The Quest for Practical DFSS (Design-for-Six-Sigma) Tools

PGMM Case Study

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ATK Advanced Weapons Division

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Charlotte, North Carolina
XM395 PGMM
Precision Guided Mortar Munition

- **Swift, ballistic flight to target** – no midcourse guidance – laser guidance in terminal phase
- **Few moving parts** – high reliability in high-G gun environment
- **Accurate** – simple, responsive thruster control
- **Lethal** – large warhead overmatches all PGMM targets
**PGMM Operational Elements**

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**PGMM Overview**

**Ballistic Flight to Target Acquisition**

**Guided Flight to Hit Designated Target**

- Fire Support Element (FSE)
- Forward Observer
- Mortar Squad
- Fire PGMM
- Heavy Mechanized M1064
- M577

PGMM Incapacitates Personnel Protected by:
- Masonry Structures,
- Earth/Timber Bunkers, or
- Light Armor Vehicles
PGMM Cartridge – Simple, Rugged, and Precise

- Modular Design
- Simple Interconnect
- Few Moving Parts
- Mature Subsystems
Objectives

1. Vigorously apply several DFSS tools to the PGMM (Precision Guided Mortar Munition) program
2. Refine and evaluate the tools (benchmark, provide lessons learned, resource planning guides)
3. Support timely execution of major PGMM program milestones (SRR, SDR, PDR, CDR)

<table>
<thead>
<tr>
<th>DFSS Tool</th>
<th>Status</th>
<th>ATK Technical Excellence Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stakeholder Analysis</td>
<td>Complete</td>
<td>2. Data Based Decision Making</td>
</tr>
<tr>
<td>Operational Crosswalk</td>
<td>Complete</td>
<td>3. Consideration of System-Level Issues and Interactions</td>
</tr>
<tr>
<td>Requirements Development and Mgmt</td>
<td>Complete</td>
<td>1. Requirements Defined and Tracked</td>
</tr>
<tr>
<td>QFD (Quality Functional Deployment)</td>
<td>Complete</td>
<td>3. Consideration of System-Level Issues and Interactions</td>
</tr>
<tr>
<td>FMEA (Failure Modes Effects Analysis)</td>
<td>Complete</td>
<td>3. Consideration of System-Level Issues and Interactions</td>
</tr>
<tr>
<td>System-Wide Defects Tracking</td>
<td>Complete</td>
<td>2. Data Based Decision Making</td>
</tr>
<tr>
<td>Producibility Scorecard</td>
<td>Complete</td>
<td>7. World Class Process Control at ATK and our Suppliers</td>
</tr>
</tbody>
</table>
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Traditional Approach to Product Development

Studies at TRW:
- 54% of all defects are detected after development testing
- 45% of these defects are requirement defects

Recent Program at ATK
- 44% of defects were detected after subsystem testing
- 62% of all defects were requirement defects

Latent Requirement Defects Are Costly

Design for Competitiveness, Advance copy by Bart Huthwaite
New Approach to Product Development

**Project Approach**

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**CUSTOMER REQUIREMENTS**

- Stakeholder Analysis
- Operational Crosswalks
- Requirements Development & MGMT
- Quality Functional Deployment

**CONTRACTOR REQUIREMENTS**

- Requirements Defined and Tracked
- ATK Technical Standard
- Requirements Defined and Tracked

**DFSS/Lean Six Sigma Initiatives/Project**

**REQUIREMENTS DISCOVERY PROCESS**

- Correct Requirements
- Complete Requirements
- Consistent Requirements
- Necessary Requirements
- Testable Requirements
- Unambiguous Requirements
- Traceable Requirements
- Modifiable Requirements

**STAKEHOLDER ANALYSIS**

- Identify Design Trade Space (CAIV)
- Identify Potential Requirement Change
- Introduce Requirements Tracking Metrics

**OPERATIONAL CROSSWALKS**

**REQUIREMENTS DEVELOPMENT & MGMT**

- CORRECT REQUIREMENTS
- COMPLETE REQUIREMENTS
- CONSISTENT REQUIREMENTS
- NECESSARY REQUIREMENTS
- TESTABLE REQUIREMENTS
- UNAMBIGUOUS REQUIREMENTS
- TRACEABLE REQUIREMENTS
- MODIFIABLE REQUIREMENTS

**QUALITY FUNCTIONAL DEPLOYMENT**

**MANAGE REQUIREMENTS**

- CONTINUE DESIGN DEVELOPMENT PROCESS

**PROJECT START**

**CONTRACTOR REQUIREMENTS**

- SRR

**SDR**

**PRELIMINARY DESIGN**

**PDR**

CONTINUE DESIGN DEVELOPMENT PROCESS
Stakeholder Analysis

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Stakeholder Analysis

Results

- This tool has utility for Program Managers, Business Development teams, and Engineering leadership
- Database protects against knowledge base turnover
- Helps to ensure that no stakeholder’s interest is ignored – develops complete set of stakeholders

