A Systems Approach to Prognostics and Health Management Requirements Defect Reduction

by
Richard Deka

Agenda

- Project Objective
- Background
- Defect Data
- Cost Benefit Analysis
- Systems Engineering Tools & Principles Employed
- Action Plan
- Final Results
- Conclusions
- Questions
Project Objective

Employ System Engineering Tools and Processes to Reduce Requirements Defects and Increase the Quality and Efficiency of the F-35 Lightning II Prognostics and Health Management Requirements Development Team

Background: What is PHM?

- Prognostics and Health Management (PHM)
  - Diagnostics
    - The process of determining the state of a component to perform its function(s)
  - Prognostics
    - Predictive diagnostics which includes determining the remaining life or time span of proper operation of a component
  - Health Management
    - The capability to make appropriate decisions about maintenance actions based on diagnostics / prognostics information, available resources and operational demand

- PHM turns ‘Bad Actors’ or ‘Intermittents’ into scheduled maintenance without affecting the success of the Mission
Background: PHM Team Org Chart

Richard Deka (Manager)  
Rex Sallade (IPT Lead)

El Segundo
- Ed Ramos
  Tech Lead / Coordination
- Sam Johnson
  RWP Author
- Don Ellis
  RWP Author
- Chau Mai
  RWP Author
- Kyle Stephens
  RWP Author

Fort Worth
- Jeff Neibauer
  Mission Systems / Air Vehicle Interfaces
- Shirley Zhang
  RWP Author
- Mike Smith
  RWP Author
- Sheila Lewis
  RWP Author
- Paul Sharp
  Block 1 / SPAR Lead
- An Bui
  RWP Author
- Nguyet Bui
  RWP Author
- Debbie Bailey
  Mission Systems / Air Vehicle Interfaces
- Mike Phillips
  Mission Systems / Air Vehicle Interfaces
- Eric Bryant
  Supplier Mgmt Support

Background: Requirements Author

- Participate in the definition, design, and development of the JSF PHM requirements as a member of the PHM Design and Integration Team

- Coordinate with the Software development team and the Systems Engineers for other Mission Systems (MS) and Air Vehicle (AV) capabilities to develop a coordinated PHM capability in support of the JSF Pilots, Logistics, and Maintainers

- Develop a PHM design which provides for efficient and economical Operation and Support of JSF through accurate detection and isolation of Air Vehicle failures
Background: RWP

- Requirements Work Package (RWP)
  - A configuration controlled change document and lifecycle that implements the developmental change control process for generation and modification of design elements
  - Develops changes to multiple products that integrate to implement a requirement, capability, or function
  - Consists of three phases of milestones, generally utilized for the incorporation of new capability into a given developmental block update

Background: SPAR / SPR RWP

- System / Software Product Anomaly Report (SPAR)
  - A configuration controlled change document and lifecycle that implements the developmental corrective action process

- System Product Anomaly Report Requirements Work Package (SPR RWP)
  - A configuration controlled change document and lifecycle that implements the developmental change control process; the SPR RWP is the Cost Account Package (CAP) for one or more design SPARs
  - Almost identical to an RWP, but with shortened lifecycle (typically more focused on smaller specific changes)
**Background: SPE**

- **Software Product Evaluation (SPE) – Peer Review**
  - A configuration controlled change document and lifecycle that implements the peer review process
  - Captures project and organizationally required data to perform process and product quality analysis
  - Identification and resolution of defects in software and interface requirements prior to release to software development
  - Coordination of work product content with other related disciplines, providing input to or receiving the resulting work product
  - Implemented as the Phase III external walkthrough (EWT)

**Background: Current / Future / Plan**

- **Requirements Current State (per RWP):**
  - ~10 – 12 months
  - ~150 – 170 comments
  - ~20 – 30 SPARs
  - Inefficient / low producing employees

- **Future State (per RWP):**
  - ~4 – 6 months
  - ~10 – 20 comments
  - ~10 – 15 SPARs
  - Inefficient / low producing employees

- **Improvement Plan:**
  - Use System Engineering tools and principles to evaluate current processes and procedures to more efficiently reallocate the team and its workflow, and improve communication, coordination, training, quality, productivity, and efficiency
Background: Present RWP Process

