# A Systems Approach to Prognostics and Health Management Requirements Defect Reduction

by
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## Agenda

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

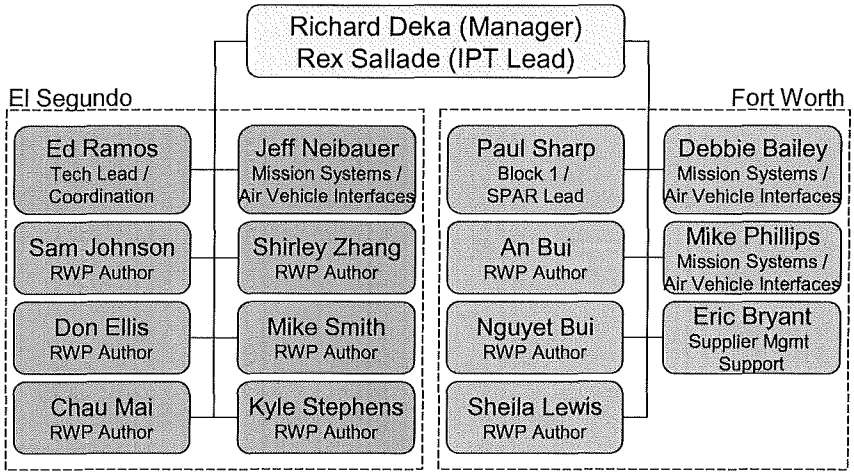
# Project Objective

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




# 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)

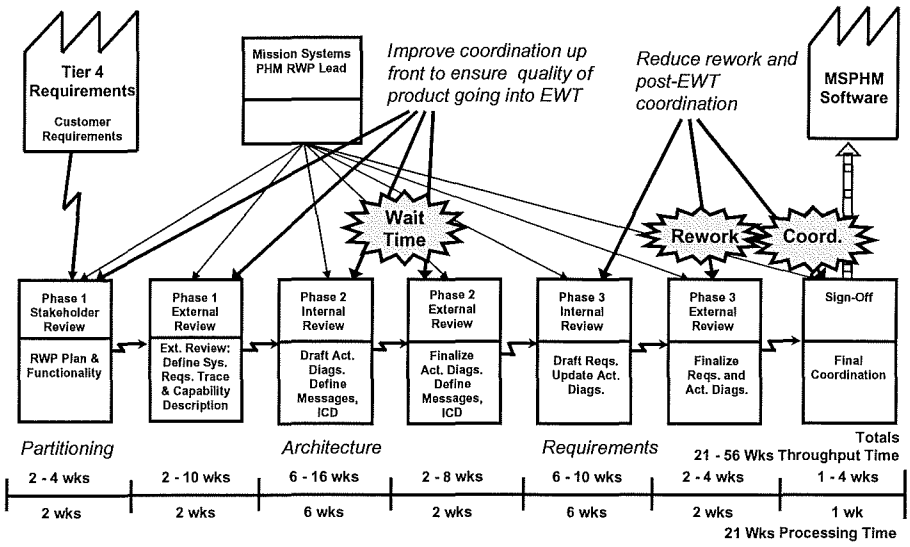
# Background: SPE

- **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)

