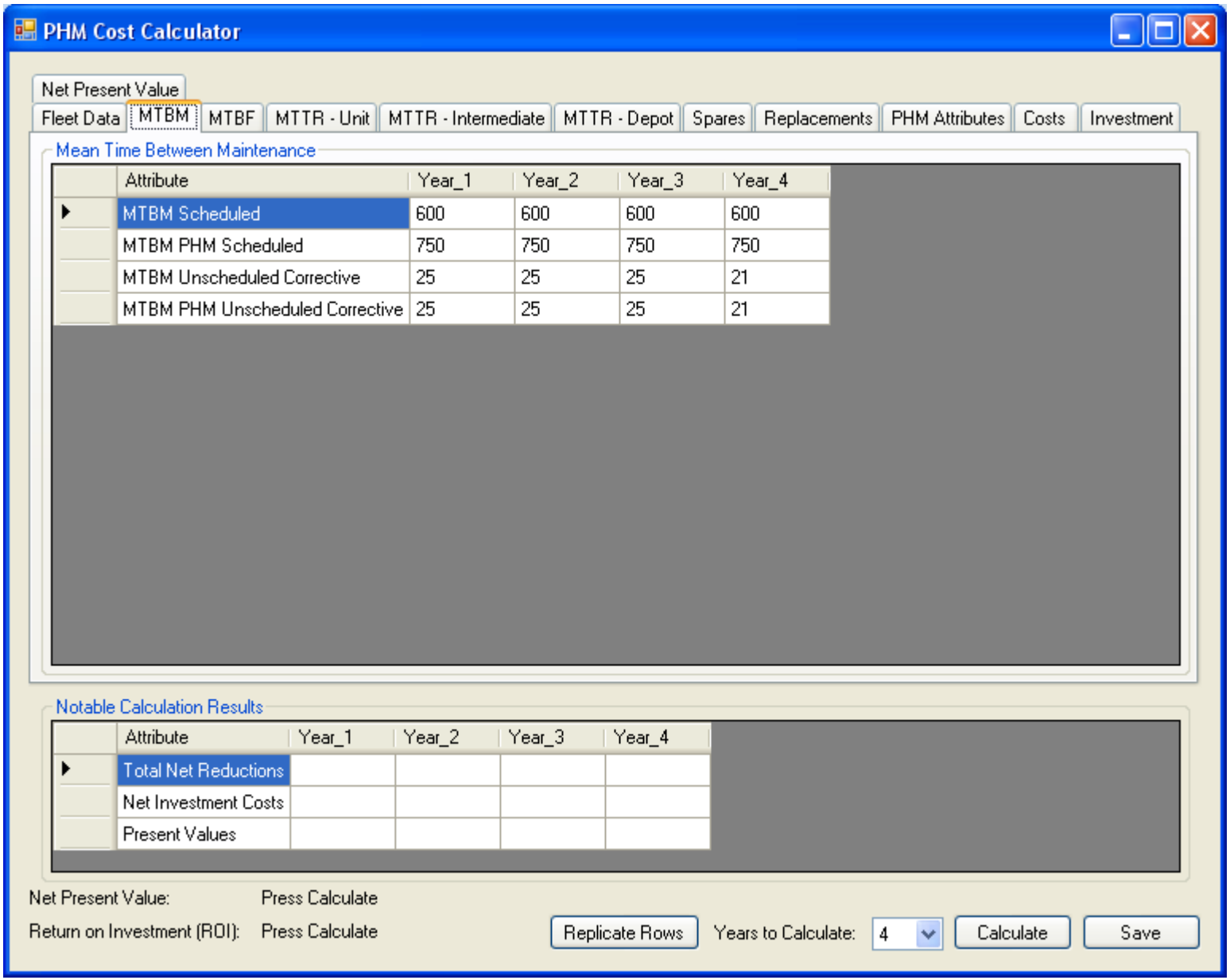
PHM Cost Calculator – Overall View



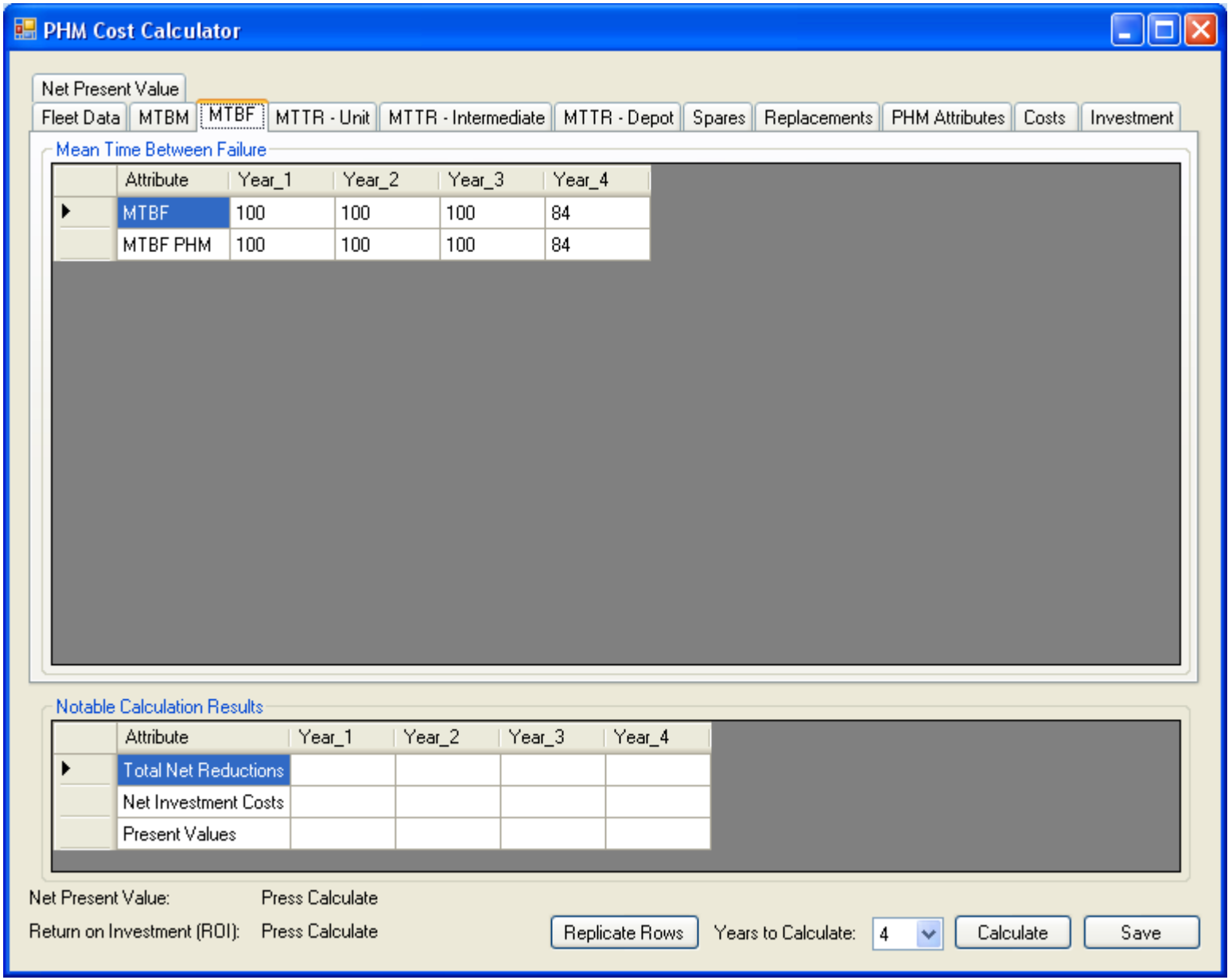
Cost Calculator Sections

- Fleet Data
- MTBM Unscheduled
- MTBF
- MTBM Scheduled
- MTTR, MDT, MMH by Support Level
  - Unit level
  - Intermediate level
  - Depot level
- Spares
- Replacements, Condemnations, Turn-Ins
- PHM Attributes
- Costs

