An Air Force S&T Directorate’s View on Applying Systems Engineering (SE) Principles to its Programs

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Presentation Outline

• Background: Current Process
• Range of Different S&T Programs Covered by AFRL/RX SE
• IPPD analysis of Systems Engineering approaches for AFRL/RX programs
• Streamlined Systems Engineering Approach
• Case study: Materials and Manufacturing S&T
• Summary and Conclusions
Background: Current Processes

Development of Systems Engineering (SE) in the Materials and Manufacturing Directorate of the Air Force Research Laboratory (AFRL/RX)
AFRL/RX Baseline SE Process

• Integrated Product & Process Development (IPPD)
  – Combination of:
    • Management Principles – technologies aimed at transition
    • Design Philosophy – improve first time transition for prototypes
    • Methodology – understand and optimize technology value
    • Tools – statistical experiments...web enabled collaboration
  – Supports a Production Environment
  – Must be tailored to be effective in S&T

• IPPD is the way one structures and performs a program, not something one does or in addition to.

-IPPD for S&T Quick Reference,
  Available at http://www.jamesgregory.com
The S&T IPPD Process

1. Determine Requirements
   - Technology Needs (MAPs, TPIPTs, etc.)
   - Customer Dialog
   - AF Technology Priorities
   - Opportunity Technologies
   - Deficiencies (MNS, ORDs)

2. Establish S&T Exit Criteria

3. Develop Technology Alternatives

4. Perform Value Analysis

5. Develop & Demonstrate Technology

6. Analyze & Deliver Project Results
   - Technology Transition Plan (TTP) (including Business Case)

Iterative

Initial Technology Transition Plan (TTP)

Customer Requirements

S&T Exit Criteria

Draft Technology Transition Plan (TTP)

Interim and Final Technical Reports

Transition Ready Technology

HOQ

Worksheets

Value Scorecard
Range of Different S&T Programs Covered by AFRL/RX SE
## AFRL Tailored SE Approach for Management Review of S&T Programs

<table>
<thead>
<tr>
<th>Key Question</th>
<th>Basic Research</th>
<th>Applied Research</th>
<th>Advanced Research</th>
<th>ATD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Who is your <strong>customer</strong>?</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>2. What are customer's <strong>requirements</strong>?</td>
<td>Partial</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>3. How will you <strong>demonstrate</strong> you have met the requirements?</td>
<td>Partial</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
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<tr>
<td>4. What are the <strong>technology options</strong>?</td>
<td>Extremely Limited</td>
<td>Nearly Complete</td>
<td>Complete</td>
<td>Complete</td>
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<tr>
<td>5. Which is the <strong>best approach</strong>?</td>
<td>Extremely Limited</td>
<td>Nearly Complete</td>
<td>Complete</td>
<td>Complete</td>
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<tr>
<td>6. What are the <strong>risks</strong> to developing the selected technology?</td>
<td>Partial</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>7. How will you <strong>structure</strong> your program to meet requirements and manage risk?</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
<td>Complete</td>
</tr>
<tr>
<td>8. What is your <strong>business-based transition plan</strong> that meets customer approval?</td>
<td>Extremely Limited</td>
<td>Partial</td>
<td>Nearly Complete</td>
<td>Complete</td>
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</table>
Development of SE in RX
(derived from broad range of program types)

GOALS: 1. Improve Program Management Effectiveness and Efficiency
2. Improve Success of Tech Transitions & Transfers
3. Comply with AF and DoD Directives
4. Develop a Systems Engineering Culture

STRATEGY: Tailored SE for all S&T Programs

APPROACH:

Program Assessment → Program Planning → Program Execution/Portfolio Mgt

- CGO IP (CP3 ish)
- Metamaterials (CP1 ish)
- Nano/Bio Inhouse (CP1 ish)
- Adv Battery (CP1 ish)
- Airbase Energy (CP2/3 ish)
- Laser Hardening (CP2 ish)
- Sustainment (CP1/2 ish)

Yellow: S&T Knowledge Generation (CP1);
Orange: Product Development (CP2);
Green: Urgent Need Response (CP3)
IPPD analysis of Systems Engineering approaches for AFRL/RX programs
**Assumptions:**

- **The Customer** is Bob Rapson, Chief Engineer
- Pre-Milestone “A” research and development programs are identified based on **Program Objectives**, such as:
  - S&T Knowledge Generation (CP1)
  - Product Development (CP2)
  - Urgent Need Response (CP3)

- The **scope** of IPPD analysis includes:
  - Program Assessment
  - Program Planning
  - Program Execution
  - Program Transition.