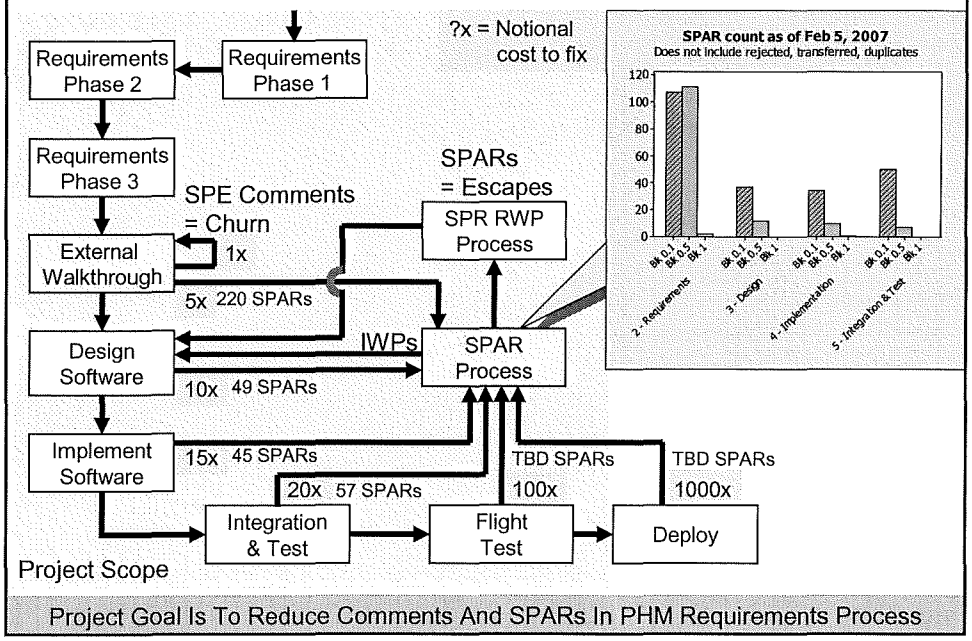
# Background: Current / Future / Plan

- 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

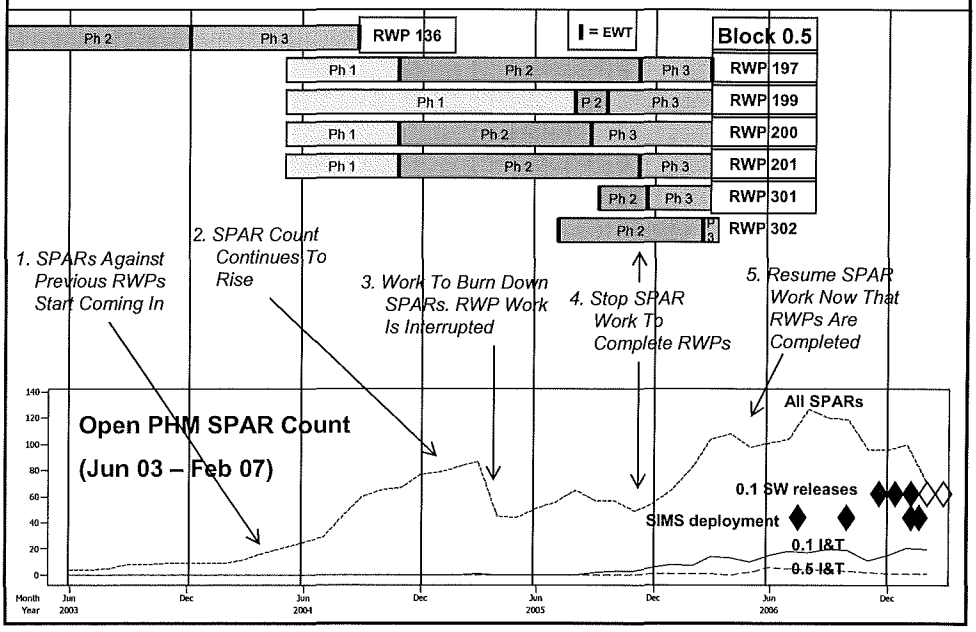



# Background: SPE Comments & SPARs

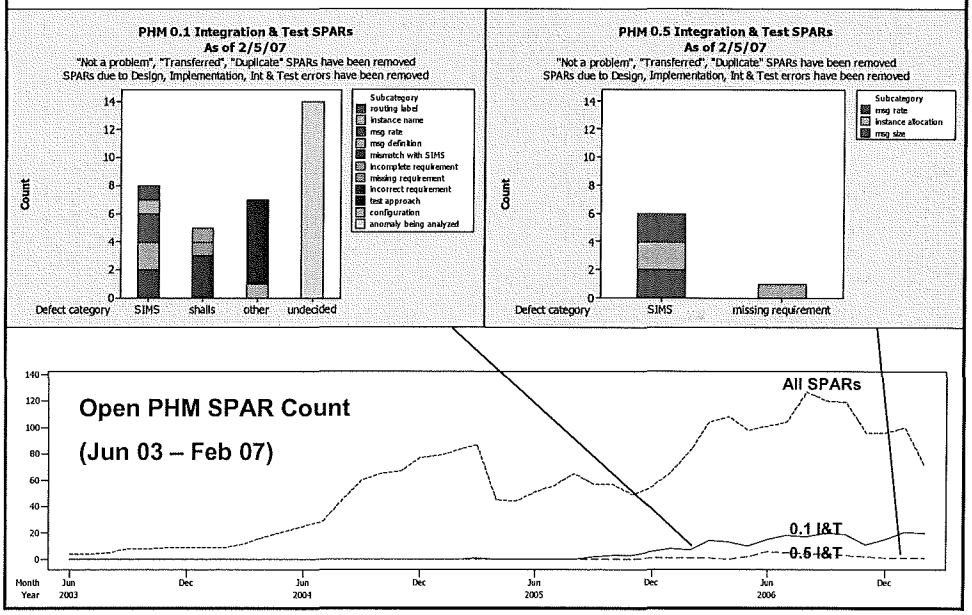



Project Goal Is To Reduce Comments And SPARs In PHM Requirements Process

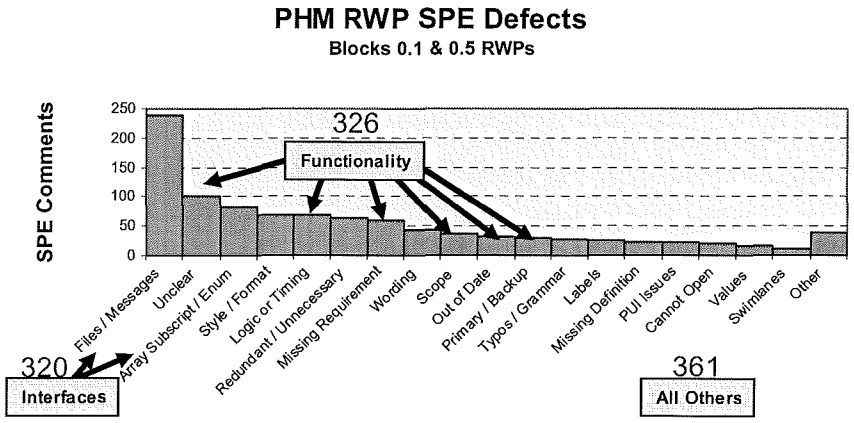
# Defect Data: SPAR Effects on RWPs




# Defect Data: Integration / Test SPAR Drivers



# Defect Data: SPE Defects




# Defect Data: Measurement Systems

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

| Metric | Status | System | Measures | Remarks |
|---|---|---|---|---|
| Lagging | In place | EV and other mgmt systems | Cost and schedule performance | |
| Lagging | In place | IPT metric reports | Effort and quality | |
| Lagging | In place | LANS | Labor hours | Serial code not used |
| Lagging | In place | SPE DEV records in Dimensions | Churn | |
| Lagging | In place | SPAR records in Dimensions | Escapes | |
| Lagging | In place | Sys req analysis in SPR RWP | Number of SPARs against individual RWPs | Requires manual trace back |
| Leading | New | EPG Product Development Course Evaluation | Effectiveness of cross-training | Feedback to course designer |
| Leading | New | SQA audit | Process compliance | Start 30 days after process has been updated and approved |