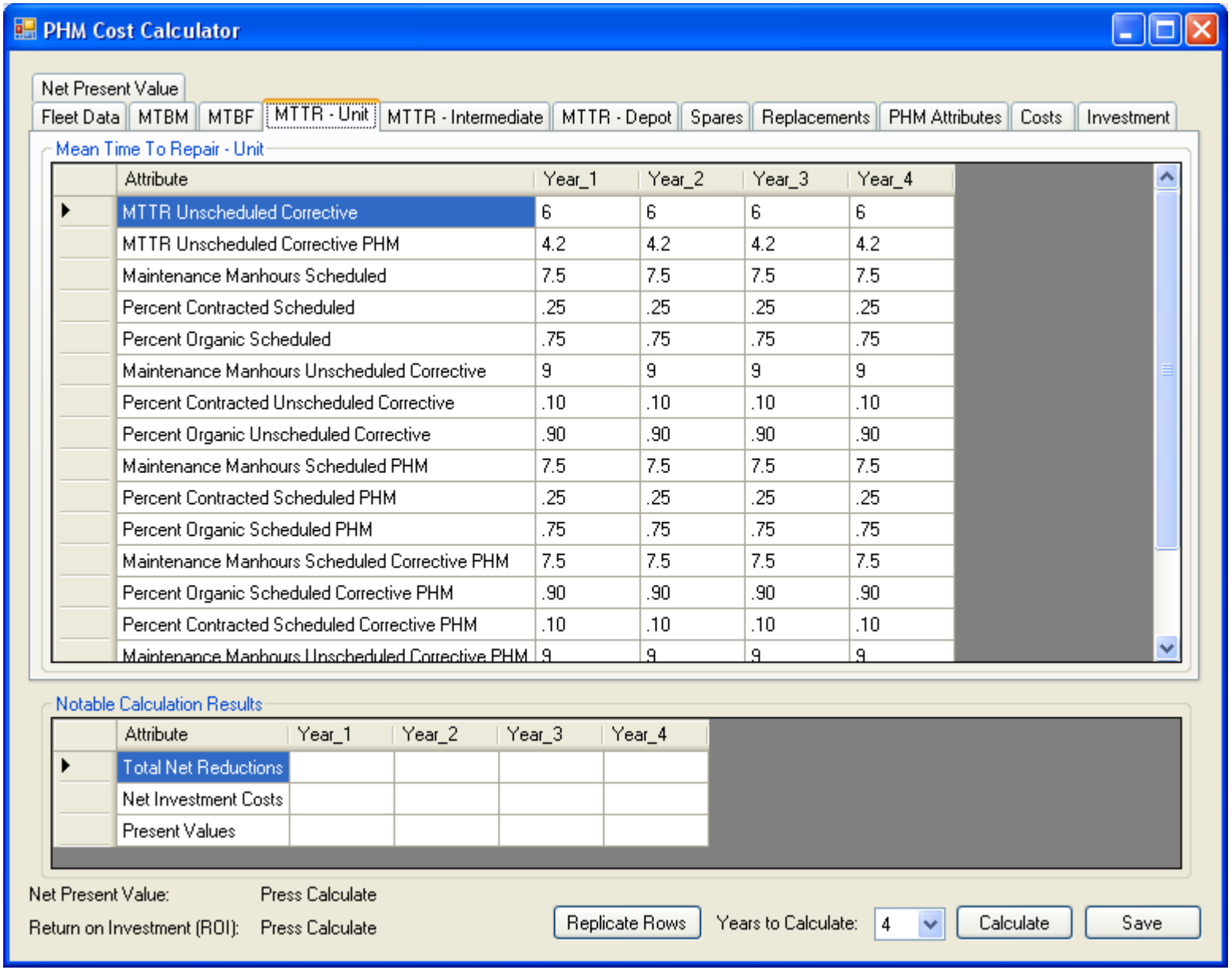
MTBM


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Mean Time Between Maintenance
Attribute
Year_1
Year_2
Year_3
Year_4
MTBM Scheduled
600
600
600
600
MTBM PHM Scheduled
750
750
750
750
MTBM Unscheduled Corrective
25
25
25
21
MTBM PHM Unscheduled Corrective
25
25
25
21
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

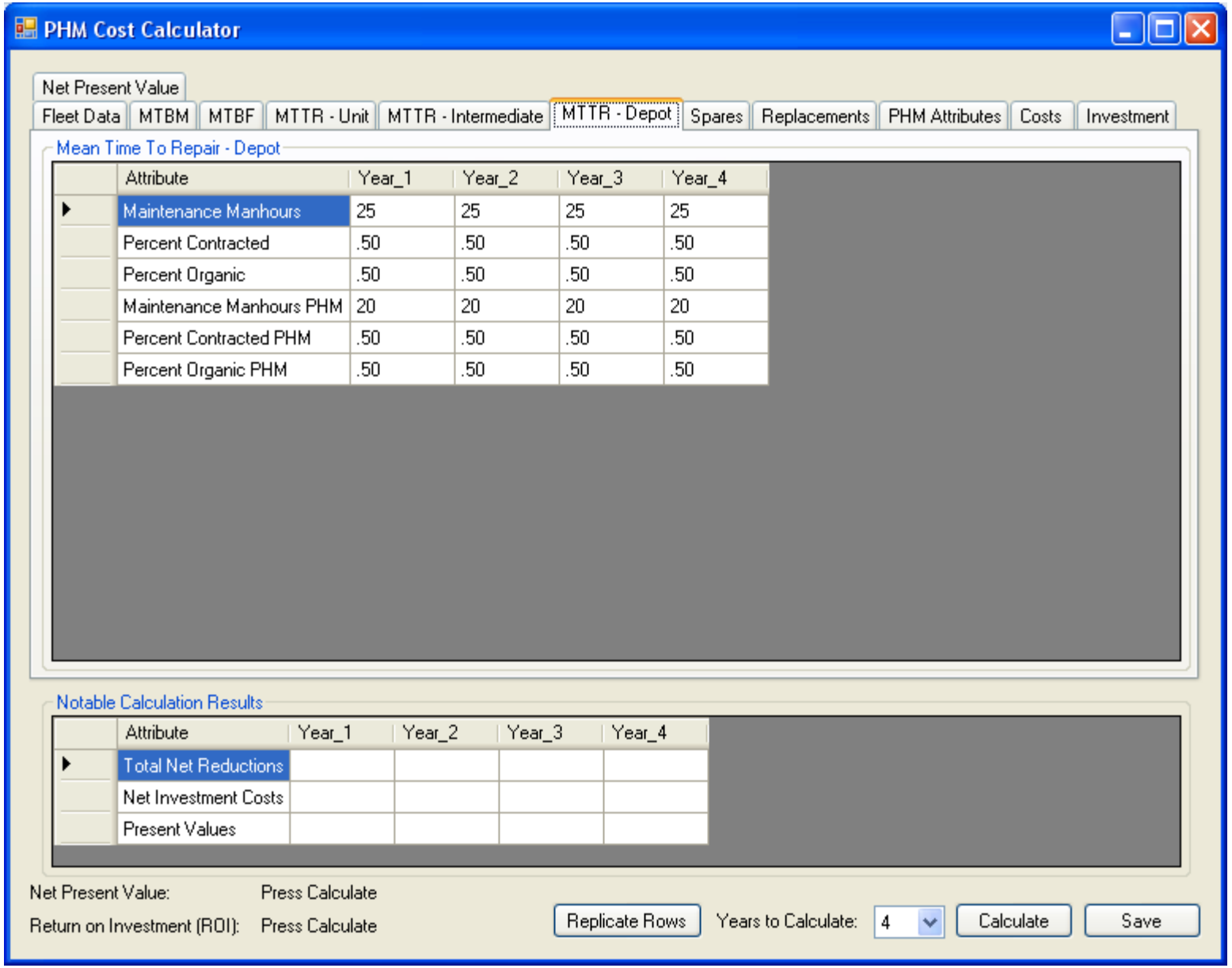
MTBF


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Mean Time Between Failure
Attribute
Year_1
Year_2
Year_3
Year_4
MTBF
100
100
100
84
MTBF PHM
100
100
100
84
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