- **Challenges** associated with large complex programs and portfolio management
- Include connects to **Program Management** such as: Key Performance Parameters, Work Breakdown Structures, and Earned Value Management.
IPPD analysis of Systems Engineering approaches for AFRL/RX programs

Form Team → Determine SE Requirements & Desiresments → Generate Alternatives → Evaluate Alternatives → Document Results

- CP1
  - Assessment
  - Planning
  - Execution
- CP2
  - Assessment
  - Planning
  - Execution
- CP3
  - Assessment
  - Planning
  - Execution

- Team brainstorm different systems engineering approaches
  - Assessment
  - Planning
  - Execution
- Recommended systems engineering methodology for CP1
- Recommended systems engineering methodology for CP2
- Recommended systems engineering methodology for CP3

- USAF Problem / Goal
- Customer(s)
- SE Team Members
- List of Prioritized Reqs & Exit Criteria
- Description of Alternative Solutions
- Value Analysis
Challenge: There are many Alternative Methods that can be used to tailor SE Approaches

- Empirical Analyses
- Theoretical Analyses
- Statistical Analyses
- Design of Experiments
- Modeling and Simulation
- House of Quality and Quality Function Deployment
- Six Sigma and Taguchi, Scorecard (Balanced and/or Value)
- Analytic Hierarchy Process
- Earned Value Management
- "The SE Conversation": 8 Questions & AFRL/RX I 61-104
- Integrated Product & Process Development (IPPD)
- SETFST Approach: Quantitative (probabilistic) trade analyses
- SETFST with modeling and simulations (e.g. HELTP)
- System Architecture and Node Decomposition analyses
- Systems of Systems Analyses
- Joint Capabilities Integration & Development System (JCIDS) Methodology: FAA, FNA, & FSA
What is the “Best” SE Approach for a Laboratory?

• Suitable for a Range of Technical Challenges
  – Basic Research
  – Advanced Development
  – Transition to the Warfighter

• Overcome limitations & Retain strengths of IPPD-Based Approach
  – Extremely Valuable
    • Proven in major pilot programs
  – Tends to be expensive
  – Can be lengthy
  – Not (best option) for all types of S&T
Streamlined Systems Engineering Approach
Integration of SE approaches into baseline CGO Initiative Program

Purpose

• Provides information and tools for good program management
• Provides baseline SE assessment process
• Provides testbed for initial evaluation of SE methods and tools

• Lessons Learned
  – Use existing proposal &/or briefing info to build a strawman SE framework
  – Two focused team meetings are usually sufficient
  – Providing checklists and other SE assessment examples are very useful
  – Involving Experienced Senior Engineer(s) is very helpful
Streamlined Systems Engineering Approach

Target Approach: Limited Number of Concise Team Meetings

1. **Form Team**
   - Update & check for completeness
   - Exit Criteria for all requirements
     - Performance
     - Affordability
     - Productivity
     - Reliability
     - Supportability
   - Prioritize & Validate with customer

2. **Determine Requirements**
   - Team brainstorm different solution approaches

3. **Generate Alternatives**
   - Technology Concept

4. **Evaluate Alternatives**
   - Technology Readiness Assessment
   - Manufacturing Readiness Assessment
   - Risk Analysis
   - Value Analysis
     - Compare Alt. Solutions with Reqts & Exit Crit
     - Create Excel Spreadsheet
   - Customer Approval of Soln

5. **Document Results**
   - USAF Problem / Goal
   - Customer(s)
   - Team Members
   - List of Prioritized Reqts & Exit Criteria
   - Description of Alternative Solutions
   - TRA and MRA
   - Risk Assessment
   - Value Analysis
USAF Problem: Ground Equipment corrodes when exposed to weather elements

