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

PGMM Case Study

James Kalberer and Doug Storsved
ATK Advanced Weapons Division

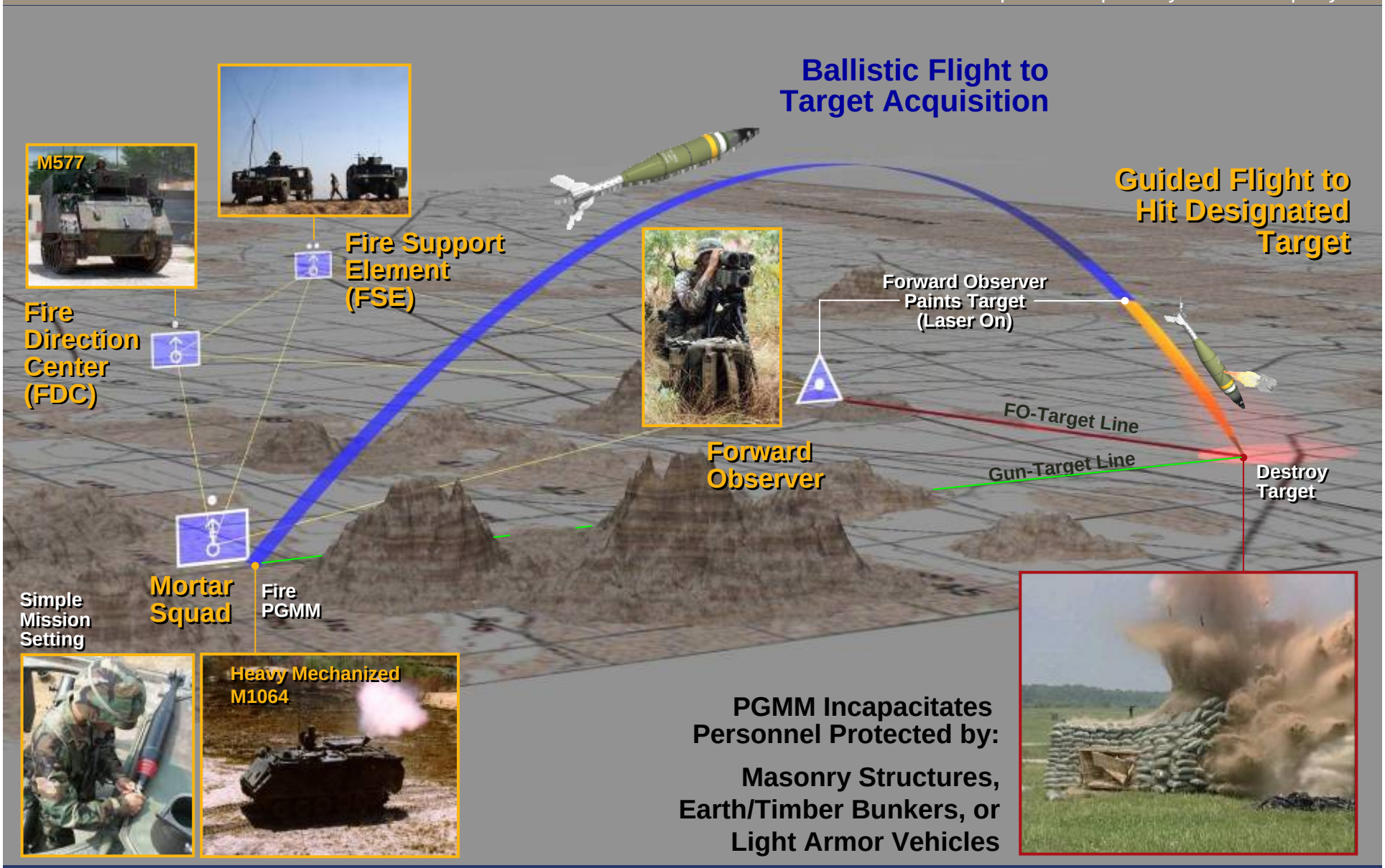
NDIA Gun and Missile Systems Conference
25 April 2007
Charlotte, North Carolina