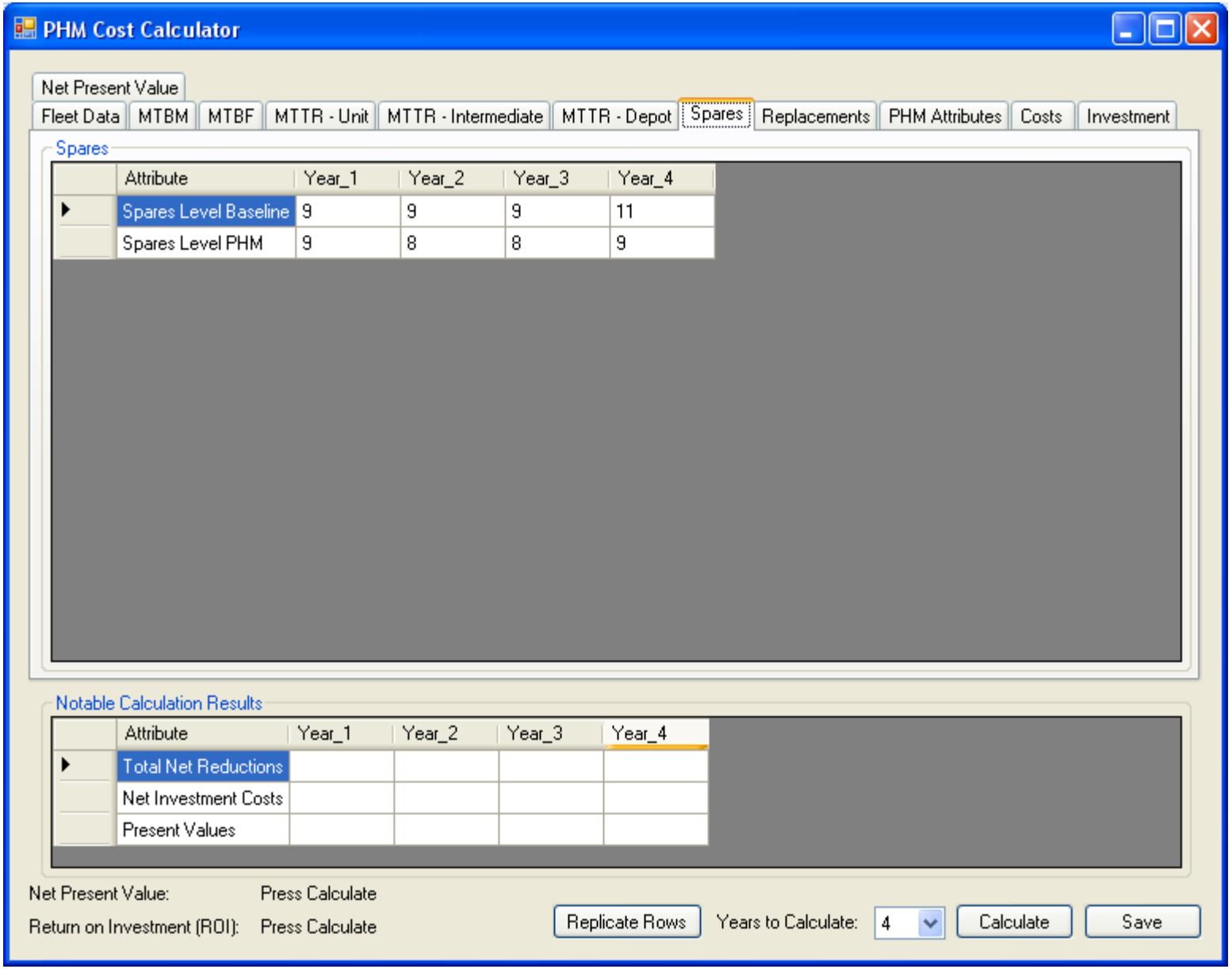
MTTR - Unit


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Mean Time To Repair - Unit
Attribute
Year_1
Year_2
Year_3
Year_4
MTTR Unscheduled Corrective
6
6
6
6
MTTR Unscheduled Corrective PHM
4.2
4.2
4.2
4.2
Maintenance Manhours Scheduled
7.5
7.5
7.5
7.5
Percent Contracted Scheduled
.25
.25
.25
.25
Percent Organic Scheduled
.75
.75
.75
.75
Maintenance Manhours Unscheduled Corrective
9
9
9
9
Percent Contracted Unscheduled Corrective
.10
.10
.10
.10
Percent Organic Unscheduled Corrective
.90
.90
.90
.90
Maintenance Manhours Scheduled PHM
7.5
7.5
7.5
7.5
Percent Contracted Scheduled PHM
.25
.25
.25
.25
Percent Organic Scheduled PHM
.75
.75
.75
.75
Maintenance Manhours Scheduled Corrective PHM
7.5
7.5
7.5
7.5
Percent Organic Scheduled Corrective PHM
.90
.90
.90
.90
Percent Contracted Scheduled Corrective PHM
.10
.10
.10
.10
Maintenance Manhours Unscheduled Corrective PHM
9
9
9
9
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