- Annual corrosion cost of $69,000,000 (and rising) directly associated with support equipment
- Labor and material costs to mitigate corrosion are increasing
- Workforce shaping has reduced available maintenance resources
Step 1: Form Team

• Form Team:
  • Principal Investigator and Funding Sponsor
  • Program Manager, Branch Tech Advisor, In-House Researcher
  • IPT Team: Program Manager, Potential Technology Recipients (SPO, JPO, DUST, MAJCOM), Branch Tech Advisor, and other technical, contractual, and financial expertise
  • IPT Team: Most key customers (Other interested TDs, program managers of related ATDs) identified and actively involved

• Lesson Learned – stay together “continuous”
**Step 2: Determine Requirements and Establish Exit Criteria**

**Determine Requirements**
1. Minimize corrosion maintenance costs of non-powered aerospace ground equipment and other steel support equipment
2. Capability to coat inner “hard-to-reach” surfaces of a piece of equipment
3. User friendly coatings and coating processes
4. Avoid coatings that are harmful to environment
5. Capability for long lasting coatings
6. Qualified coating process
7. More than 1 tool in toolbox for combating corrosion

**Establish S&T Criteria / Exit Criteria**

a. Coating technologies that ensure adequate corrosion protection
b. Coating technologies that ensure adhesion to substrate
c. Surface profile for applying stencils/markings
d. Proper surface pretreatment process
e. Techniques for repairing damage to galvanized coatings
f. Documentation of laboratory test results
### Step 2: Determine Requirements and Establish Exit Criteria

#### Before

**Determine Requirements**
1. Minimize corrosion maintenance costs of non-powered aerospace ground equipment and other steel support equipment
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F. Documentation of laboratory test results

#### After

**Determine Requirements**
1. Minimize corrosion related costs while not impacting other maintenance costs for non-powered aerospace ground equipment and other steel support equipment
2. Capability to treat inner “hard-to-reach” surfaces of a piece of equipment
3. Readily available, mature, demonstrated coating methods that don’t change metallurgical properties. (User friendly coatings and coating processes)
4. Reduce environmental waste stream of current coating repair processes (Avoid coatings that are harmful to environment) 1/3 impact reduction (ref E)
5. Clean Appearance
6. Different than existing approach
7. at least as damage tolerant as current coating system

**Establish S&T Criteria / Exit Criteria**
A. Coating technologies that ensure adequate corrosion protection
B. Coating technologies that ensure adhesion to substrate
C. No surface prep changes for applying stencils/markings
D. Utilize existing Repair techniques
E. Documentation of laboratory test results that compare performance with baseline paint
   - ASTM G1 boldly exposed
   - ASTM G44 Alternate immersion
   - Field testing/beach exposure
F. Meet or exceed MIL STD 808
G. Apply to specification thickness, minimum of 4 ft, and 1 inch internal diameter
H. Qualified coating process in accordance with industrial standards
I. Need 2X, Want 10X coating life improvement with capability to do touch-up repairs
J. Repair looks the same as original; match color, texture, gloss
Step 3: Generate Alternatives

**Before**

Develop Technology Alternatives
- Coatings conforming to MIL-PRF-26915
- Metallization (aka Metal Wire Arc Spray)
- Hot-dip galvanization
- ???
- ???

**After**

Develop Technology Alternatives
- Coatings conforming to MIL-PRF-26915
- Metallization (aka Metal Wire Arc Spray)
- Hot-dip galvanization
- Build Stainless Steel Equipment
- Paint over Zinc coating
- Electrogalvanization
Step 4: Evaluate Alternatives (Conduct TRA, MRA, & Risk Assessment on Feasible Solutions)

1. Identify Critical Technology Elements and TRL for each Element
2. Identify Critical Manufacturing Processes and MRL for each Process

**Technology Alternatives:**
- Coatings conforming to MIL-PRF-26915
- Metallization (aka Metal Wire Arc Spray)
- Hot-dip galvanization
- Build Stainless Steel Equipment
- Paint over Zinc coating
- Electrogalvanization
Step 5: Document Results

A Key Benefit of SE in the S&T Environment:

*Items Documented:*

- USAF Problem / Goal
- Customer(s)
- SE Team Members
- List of Prioritized Requirements and Exit Criteria
- Description of Alternative Solutions
- TRA & MRA
- Risk Assessment
- Value Analysis
Case Study: Materials and Manufacturing S&T
Aerospace Ground Equipment Lifetime Coating Evaluation for System Sustainment (AGELESS) CGO Initiative Program
16 May 2008

Materials & Manufacturing Directorate
Systems Support Branch

Ben Wilkerson, 2Lt
Program Manager
Phone: 937.656.9566
Benjamin.Wilkerson@wpafb.af.mil
AGELESS
Overview

Project Lead: Lt Ben Wilkerson
Team: Mr. Corey Bliss, MSgt Royce Stamps, SMSgt Byron Wilson, Mr. Dennis Douglas, Mr. Larry Perkins
Start/End Dates: 19 March 07 – 30 Sept 08
Amount Funded: $74.1K
Completed Milestone: 2/3

General Description of Technical Work:
• Galvanization is a method of applying a thin coating of zinc onto a B-4 maintenance stand at Hill AFB
• Conduct full-scale galvanization of non-powered AGE
• Evaluate the costs associated with infrequent painting of AGE/SE vs. a one-time galvanization
• Perform select laboratory tests on galvanized steel with respect to other coating technologies (MIL-PRF-26915 (informally known as “Zinc-Rich Primers and Metallization (a.k.a. Metal Wire Arc Spray (MWAS)))) to ensure adequate
  • Corrosion protection
  • Adhesion to substrate
  • Surface profile for applying stencils/markings

Motivation/Need/Payoffs:
• Annual corrosion cost of $69,000,000 (and rising) directly associated with support equipment
• Labor and material costs to mitigate corrosion are increasing
• Workforce shaping has reduced available maintenance resources
• Extend coating life, but not necessarily extend of support equipment life
• Send final recommendation to 642nd Combat Sustainment Group for analysis
  • Todd Balducci and Traci Messick

Overall Programmatic Approach:
• Phase 1 – Demo galvanization on existing non-powered AGE (Out-house)
• Phase 2 – Supplemental lab and field testing to verify/validate coating performance, address issues of reparability (In-house)
• Phase 3 – Technology transition efforts (In-house)
### VALUE ANALYSIS

#### Alternative Technology Solutions

<table>
<thead>
<tr>
<th>Prioritized Requirements</th>
<th>Coatings conforming to MIL-PRF-26915</th>
<th>Metallization (aka Metal Wire Arc Spray)</th>
<th>Hot-dip galvanization</th>
<th>Paint over Zinc coating</th>
<th>Electrogalvanization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Min Corrosion Costs</td>
<td>zero</td>
<td>minus</td>
<td>plus</td>
<td>minus</td>
<td>plus</td>
</tr>
<tr>
<td>2. Reduce Environmental impact</td>
<td>zero</td>
<td>plus</td>
<td>plus</td>
<td>minus</td>
<td>plus</td>
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<tr>
<td>3. Damage Tolerant</td>
<td>zero</td>
<td>plus</td>
<td>plus</td>
<td>zero</td>
<td>plus</td>
</tr>
<tr>
<td>4. Available &amp; Mature Method</td>
<td>zero</td>
<td>zero</td>
<td>zero</td>
<td>zero</td>
<td>zero</td>
</tr>
<tr>
<td>5. Clean Appearance</td>
<td>zero</td>
<td>minus</td>
<td>zero</td>
<td>zero</td>
<td>zero</td>
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<tr>
<td>6. Different Approach</td>
<td>zero</td>
<td>plus</td>
<td>plus</td>
<td>zero</td>
<td>plus</td>
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<tr>
<td>7. Treats hard-to-reach surfaces</td>
<td>zero</td>
<td>minus</td>
<td>zero</td>
<td>minus</td>
<td>minus</td>
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</tbody>
</table>
AGELESS
Program Risk Assessment