<table>
<thead>
<tr>
<th>Database Information</th>
<th>Database Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Category</td>
<td>Seeker Subsystem</td>
</tr>
<tr>
<td>Organization</td>
<td>US Industry</td>
</tr>
<tr>
<td>Stakeholder</td>
<td>BAE Systems</td>
</tr>
<tr>
<td>Location</td>
<td>Nashua, NH</td>
</tr>
<tr>
<td>Role</td>
<td>SAL Seeker Supplier</td>
</tr>
<tr>
<td>Motivation</td>
<td>Expand SAL Seeker Product Base</td>
</tr>
<tr>
<td>Level of Support [+3 For, -3 Against]</td>
<td>3</td>
</tr>
<tr>
<td>Level of Influence [+5 High, +1 Low]</td>
<td>2</td>
</tr>
<tr>
<td>Stakeholder Effect</td>
<td>6</td>
</tr>
<tr>
<td>Strategic Action</td>
<td></td>
</tr>
</tbody>
</table>

ATK Technical Standard
Data-Based Decision Making
Operational Crosswalks

Light Forces

- Dismounted M120 Mortar (Current)
- Palletized Mortar Rounds

Heavy Mechanized Forces

- MFCS – Mortar Fire Control System
- MMS - Mortar Mission Setter
- Mortar Extraction Tool
- LRRS _ Loose Round Restraint System
- Helicopter Transport
- Vehicle Weapon Racks
- Autoloaders/Breechloaders

- M1064A3 Mortar Carrier
- M121 Mortar (Current)
- FCS NLOS-M (Future)
- Stryker BCT-MC Soltam Vb (Current)
- Stryker BCT-MC Soltam Vb (Current)
### REFERENCE: System Performance Specification Draft 31-Jan-03

#### DESCRIPTION:
3.3.5.2 KPP 2 – Lethality. The XM395 cartridge SHALL have the ability to incapacitate or fractionally casualitize personnel protected within and by point...

#### EVALUATION:
- [ ] INCOMPLETE
- [x] INCONSISTENT
- [x] INCORRECT
- [ ] INFEASIBLE
- [ ] UNMODIFIABLE
- [ ] UNNECESSARY
- [ ] UNTESTABLE
- [ ] UNTRACEABLE
- [ ] AMBIGUOUS

#### CROSS-REFERENCE:
CTP 9. Draft ORD Para. 4.1.1.1.1, 4.1.1.1.2

#### OWNER:
USAIC

#### SOURCE:
ORD

#### PRIORITY:
- [x] MISSION/SAFETY CRITICAL
- [x] UNLIKELY TO CHANGE
- [ ] MOST LIKELY TO CHANGE
- [x] NON-NEGOTIABLE
- [ ] MAY CHANGE
- [ ] FLEXIBLE
- [ ] NEGOTIABLE (CAIV)

#### ISSUE:
Why two rounds or less? Why not specify single round, when we are assuming (in evaluation) independence in probability? How do we assign how the laser designator operation influences lethality? How do we model delivery errors?

#### CORRECTIVE ACTION:
Probability of collapse is now also included for the Earth & Timber bunker. We would like to have guidance on how to constrain or define the operational conditions and “real world” error sources under which we are to perform. Can we refer to an error budget within the spec (Section 4)?

#### METHOD OF VERIFICATION:
4.3.5.2 Lethality. To be verified via analysis and test of XM395 subsystem and system flight hardware against all targets specified in section...

Note: Since we are verifying performance through modeling, we are most interested in validating our models. Further discussion needed.
### Requirements Walkthough

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**MISSION/SAFETY CRITICAL**
- USEFUL
- NON-NEGOTIABLE (CAIV)
- FLEXIBLE
- UNLIKELY TO CHANGE
- MAY CHANGE
- MOST LIKELY TO CHANGE

**SOURCE:** ORD

**RATIONALE:**
The user wants to envision how many rounds they will need to kill a target (hence two rounds specified).

**METHOD OF VERIFICATION:**
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**Note:** Since we are verifying performance through modeling, we are most interested in validating our models. Further discussion needed.
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### Requirements Walkthrough Statistics

#### Customer Priorities

<table>
<thead>
<tr>
<th>Priority Type</th>
<th>129 Non-ENV REQ</th>
<th>70 ENV REQ</th>
<th>199 Total REQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission/Safety Critical</td>
<td>39</td>
<td>52</td>
<td>91</td>
</tr>
<tr>
<td>Useful</td>
<td>85</td>
<td>18</td>
<td>103</td>
</tr>
<tr>
<td>Desireable</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Non-Negotiable</td>
<td>89</td>
<td>68</td>
<td>157</td>
</tr>
<tr>
<td>Negotiable</td>
<td>39</td>
<td>2</td>
<td>41</td>
</tr>
<tr>
<td>Flexible</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Unlikely to Change</td>
<td>118</td>
<td>72</td>
<td>190</td>
</tr>
<tr>
<td>May Change</td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Most Likely to Change</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Criticality