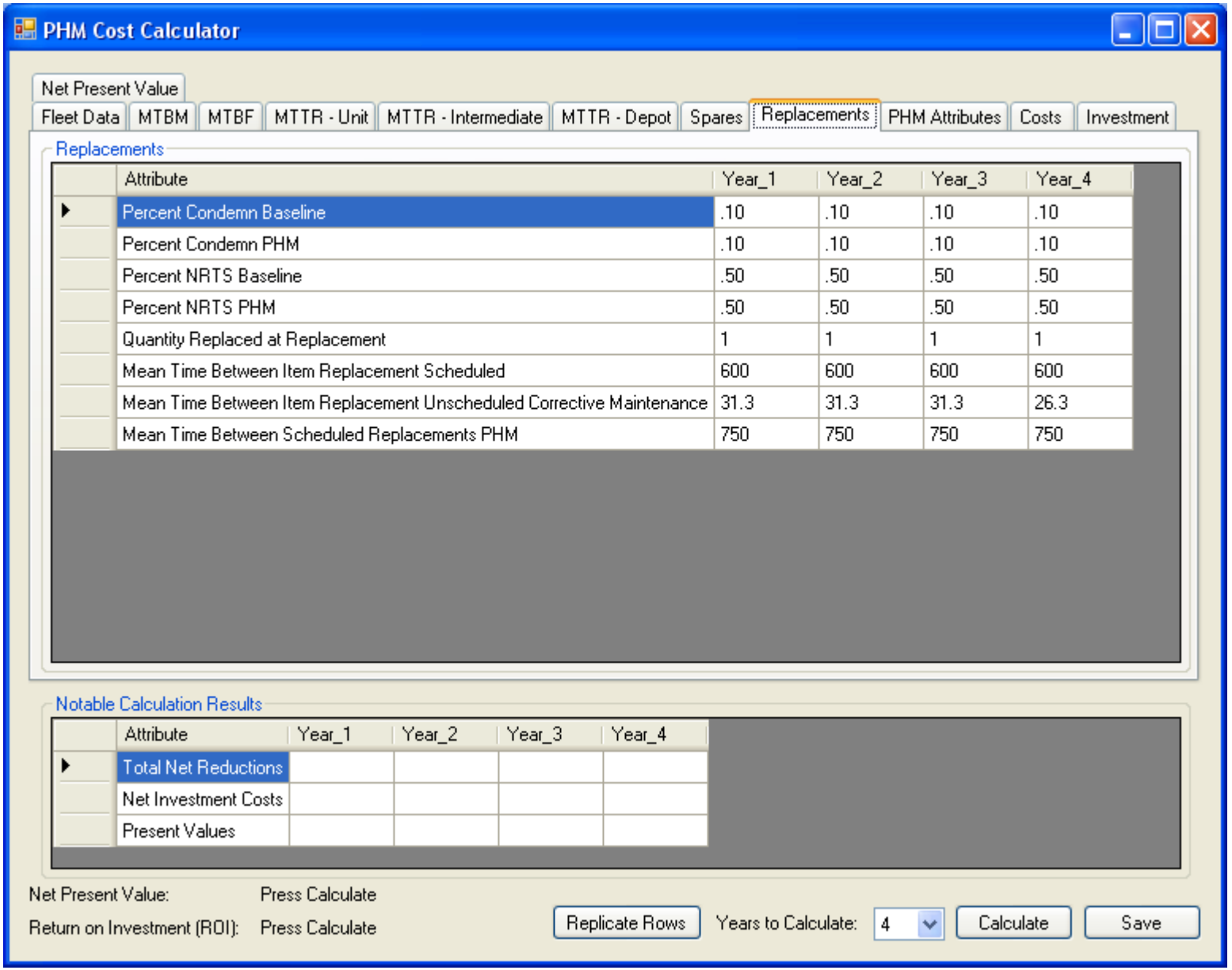
MTTR - Depot


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Mean Time To Repair - Depot
Attribute
Year_1
Year_2
Year_3
Year_4
Maintenance Manhours
25
25
25
25
Percent Contracted
.50
.50
.50
.50
Percent Organic
.50
.50
.50
.50
Maintenance Manhours PHM
20
20
20
20
Percent Contracted PHM
.50
.50
.50
.50
Percent Organic PHM
.50
.50
.50
.50
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

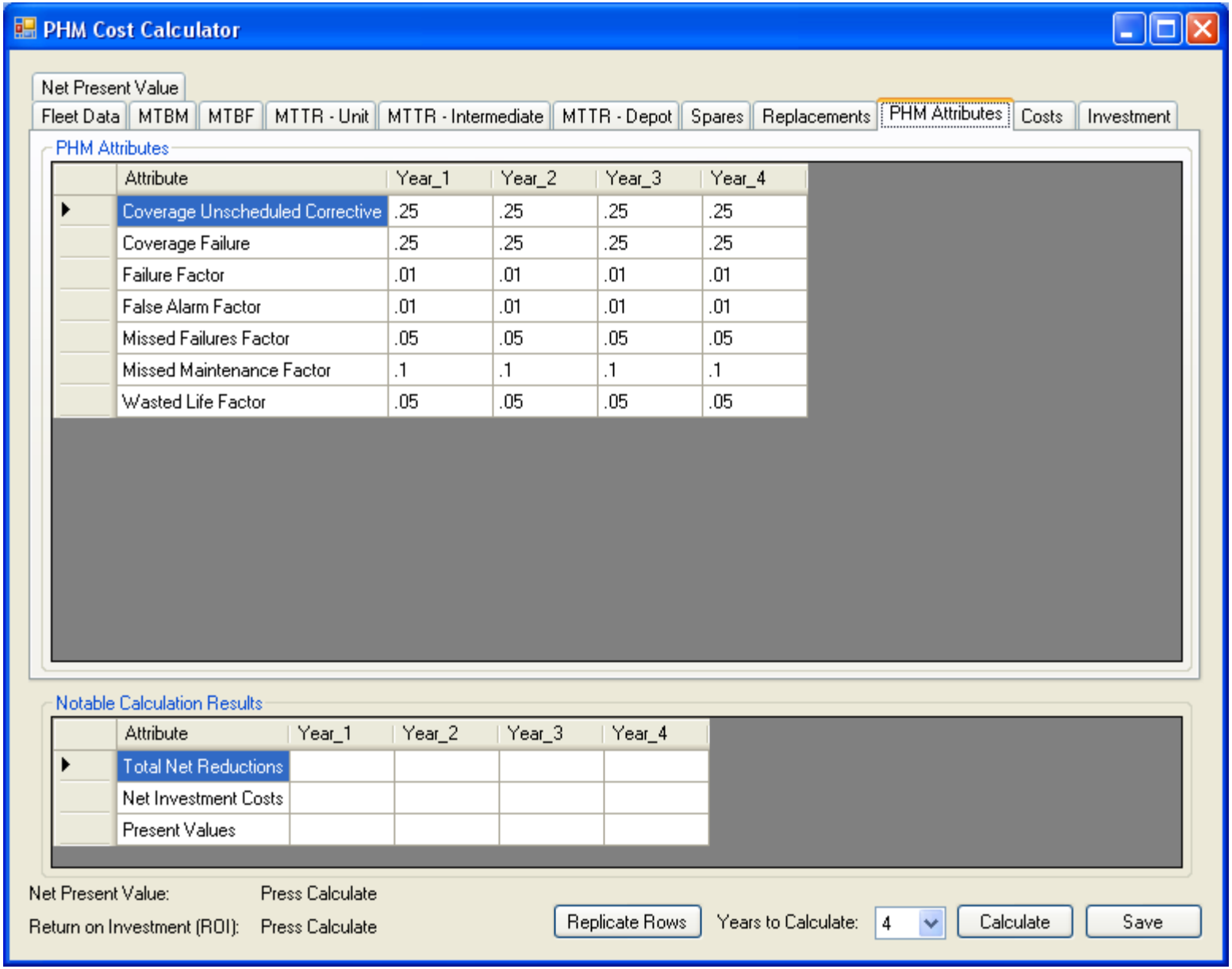
Spares


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Spares
Attribute
Year_1
Year_2
Year_3
Year_4
Spares Level Baseline
9
9
9
11
Spares Level PHM
9
8
8
9
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