<table>
<thead>
<tr>
<th>Risk / Mitigation (PxC)</th>
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</thead>
<tbody>
<tr>
<td>A. Unidentified way to repair Hot Dipped Galvanization (HDG) (5x1)</td>
</tr>
<tr>
<td>Contact subject matter experts at the Corrosion Office &amp; AGE Office for solutions</td>
</tr>
<tr>
<td>Work with the transportation industry to determine fix</td>
</tr>
<tr>
<td>B. Inability to match current Galvanization coating color (3x1)</td>
</tr>
<tr>
<td>Work with the transportation industry to determine way to match current coating color</td>
</tr>
<tr>
<td>C. Logistical aspects of transporting aerospace ground equipment to and from hot-dip galvanization vendors (3x2)</td>
</tr>
<tr>
<td>The majority of AGE is contracted out; therefore, the logistics has already been completed</td>
</tr>
<tr>
<td>HDG of AGE should only be completed on equipment coming from the manufacturer</td>
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</table>
### AGELESS
FA8601-06-D-0013 University of Dayton Research Institute

<table>
<thead>
<tr>
<th>ASSESSMENT AREA</th>
<th>E</th>
<th>S</th>
<th>M</th>
<th>U</th>
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<th>ASSESSMENT AREA</th>
<th>E</th>
<th>S</th>
<th>M</th>
<th>U</th>
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<tbody>
<tr>
<td>a. Technical Performance</td>
<td>x</td>
<td></td>
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<td></td>
<td>e. Contracting</td>
<td>x</td>
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<tr>
<td>b. Financial</td>
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<td>x</td>
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<td>f. Staffing</td>
<td>x</td>
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<td>c. Cost vs. Accomplishment</td>
<td>x</td>
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<td>g. Testing</td>
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<td>x</td>
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<td>d. Progress vs. Schedule</td>
<td>x</td>
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<td></td>
<td>h. Transition and Other</td>
<td></td>
<td></td>
<td>x</td>
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</tbody>
</table>

- The program is on schedule and on budget
- The Galvanized B-4 maintenance stand was sent from Hill AFB to Eglin AFB
  - Stand was moved to a more corrosive environment
- All lab testing has been completed
  - Better repair procedure needs to be identified in future effort
- A trip to Eglin AFB is scheduled for the beginning of June to gather field data for final report
- Transition efforts through the Air Force Corrosion and 642nd Combat Sustainment Group have been made
## AGELESS

### Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Quarter</th>
<th>2nd Quarter</th>
<th>3rd Quarter</th>
<th>4th Quarter</th>
<th>1st Quarter</th>
<th>2nd Quarter</th>
<th>3rd Quarter</th>
<th>4th Quarter</th>
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<tbody>
<tr>
<td>AGELESS_Wilkerson</td>
<td>Feb</td>
<td>Mar</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
<td>Jul</td>
<td>Aug</td>
<td>Sep</td>
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<tr>
<td>Proposal was written</td>
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<td>Money was placed on contract</td>
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<tr>
<td>Hot Dipped Galvanization of B-4 Stand</td>
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<tr>
<td>In-house testing of Hot Dipped Galvanization</td>
<td>3/19</td>
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<tr>
<td>Commence field test</td>
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<tr>
<td>Final Report</td>
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</tbody>
</table>
• Program was successfully completed.
  – Maintained constant communications with Air Force Corrosion, the 642\textsuperscript{nd} Combat Sustainment Group, and PACAF.
  – Reevaluating the program allowed for a better understanding of what steps are required to have a successful program.
  – Lab testing was completed
  – Lab results were presented to the Aircraft Ground Support Equipment Working Group (AGSEWG)
  – The Galvanized B-4 maintenance stand was sent from Hill AFB to Eglin AFB for field testing.

• Transition
  – Transitioned through the Air Force Corrosion Prevention and Control Office and the 642\textsuperscript{nd} Combat Sustainment Group.
Systems Engineering
Summary and Conclusion
AFRL/RX Systems Engineering
Summary and Conclusions

• Adapting Systems Engineering to Laboratory Programs
  – Affordable, Time Efficient, Recognized as Beneficial
• Baseline Approach: IPPD
• Tailor SE Methods to Different Types of S&T programs
• Initial Case Studies have shown Applicability and Value at Different S&T Levels
• Ultimate Goal: Baseline Streamlined Process followed by Detailed Analysis, as Appropriate