**Tier 4 Requirements**
- **Customer Requirements**
- **Mission Systems PHM RWP Lead**

**RWP Plan & Functionality**
- **Partitioning**
  - 2-4 wks
- **Architecture**
  - 2-10 wks
- **Requirements**
  - 2-8 wks
- **MSPHM Software**

**Mission Systems PHM RWP Lead**
- **Diags.**
  - Define Messages, CD, Architecture
  - 6 -16 wks

**Improve coordination up front to ensure quality of product going into EWT**
- **Finalize Rqs. and Act. Diags.**

**Totals**
- 21 - 56 Wks Throughput Time
- 21 Wks Processing Time

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Background: SPE Comments & SPARs

**Requirements Phase 2**

**Requirements Phase 3**

**SPARs = Escapes SPR RWP Process**

**SPE Comments = Churn**

**External Walkthrough**
- 5x 220 SPARs
- 10x 49 SPARs

**Design Software**
- 10x 49 SPARs

**Implement Software**
- 15x 45 SPARs
- 20x 57 SPARs

**TBD SPARs**
- 100x
- 1000x

**TBD SPARs**

**Deployment**

**Project Scope**

**Project Goal Is To Reduce Comments And SPARs In PHM Requirements Process**

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**SPAR count as of Feb 5, 2007**

- Does not include rejected, transferred, duplicates
Defect Data: SPAR Effects on RWPs

1. SPARs Against Previous RWPs Start Coming In

2. SPAR Count Continues To Rise

3. Work To Burn Down SPARs, RWP Work Is Interrupted

4. Stop SPAR Work To Complete RWPs

5. Resume SPAR Work Now That RWPs Are Completed

Open PHM SPAR Count (Jun 03 – Feb 07)

Defect Data: Integration / Test SPAR Drivers

PHM 0.1 Integration & Test SPARs

"Not a problem", "Transferred", "Duplicate" SPARs have been removed
SIMS due to Design, Implementation, Int & Test errors have been removed

PHM 0.5 Integration & Test SPARs

"Not a problem", "Transferred", "Duplicate" SPARs have been removed
SIMS due to Design, Implementation, Int & Test errors have been removed

Open PHM SPAR Count (Jun 03 – Feb 07)
Defect Data: SPE Defects

PHM RWP SPE Defects
Blocks 0.1 & 0.5 RWPs

Defect Data: Measurement Systems

- Lagging metrics show what has happened
- Leading metrics give insight into what will happen

<table>
<thead>
<tr>
<th>Metric</th>
<th>Notes</th>
<th>System</th>
<th>Measure</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagging in place</td>
<td>EV and other mental models</td>
<td>Cost and schedule performance</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>PT metric reports</td>
<td>Effort and quality</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>SPE DEV records in Dimensions</td>
<td>Churn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lagging in place</td>
<td>SPE records in Dimensions</td>
<td>Exposure</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>SPE metric analysis in SPE RWP</td>
<td>Number of SPE metrics against individual RWPs</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>EPG Product Development Counsel</td>
<td>Effectiveness of cross-training</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>SQA audit</td>
<td>Process capability</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>Attendance log on IC and other tools</td>
<td>Software development team participation in walkthroughs and stakeholder meetings</td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>Stakeholders</td>
<td>Effectiveness of walkthroughs and phase 1 stakeholder meetings</td>
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<tr>
<td>Lagging in place</td>
<td>Serial code in LANS</td>
<td>Labor hours spent on each RWP</td>
<td></td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>Serial code field in LANS</td>
<td>Labor hours spent on each RWP between Phase III and RWP signoff by both requirements team and software development team</td>
<td>Churn</td>
<td></td>
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<tr>
<td>Lagging in place</td>
<td>Software team labor hours to rework software because of defects</td>
<td>Escapes</td>
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</table>
SE Tools and Principles Employed

- Root Cause Analysis
  - "5 Why's"
  - Pareto Analysis
- Lean Thinking
  - Single Piece Flow
  - Pull and Just-In-Time Methodology
- Trade Studies
- Morale and Team Building
- Time Estimating and Budget Planning
- Risk Analysis