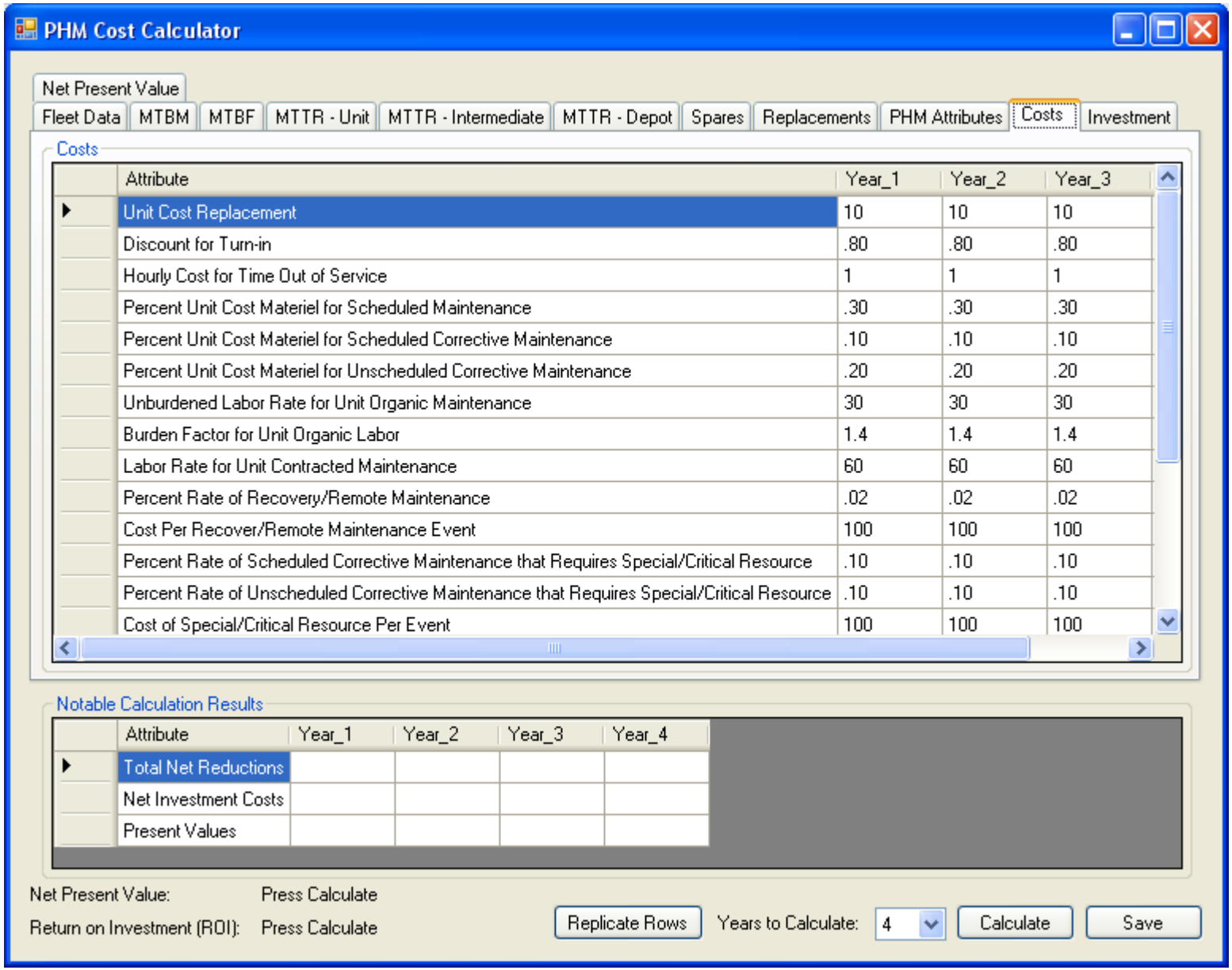
Replacements



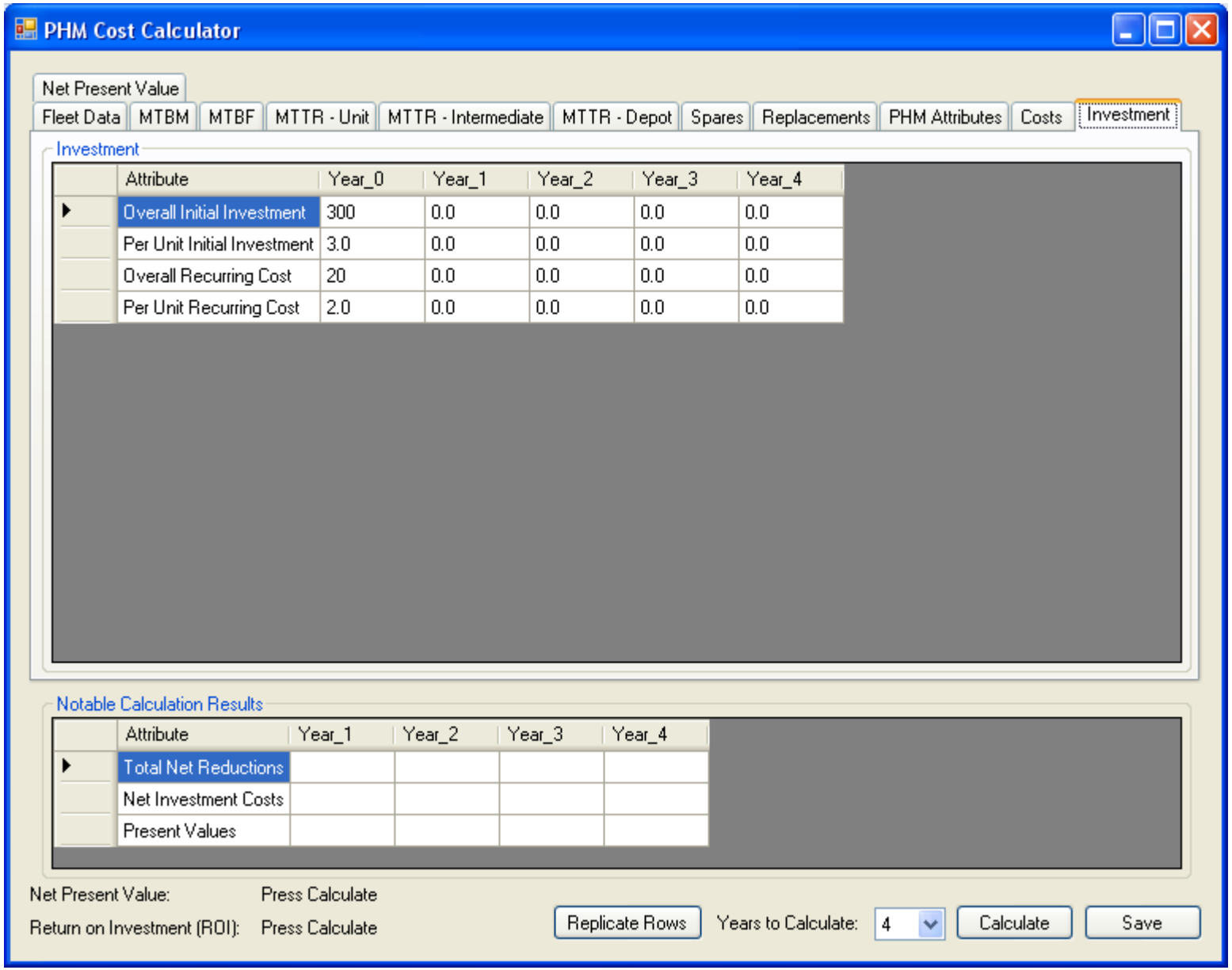
PHM Attributes



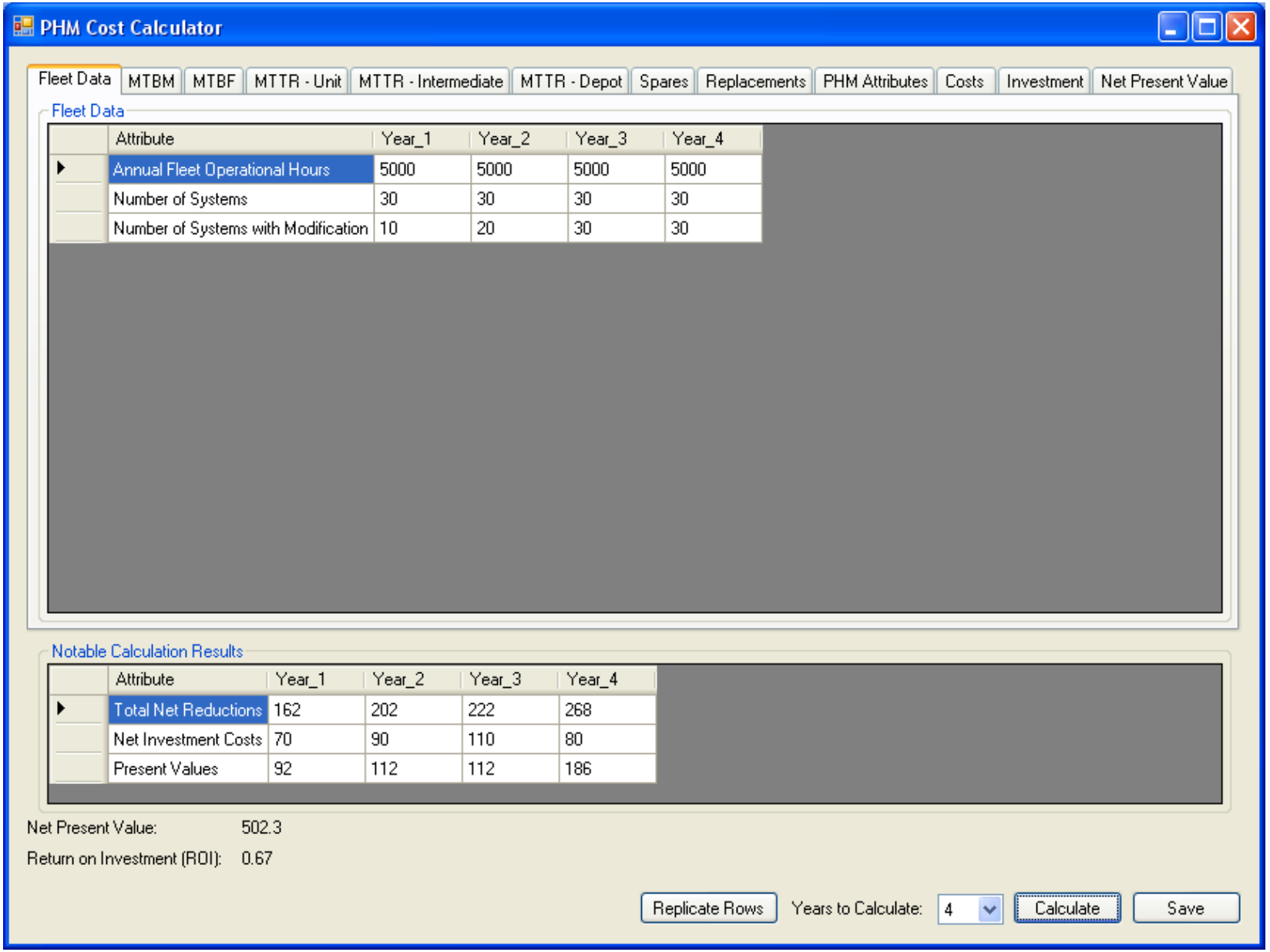
Costs


PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Costs
Attribute
Year_1
Year_2
Year_3
Unit Cost Replacement 10 10 10
Discount for Turn-in .80 .80 .80
Hourly Cost for Time Out of Service 1 1 1
Percent Unit Cost Materiel for Scheduled Maintenance .30 .30 .30
Percent Unit Cost Materiel for Scheduled Corrective Maintenance .10 .10 .10
Percent Unit Cost Materiel for Unscheduled Corrective Maintenance .20 .20 .20
Unburdened Labor Rate for Unit Organic Maintenance 30 30 30
Burden Factor for Unit Organic Labor 1.4 1.4 1.4
Labor Rate for Unit Contracted Maintenance 60 60 60
Percent Rate of Recovery/Remote Maintenance .02 .02 .02
Cost Per Recover/Remote Maintenance Event 100 100 100
Percent Rate of Scheduled Corrective Maintenance that Requires Special/Critical Resource .10 .10 .10
Percent Rate of Unscheduled Corrective Maintenance that Requires Special/Critical Resource .10 .10 .10
Cost of Special/Critical Resource Per Event 100 100 100
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value: Press Calculate
Return on Investment (ROI): Press Calculate
Replicate Rows
Years to Calculate: 4
Calculate
Save

Investment