| Leading | New | Attendance log on K drive and also in JDL | Software development team participation in walkthrough and phase 1 stakeholder mtgs | Expand current attendance log for ITAR to include walkthroughs and stakeholder meetings, Stakeholder / delegate list and invitation email with yes / no |
| Leading | New | Triage | To what degree RWP authors and reviewers use the same criteria to determine good from bad | Use SPE DEV defect log with major/minor field |
| Leading | Considering | Periodic surveys, or evaluation form for each instance of a mtg | Effectiveness of walkthroughs and phase 1 stakeholder meetings | Kaizen or Causal Analysis to address deficiencies |
| Lagging | Considering | Serial code field in LANS | Labor hours spent on each RWP | To identify best practice |
| Lagging | Considering | Serial code field in LANS | Labor hours spent on each RWP between Phase III EWT and RWP sign-off by both requirements team and software development team | Churn |
| Lagging | Considering | Serial code field in LANS | Software team labor hours to rework software because of defective requirements | Escapes |

# 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

| Cost Item | REQ | SW | Total |
|---|---|---|---|
| 50% Reduction In SPE Comments | $0.15M | $0.07M | $0.22M |
| 50% Reduction In SPARs | $1.72M | $0.34M | $2.06M |
| Cost Of Training | | | ($0.10M) |
| Additional Travel | ($0.08M) | | ($0.08M) |
| | | Net Cost Avoidance | $2.10M |