Cost Benefit Analysis

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>REQ</th>
<th>SW</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>50% Reduction In SPE Comments</td>
<td>$0.15M</td>
<td>$0.07M</td>
<td>$0.22M</td>
</tr>
<tr>
<td>50% Reduction In SPARs</td>
<td>$1.72M</td>
<td>$0.34M</td>
<td>$2.06M</td>
</tr>
<tr>
<td>Cost Of Training</td>
<td></td>
<td></td>
<td>($0.10M)</td>
</tr>
<tr>
<td>Additional Travel</td>
<td>($0.08M)</td>
<td>($0.08M)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Net Cost Avoidance $2.10M</td>
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</table>

Assumptions:
- $100 per hour notional wrap rate; actual rate is NGC Proprietary
- 50% reduction of SPARs and SPE comments due to improvements
- Block 0.1 rework excluded from calculation because the design was agreed to and signed off with an incomplete RWP
- Est. 50% of 0.5 SPARs have been submitted
- Block 1 and Block 2 work remains and no new requirements for Block 3
- Blocks 1 - 3 SPE effort = combined Blocks 0.1 & 0.5 SPE effort
- SW team SPE comment effort = 50% of requirements team effort
- Exclude estimated 20% change-related SPARs
- 33% SPE comment reduction from triage process (eliminates all of cosmetic defect comments)
- 17% SPE comment reduction in operational defect comments (25% of 66% operational defects)
Action Plan: Coordination (1/3)

- **Current Lack of Coordination**
  - Inter-group
    - Between RWP authors, stakeholders, and subject matter experts
  - Intra-group
    - Between RWP products
      - Requirements, ADD
    - Interface Control Document (ICD) development
      - Supplier management and RWP authors
      - MS, VS, structure
      - Knowledge base designers
  - **Effect**
    - Designing In A Vacuum
      - Too much requirements comments / poor design
        - During RWP development
        - Escaped defects
      - Last minute surprises during review
        - Hidden requirements
      - Misunderstanding between groups

Action Plan: Coordination (2/3)

- **Future**
  - Review Readiness
    - Reviews are no longer design coordination meetings
  - RWP Author, Stakeholders, and Subject Matter Expert (SME) Coherency
  - Mandates and Ideas
    - Clear and concise documentation
    - Follow through and enforce
  - **Payoff**
    - Less rework / SPARs
    - Less schedule slip
    - Higher quality product
Action Plan: Coordination (3/3)

- **Accomplishments To Date**
  - Developing a generalized schedule to allow for milestone “bottlenecks” to be determined
  - Created draft quality checklist
  - Created draft reviewer side SPE DEV triage process
  - Adding leading metrics to measurement system

- **Next Steps**
  - Obtain stakeholder buy-in for quality checklist and triage process
  - Create measurement plan for control phase (control plan)

Action Plan: Schedule (1/3)

- **Current Lack of Scheduling**
  - Inter-group coordination
    - PHM to MS / VS design
    - PHM to MS / VS software build plan
    - MS / VS SIMS design and schedule
  - Intra-group coordination
    - PHM design to software build plan
    - PHM design to ICD
  - RWP development
    - Not tied to complexity of RWP, amount of collaboration, or ICD level
    - Too many reviews scheduled in a short period of time
      - RWP reviews all scheduled simultaneously

- **Effect**
  - Mismatch between requirements and ICD
  - Ineffective design review process
  - Reactive rather than proactive
Action Plan: Schedule (2/3)

- **Future**
  - Coordinated, coherent RWP product
  - Review readiness
    - More possibility of capturing defects before they enter the next phase
    - More participation

- **Payoff**
  - Less "11th hour" engineering
  - Defect avoidance
  - Higher quality product

Action Plan: Schedule (3/3)

- **Accomplishments To Date**
  - The current block RWP work has already been scheduled, so with the exception of major schedule change, nothing can be done to improve this condition at this time

- **Next Steps**
  - Develop a method to calculate PHM schedules accounting for staggering review schedules, coordination, and complexity issues
Action Plan: PHM Growth Plan (1/3)

• Current
  – Current and future plans
    • Not always coordinated
    • Not always communicated, documented, flowed down

• Effect
  – Vision is not communicated
  – Working in the dark
    • No path forward
    • Reliant upon core legacy “grey beards” for direction

Action Plan: PHM Growth Plan (2/3)

• Future
  – Well defined PHM architecture
  – Functionality growth plan
  – Block lead / system architect role

• Payoff
  – RWP scope is optimized
  – Reduced conflict between users
    • PHM to non-PHM
    • Within group
  – Importance of what’s being done
    • Appreciation
Action Plan: PHM Growth Plan (3/3)