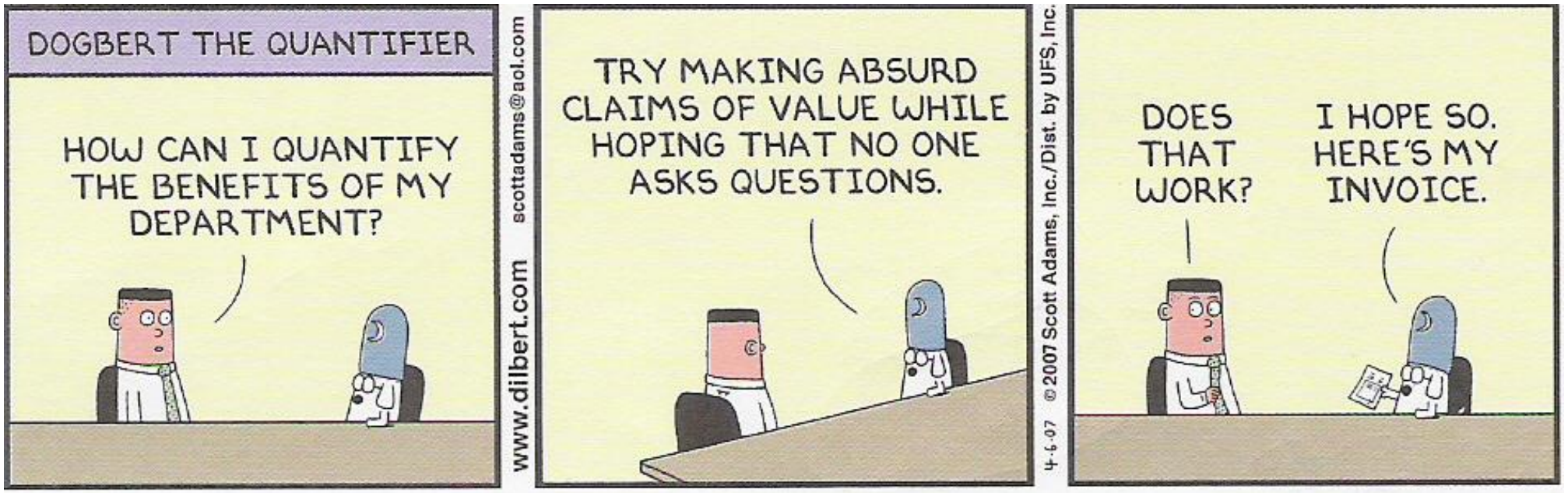

PHM Cost Calculator
Net Present Value
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Investment
Attribute
Year_0
Year_1
Year_2
Year_3
Year_4
Overall Initial Investment
300
0.0
0.0
0.0
0.0
Per Unit Initial Investment
3.0
0.0
0.0
0.0
0.0
Overall Recurring Cost
20
0.0
0.0
0.0
0.0
Per Unit Recurring Cost
2.0
0.0
0.0
0.0
0.0
Notable Calculation Results
Attribute
Year_1
Year_2
Year_3
Year_4
Total Net Reductions
Net Investment Costs
Present Values
Net Present Value:
Press Calculate
Return on Investment (ROI):
Press Calculate
Replicate Rows
Years to Calculate:
4
Calculate
Save

Results


PHM Cost Calculator
Fleet Data
MTBM
MTBF
MTTR - Unit
MTTR - Intermediate
MTTR - Depot
Spares
Replacements
PHM Attributes
Costs
Investment
Net Present Value
Fleet Data
Attribute | Year_1 | Year_2 | Year_3 | Year_4
Annual Fleet Operational Hours | 5000 | 5000 | 5000 | 5000
Number of Systems | 30 | 30 | 30 | 30
Number of Systems with Modification | 10 | 20 | 30 | 30
Notable Calculation Results
Attribute | Year_1 | Year_2 | Year_3 | Year_4
Total Net Reductions | 162 | 202 | 222 | 268
Net Investment Costs | 70 | 90 | 110 | 80
Present Values | 92 | 112 | 112 | 186
Net Present Value: 502.3
Return on Investment (ROI): 0.67
Replicate Rows
Years to Calculate: 4
Calculate
Save