XM395 PGMM

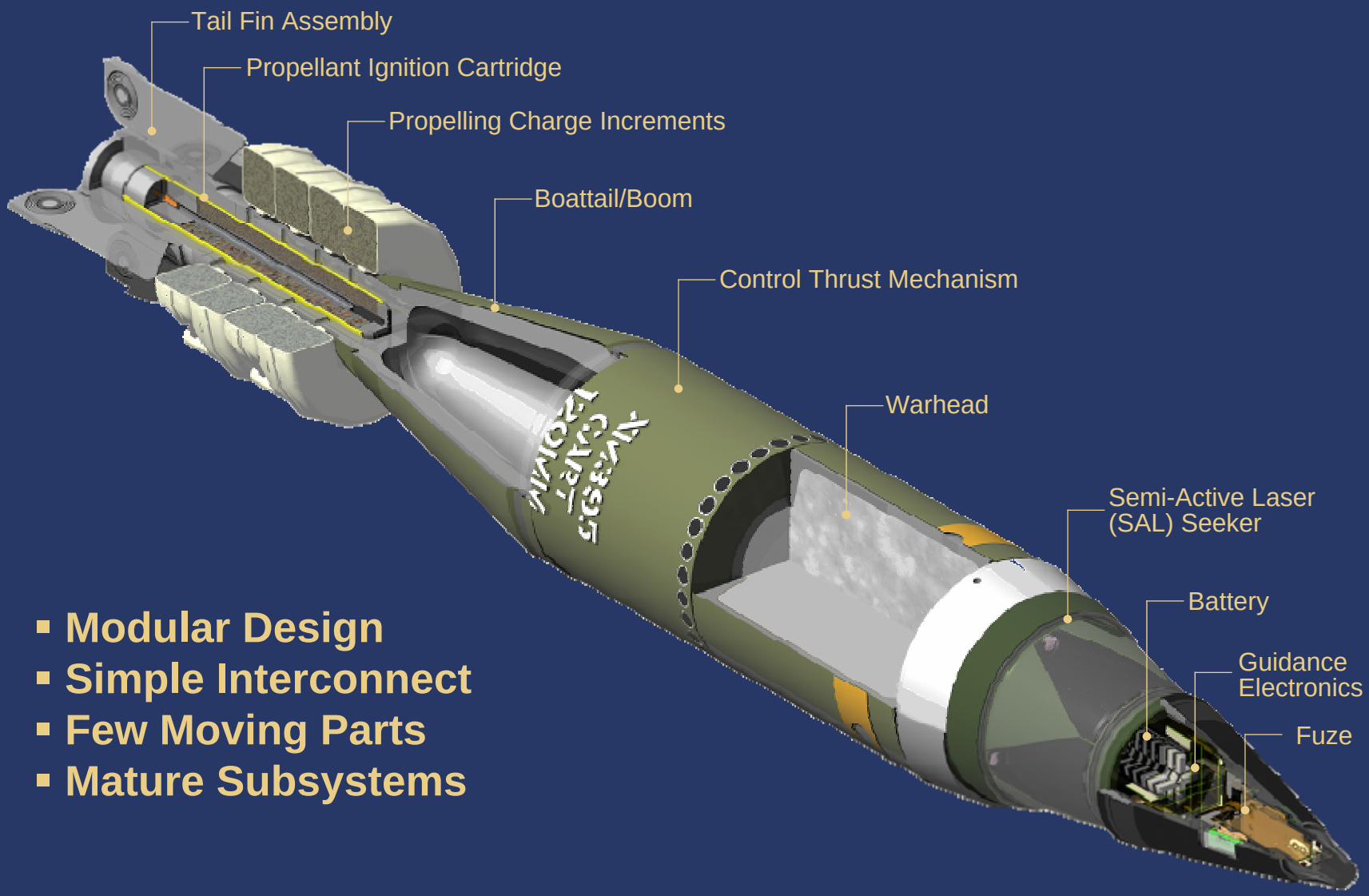
Precision Guided Mortar Munition

- **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