- **2/3 Non-Critical**
- **30%**
- **66%**

#### Tradeoffs

- **3/10 Negotiable**
- **69%**
- **30%**

#### Stability

- **8% May Change**
- **92%**
- **8%**

### Contractor Feedback (64 Issues)

- **Miscellaneous**: 17
- **Ambiguous**: 15
- **Unnecessary**: 8
- **Infeasible**: 8
- **Incomplete**: 8
- **Inconsistent**: 6
- **Incorrect**: 2

- The PGMM Performance Specification was very well written by OP-Mortars, USAIC, and ARDEC.
- Only 64 issues (32% of 199 requirements).
- The 64 issues spawned 58 Actions (9 of which were critical).
Reduced Customer Requirements

- 199 “SHALL” requirements in US Army SPS (System Performance Specification)
- Deleted 17 requirements (8.5%)
- Relaxed another 5 requirements (2.5%) \( \left\{ 11\% \right\) 

Significance

Eliminated requirement to meet safety and reliability performance for one environmental requirement (unnecessary)

- Avoided fuze redesign cost of \(~$300K\) to safely reset after exposure to the second environment

Relaxed a second environmental requirement to be met in an in-package, un-powered condition rather than in an un-packaged, powered condition

- Avoided special testing at government facility to verify redesign
PGMM Requirements Audit and Defect Tracking

Results

- 946 System and subsystem requirements audited
- 46% had at least 1 potential defect
- 87% of potential defects realized a change to the requirement

<table>
<thead>
<tr>
<th>Requirement Defects</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect Information</td>
<td>Incorrect Test Standard, Incorrect Paragraph Reference, Incorrect Environmental Levels</td>
</tr>
<tr>
<td>Omissions</td>
<td>Missing Test Standard, Missing Requirement, Missing Verification</td>
</tr>
<tr>
<td>Ambiguities</td>
<td>More Than One Interpretation</td>
</tr>
<tr>
<td>Poorly Written</td>
<td>Multiple “Shalls” In One Requirement, Spelling and Grammar, Requirement Not Clear</td>
</tr>
<tr>
<td>Misplaced</td>
<td>Requirement in Wrong Section, Requirement Applied to Wrong Subsystem</td>
</tr>
</tbody>
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ATK Technical Standard
Early elimination of deficiencies
Quality Functional Deployment

CUSTOMER REQUIREMENTS

STAKEHOLDER ANALYSIS

OPERATIONAL CROSSWALKS

REQUIREMENTS DEVELOPMENT & MGMT

QUALITY FUNCTIONAL DEPLOYMENT

REQUIREMENTS DISCOVERY PROCESS

CORRECT REQUIREMENTS
COMPLETE REQUIREMENTS
CONSISTENT REQUIREMENTS
NECESSARY REQUIREMENTS
TESTABLE REQUIREMENTS
UNAMBIGUOUS REQUIREMENTS
TRACEABLE REQUIREMENTS
MODIFIABLE REQUIREMENTS

IDENTIFY DESIGN TRADE SPACE (CAIV)
IDENTIFY POTENTIAL REQUIREMENT CHANGE
INTRODUCE REQUIREMENTS TRACKING METRICS

MANAGE REQUIREMENTS

CONTINUE DESIGN DEVELOPMENT PROCESS

ATK Technical Standard
Requirements Defined and Tracked
Quality Functional Deployment (QFD)

Results

- QFD characterized nose protector as a net liability in meeting requirements.
- Finally, optical window testing at supplier characterized SAL sensor performance with smears and scratches typical of handling – confirmed low risk in elimination
- **Cost Avoidance:** Aerodynamic flight testing at Yuma to confirm separation ~$100K
Quality Functional Deployment (QFD) - Results

Fuze, WIM = Safety Critical
Monopack = Environmental Protection
CTM, SAL, GNC, Warhead = Mission Critical
Battery & PC = Reliability Critical
Propelling Charge, Ignition Cartridge = Range Critical

Quality Functional Deployment (QFD)
Completed 27 Jan 2005

Key Subsystems

Satisfies Critical Requirements
Quest for Practical DFSS Tools Summary

Project Objectives Met

- **Vigorously Applied DFSS to PGMM:** Tools successfully applied to the Precision Guided Mortar Munition Program
- **Refined and Evaluated Tools:** Provided benchmarks, lessons learned, resource planning guides
- **Major PGMM Program Milestones Met:** SRR, SDR, PDR and CDR were held on schedule, within budget, and with high quality

Additional Benefits

- **Simplification Achieved:** Eliminated or relaxed 11% of US Army system performance requirements; cost avoidance well over $450K
- **Forged Strong Customer Relationship:** DFSS Tool application facilitated communication across the design team

Developed Product = User Need

DFSS Project Investment

Program Cost Savings of 5x to 10x DFSS Investment
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