- 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

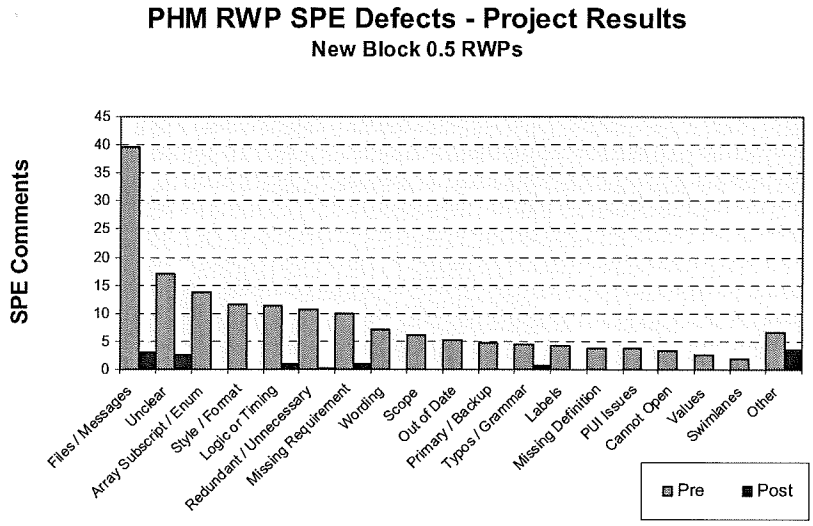
## Action Plan: Quality (2/3)

- **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)




# 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

| Defect | Pre- Project | | | Post-Project | | |
|---|---|---|---|---|---|---|
| Files / Messages | 238 | 40 | 24% | 9 | 3 | 0% |
| Unclear | 102 | 17 | 10% | 8 | 3 | 29% |
| Array Subscript / Enum | 82 | 14 | 8% | 0 | 0 | 0% |
| Style / Format | 69 | 12 | 7% | 0 | 0 | 0% |
| Logic or Timing | 68 | 11 | 7% | 3 | 1 | 11% |
| Redundant / Unnecessary | 64 | 11 | 6% | 1 | 0 | 4% |
| Missing Requirement | 59 | 10 | 6% | 3 | 1 | 11% |
| Wording | 43 | 7 | 4% | 0 | 0 | 0% |
| Scope | 37 | 6 | 4% | 0 | 0 | 0% |
| Out of Date | 31 | 5 | 3% | 0 | 0 | 0% |
| Primary / Backup | 29 | 5 | 3% | 0 | 0 | 0% |
| Typos / Grammar | 27 | 5 | 3% | 2 | 1 | 7% |
| Labels | 26 | 4 | 3% | 0 | 0 | 0% |
| Missing Definition | 23 | 4 | 2% | 0 | 0 | 0% |
| PUI Issues | 23 | 4 | 2% | 0 | 0 | 0% |
| Cannot Open | 20 | 3 | 2% | 0 | 0 | 0% |
| Values | 15 | 3 | 1% | 0 | 0 | 0% |
| Swimlanes | 11 | 2 | 1% | 0 | 0 | 0% |
| Other | 40 | 7 | 4% | 11 | 4 | 39% |
| **Total** | **1007** | **168** | **100%** | **37** | **12** | **100%** |

## 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 | 2,957 hrs |

| | |
|---|---|
| REQ SPE effort per block | = 2,957 / 2 ≈ 1,479 hrs |
| Cost of SPE effort per block | = 1,479 hrs x $100 per hr = $0.15 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**

| | | |
|---|---|---|
| SPAR Management | | 30 hrs |
| Block 0.2 Initial Spar Burndown | | 127 hrs |
| Block 0.5 Increment 1 SPAR and Integration & Test Support | | 5,316 hrs |
| Block 0.5 Increment 2 / Increment 3 SPAR & Integration & Test | | 5,278 hrs |
| Total Block 0.5 SPAR Labor | (sum) | 10,751 hrs (a) |
| 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) x 2 | 43,004 hrs (d) |
| Estimated 20% of Block 0.1 & 0.5 SPARs due to change | | 20 % (e) |
| Estimated Reduction Opportunity[4] | (d) x (1 - e) | 34,403 hrs (f) |
| Improvement: Est. 50% reduction in SPARs | | 50 % (g) |
| Final Projected Cost Reduction | (f) x (g) | 17,202 hrs (h) |
| Final REQ Projected Cost Avoidance | (h) x $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 cause
2. Only 3 of 13 0.1 SW builds have been released and the last planned 0.1 SW release is in Jun 08, 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

| | |
|---|---|
| SW budget | $11 M |
| Budgeted rework | 20 % |
| SPARs due to requirement issues | 31 % |
| REQ improvement | 50 % |

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