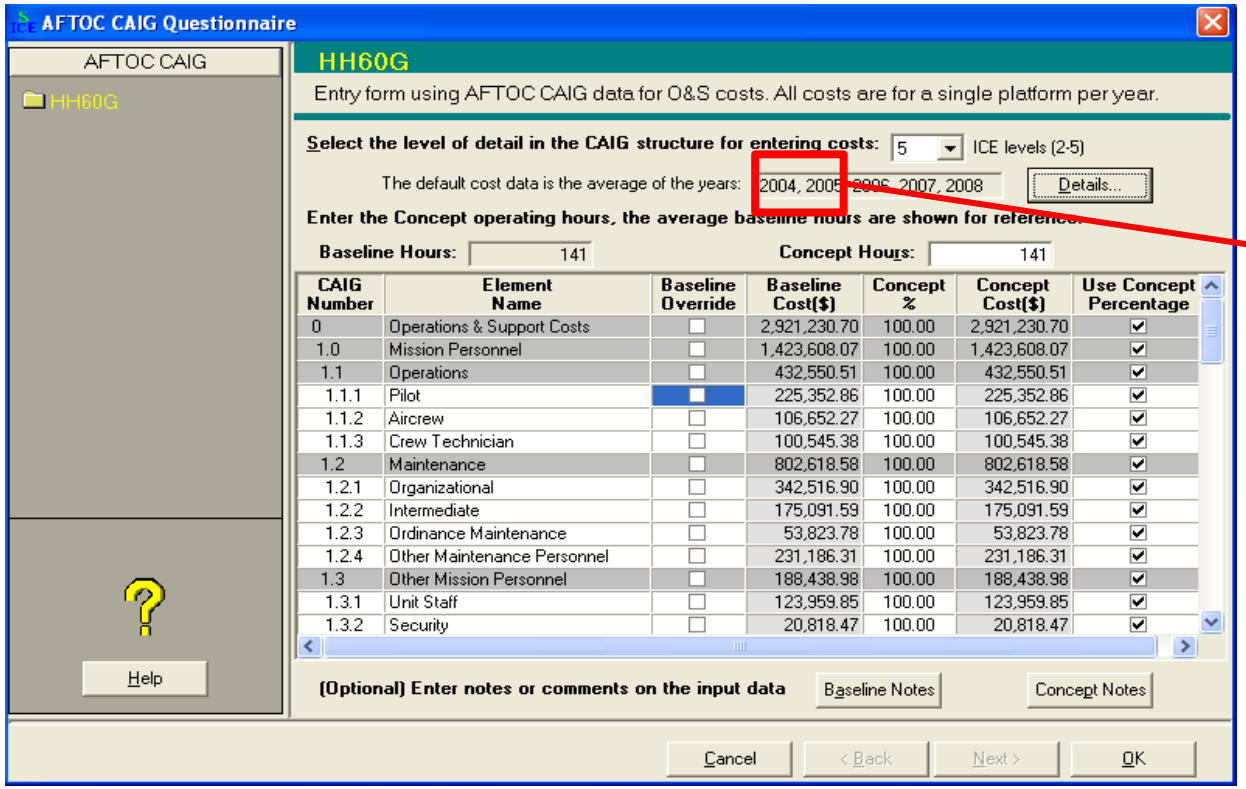
Final Thoughts

One Method for Quantifying Benefits



Observations on Proving CBM+ Benefit

- **CBM+ cost benefit does not always match well with reporting cost elements**
  - **Corollary: The cost data you need may not be collected**



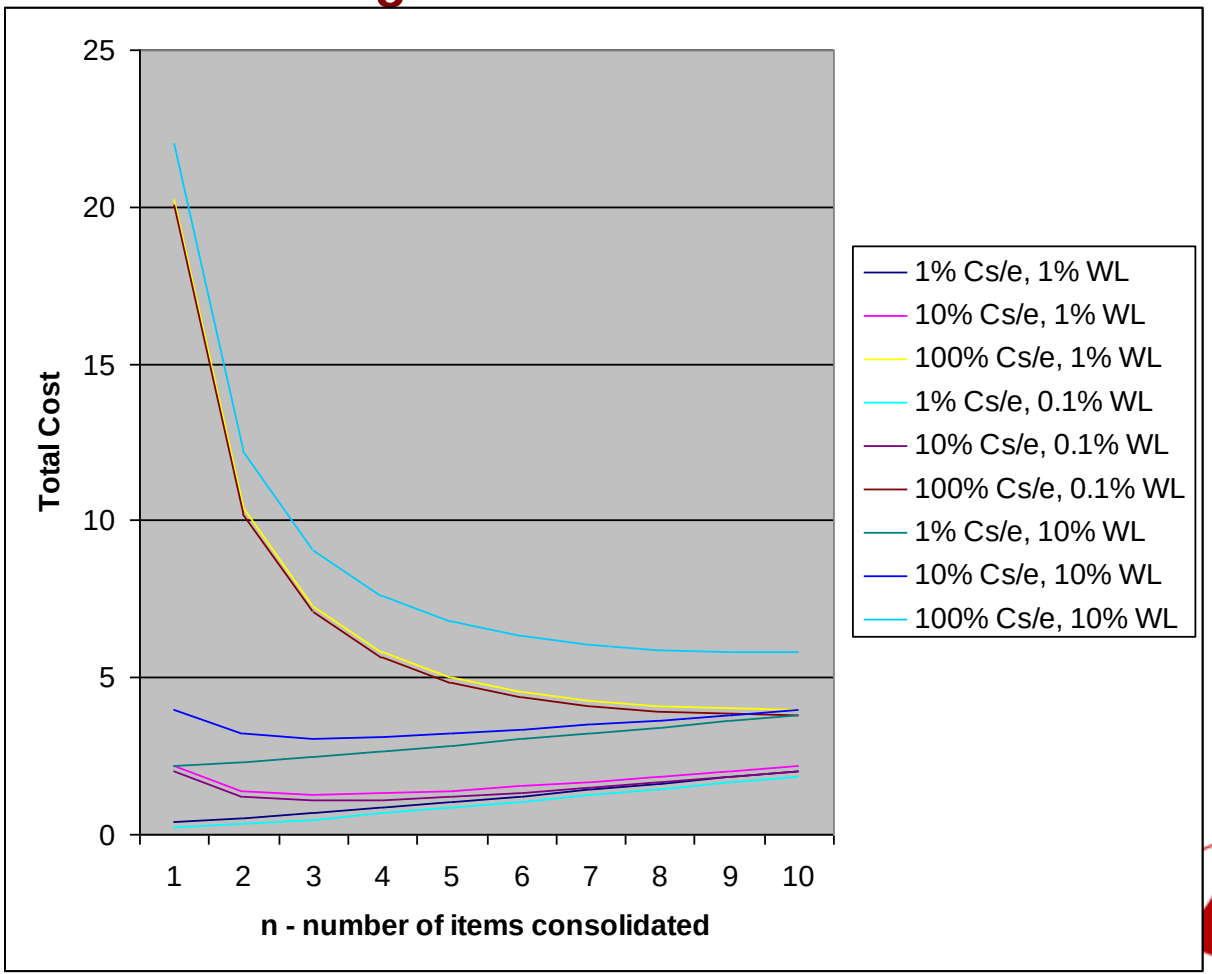
CAIG Number	Element Name	Baseline Override	Baseline Cost($)	Concept %	Concept Cost($)	Use Concept Percentage
0	Operations & Support Costs	☐	2,921,230.70	100.00	2,921,230.70	☑
1.0	Mission Personnel	☐	1,423,608.07	100.00	1,423,608.07	☑
1.1	Operations	☐	432,550.51	100.00	432,550.51	☑
1.1.1	Pilot	☐	225,352.86	100.00	225,352.86	☑
1.1.2	Aircrew	☐	106,652.27	100.00	106,652.27	☑
1.1.3	Crew Technician	☐	100,545.38	100.00	100,545.38	☑
1.2	Maintenance	☐	802,618.58	100.00	802,618.58	☑
1.2.1	Organizational	☐	342,516.90	100.00	342,516.90	☑
1.2.2	Intermediate	☐	175,091.59	100.00	175,091.59	☑
1.2.3	Ordinance Maintenance	☐	53,823.78	100.00	53,823.78	☑
1.2.4	Other Maintenance Personnel	☐	231,186.31	100.00	231,186.31	☑
1.3	Other Mission Personnel	☐	188,438.98	100.00	188,438.98	☑
1.3.1	Unit Staff	☐	123,959.85	100.00	123,959.85	☑
1.3.2	Security	☐	20,818.47	100.00	20,818.47	☑

Adjust concept O&S costs based on PHM cost element calculator results

NOTE: Notional AFTOC shown. Will require AFTOC account to use real data.