PGMM Cartridge – Simple, Rugged, and Precise

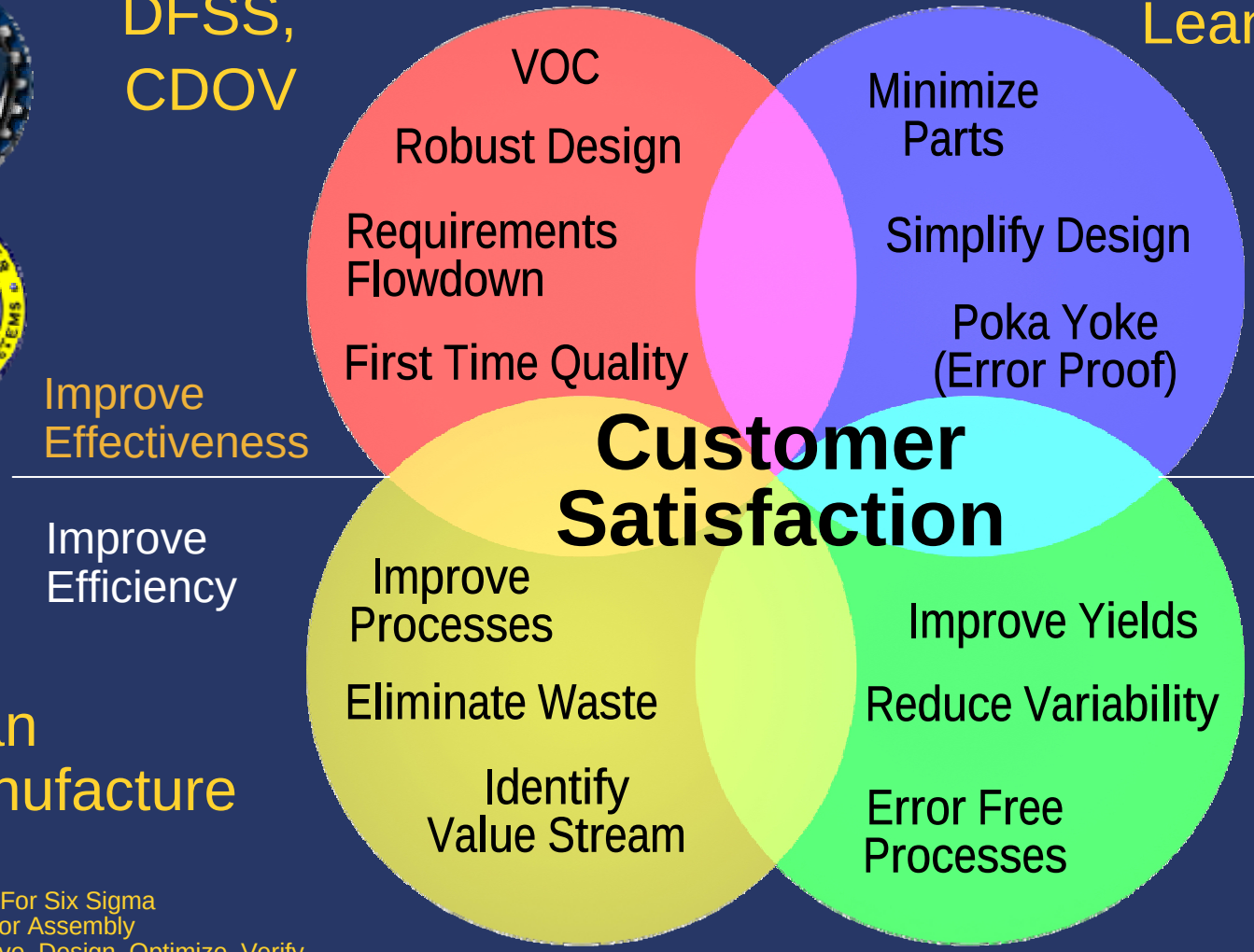


- **Modular Design**
- **Simple Interconnect**
- **Few Moving Parts**
- **Mature Subsystems**