• **Accomplishments To Date**
  - MS meeting relevant to PHM architecture identified
  - Buy-in by leads for PHM design documentation acknowledged
  - Worked PHM presence at MS meeting
  - Proposed scope of PHM design documentation

• **Next Steps**
  - Obtain agreement on scope
  - Complete PHM design documentation

Action Plan: Quality (1/3)

• **Current**
  - Lack of product ownership and accountability
  - Inconsistent enforcement of guidelines
  - Inconsistent understanding of guidelines

• **Effect**
  - Poor product
  - Large amount of comments during design / rework after release
Action Plan: Quality (2/3)

• **Future**
  - Produce quality instead of checking the boxes
  - Recognize that quality cannot be sacrificed for schedule

• **Payoff**
  - Better product produced faster

Action Plan: Quality (3/3)

• **Accomplishments To Date**
  - Identified central location to store PHM process documentation
  - Obtained commitment from Software Quality Assurance (SQA) to audit PHM requirements process
    • First audit tentatively scheduled for early May, predicated on having approved PHM process documentation in the repository at least 30 days prior to audit
  - Identified areas in PHM RWP process documentation to update

• **Next Steps**
  - Update identified areas of RWP process documentation
  - Upload documentation to storage location
  - Schedule SQA audit
Final Results (1/2)

PHM RWP SPE Defects - Project Results
New Block 0.5 RWP

Final Results (2/2)

- **Churn And Escapes Before WorkOut**
  - Average number of comments per RWP = 168
  - Number of SPARs in blocks 0.1 and 0.5 = 371

- **Churn And Escapes After WorkOut**
  - Average number of comments per RWP = 12 = 93% DECREASE!
  - Assuming similar decrease, number of SPARs in blocks 1 & 2 = 26, though actual results may vary

### Defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>Pre-Project</th>
<th>Post-Project</th>
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<tbody>
<tr>
<td>Files / Messages</td>
<td>239 49</td>
<td>9 3</td>
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<tr>
<td>Unread</td>
<td>102 17</td>
<td>8 3</td>
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<tr>
<td>Array Subscript / Enum</td>
<td>82 14</td>
<td>0 0</td>
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<tr>
<td>Style / Format</td>
<td>69 12</td>
<td>0 0</td>
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<tr>
<td>Logic / Timing</td>
<td>68 11</td>
<td>3 1</td>
</tr>
<tr>
<td>Redundant / Unnecessary</td>
<td>64 11</td>
<td>1 0</td>
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<tr>
<td>Missing Requirement</td>
<td>59 10</td>
<td>3 1</td>
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<tr>
<td>Wording</td>
<td>43 7</td>
<td>0 0</td>
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<tr>
<td>Scope</td>
<td>37 6</td>
<td>0 0</td>
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<tr>
<td>Out of Date</td>
<td>31 5</td>
<td>0 0</td>
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<tr>
<td>Primary / Backup</td>
<td>29 6</td>
<td>0 0</td>
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<td>Typos / Grammar</td>
<td>27 5</td>
<td>2 1</td>
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<td>Semantics</td>
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<td>Other</td>
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<td>11 4</td>
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<td><strong>Total</strong></td>
<td>1007 168</td>
<td>37 12</td>
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</table>
Conclusions

• Systems Engineering Tools And Processes Yielded 93% Reduction In SPE Comments, Indicating Improved Quality Product

• Should Translate Into At Least 50% Reduction In Spars, Which Meets The Goal

• PHM Team Should Mitigate Over $2M Of Rework Costs!

Questions
Back-Up Slides

Cost Of Churn

**Typical REQ team effort, including coordination:**

- Message / File: 2 hrs per comment = 320 x 2 = 640 hrs
- Functionality: 6 hrs per comment = 326 x 6 = 1,956 hrs
- All Others: 1 hr per comment = 361 x 1 = 361 hrs

Total Block 0.1 & 0.5 SPE comment effort = 320 x 2 = 640 hrs

\[
\text{REQ SPE effort per block} = \frac{2,957}{2} = 1,479 \text{ hrs}
\]

\[
\text{Cost of SPE effort per block} = 1,479 \text{ hrs} \times 100 \text{ per hr} = 0.15 \text{ M}
\]