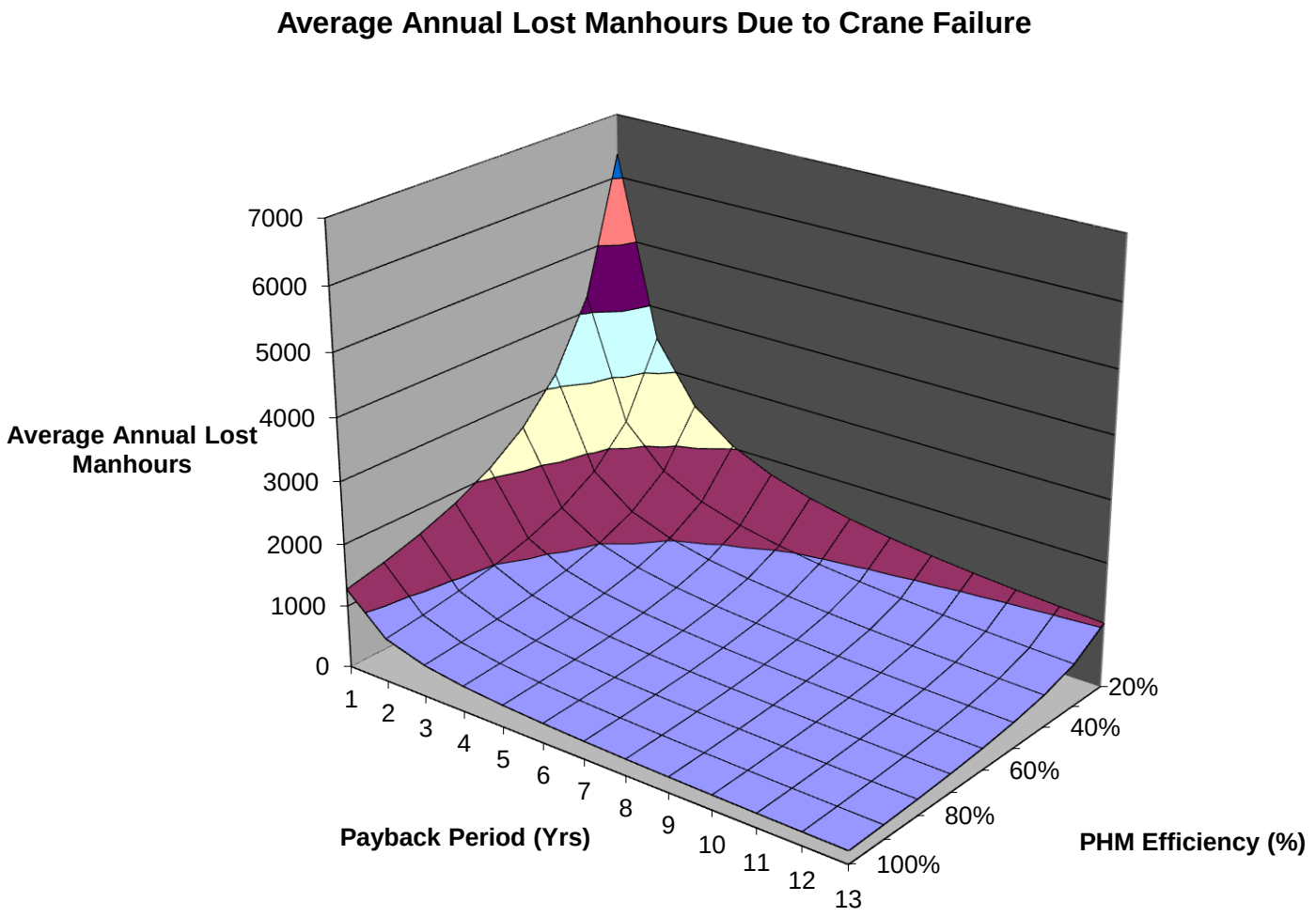
Observations on Proving CBM+ Benefit

- **Optimal maintenance manpower workload and optimal readiness are inversely related**
  - **Optimal workload = spread out over time**
  - **Optimal readiness = bunched together**
- **Optimal maintenance in advance of failure may not be "fix all that you can"**



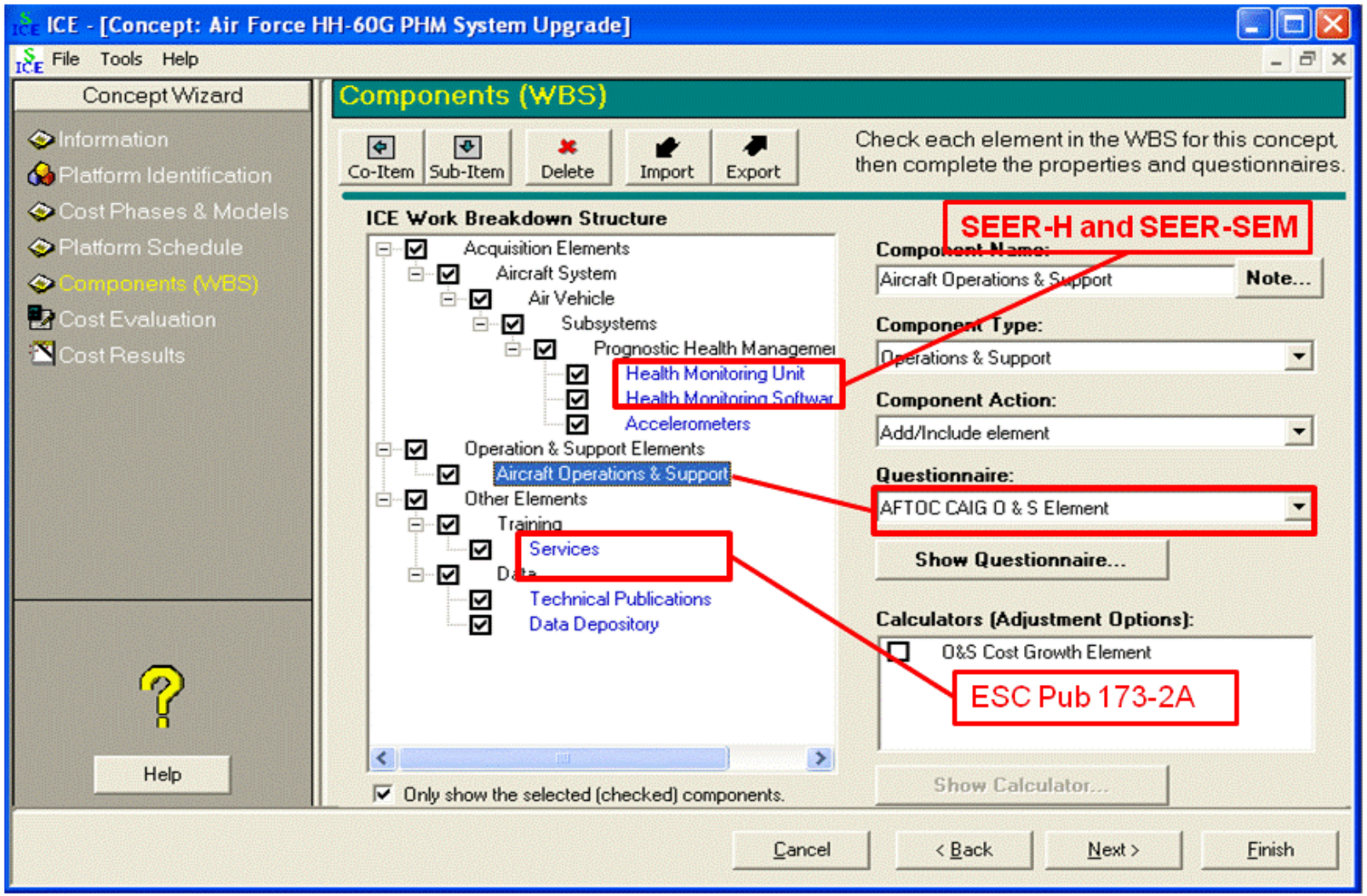
Observations on Proving CBM+ Benefit

- **In the absence of data, try reverse engineering the missing data**



Observations on Proving CBM+ Benefit

- **Investment cost estimating is just as important as avoided cost estimating**



Observations on Proving CBM+ Benefit

- **Cost benefit of readiness improvement**
  - **% improvement * system cost?**
  - **$/ready flight hour?**
  - **What value has already been expressed?**
- **Policy and the status quo can be as big a barrier as the technology or lack of funding**
  - **e.g., Need carcass for spare or lower priority in advance**
- **Analysis may depend on the benefit area being targeted**

Prognostic Benefit Scenarios

- Reduce Lead Times
  - Advanced warning of failure allows for logistics planning and actions before failure occurs, reducing lead times for implementing repair/replacement
- Avoid Consequences of Failure

  Advanced warning of failure allows for…
  - Repair/replacement before failure occurs, thus avoiding its potential consequences
  - Fix at convenient time, location, etc.
- Extend Life/Reduce Maintenance Frequency
  - Advanced warning of failure allows for transition from time-based to condition-based maintenance
- Optimize Resource Use
  - Advanced warning of failure allows for potential failures to be grouped to optimize use of scarce/costly resources

Final Thought

Q: What is harder than trying to get someone to pay for PHM?

A: Getting someone to pay for benefit analysis of PHM