**Typical SW team effort, including coordination:**

- SW SPE effort per block = 1,479 x 50% = 740 hrs
- Cost of SPE effort per block = 740 hrs x $100 per hr = $0.07 M

Total SPE effort = 1,479 + 740 = 2,219 hrs

Total Cost of Churn = $0.15 M + $0.07 M = $0.22 M
SPAR (Escape) Reduction Assumptions

Estimated PHM SPAR cost reduction assumptions:
- Block 0.1 & 0.5 requirements signed off, so future cost reduction not applicable
- Block 3.0 not started, but no new requirements planned, so reduction not applicable
- Block 1.0 & 2.0 requirements not started and requirements will be added, therefore 2 Blocks of labor remaining
- Size of SPAR effort for Blocks 1.0 – 3.0 is approximately equivalent to Blocks 0.1 & 0.5 combined
- The size of SPAR effort for blocks 1 through 3 is approximately equivalent to Blocks 0.1 and 0.5 combined
- 50% reduction in SPARs produced
- 50% through life cycle
  - Doubling of defects in spreadsheets accounts for both new pre-released defects and delivered defects
  - Constant cost for El Segundo statement of work to fix defects regardless of Phase found (i.e. flight test defect cost = pre-release defect cost)

REQ Cost Avoidance Calculations

Requirements team SPAR related effort: Block 0.5\(^1\) actuals, as of 1/19/07

<table>
<thead>
<tr>
<th>Item</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPAR Management</td>
<td>30 hrs</td>
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<tr>
<td>Block 0.2 Initial Spar Burndown</td>
<td>127 hrs</td>
</tr>
<tr>
<td>Block 0.5 Increment 1 SPAR and Integration &amp; Test Support</td>
<td>5,316 hrs</td>
</tr>
<tr>
<td>Block 0.5 Increment 2 / Increment 3 SPAR &amp; Integration &amp; Test</td>
<td>5,278 hrs</td>
</tr>
<tr>
<td>Total Block 0.5 SPAR Labor (sum)</td>
<td>10,751 hrs (a)</td>
</tr>
</tbody>
</table>

Estimated 0.5 new SPAR rework\(^2\) | 10,751 hrs (b) |
Estimated 0.5 Total SPAR related labor hours remaining \((a) + (b)\) | 21,502 hrs (c) |

Remaining Block SPAR Cost Reduction Opportunity\(^3\) \((c) \times 2\) | 43,004 hrs (d) |
Estimated 20% of Block 0.1 & 0.5 SPARs due to change | 20 % (e) |
Estimated Reduction Opportunity\(^4\) \((d) \times (1 - e)\) | 34,403 hrs (f) |

Improvement: Est. 50% reduction in SPARs | 50 % (g) |
Final Projected Cost Reduction \((f) \times (g)\) | 17,202 hrs (h) |

**Final REQ Projected Cost Avoidance** \((h) \times $100 per hr\) | $1.72 M |

Note:
1. Block 0.1 rework excluded due to special case (agreed to sign off incomplete RWP). Block 0.5 rework is a better representation of process common case
2. Only 3 of 13 0.1 SW builds have been released and the last planned 0.1 SW release is in Jun 06, 1.5 years away. No 0.5 SW builds have been released as of 1/19/07. So we can expect more 0.1 and 0.5 SPARs in the future. This accounts for both pre-release and delivered defects.
3. (0.5 Total SPAR Effort) x (2 Blocks remaining)
4. Exclude SPARs due to change
SW Cost Avoidance Calculations

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>SW budget</td>
<td>$11 M</td>
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<tr>
<td>Budgeted rework</td>
<td>20%</td>
</tr>
<tr>
<td>SPARs due to requirement issues</td>
<td>31%</td>
</tr>
<tr>
<td>REQ improvement</td>
<td>50%</td>
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</tbody>
</table>

Total SW improvement = $11M x 20% x 0.31% x 50% = $0.34 M

Offset Calculations

• **Cost Of Training:**
  • 10 sessions x 2.5 hours per session x up to 40 people x $100 per hour = $100,000

• **Additional Travel for Coordination:**
  • Block 1: 6 RWPs, 2 trips per RWP
  • Block 2: 7 RWPs, 4 trips per RWP
  • $2,000 cost per trip
  • = ((6 x 2) + (7 x 4)) x $2000 = $80,000