Six Sigma & Lean Enterprise Model for PGMM

DFSS, CDOV

Lean Design,™ DFA



Improve Effectiveness

Avoid Problems

Customer Satisfaction

Improve Efficiency

Fix Problems

Lean Manufacture

Six Sigma, DMAIC

DFSS: Design For Six Sigma
DFA: Design for Assembly
CDOV: Conceive, Design, Optimize, Verify
VOC: Voice of the Customer
DMAIC: Define, Measure, Analyze, Improve, Control

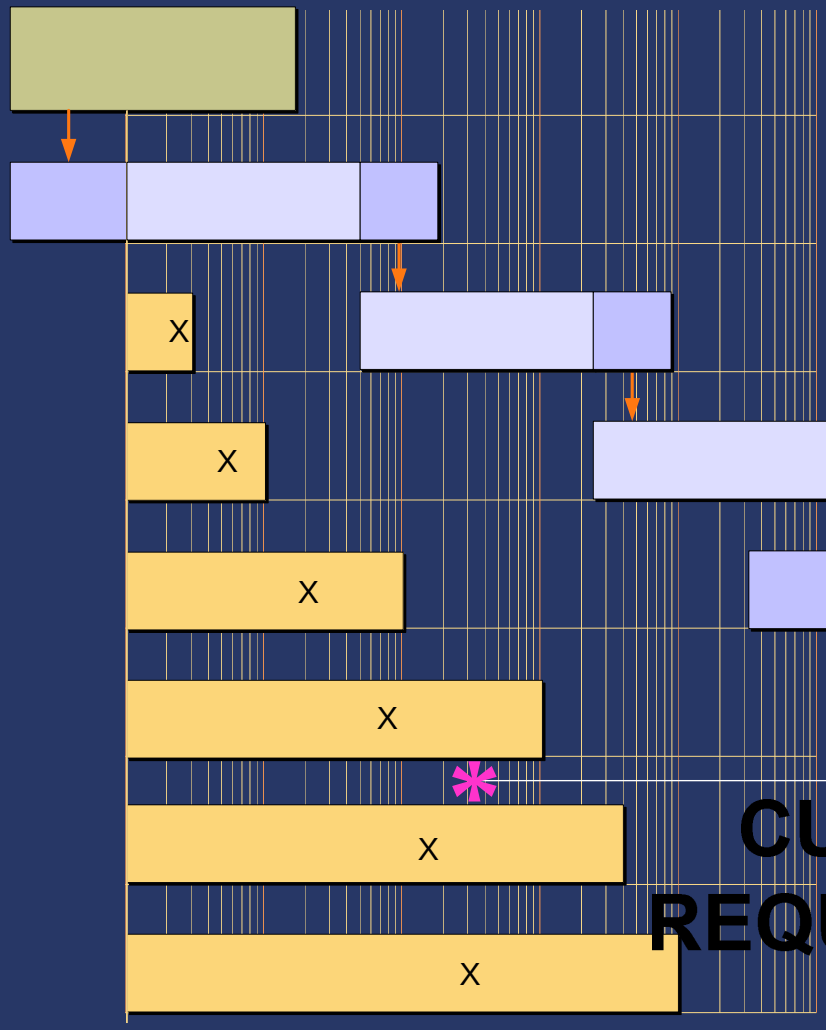
Project Objectives

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)

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

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

CUSTOMER REQUIREMENTS

Latent Requirement Defects Are Costly

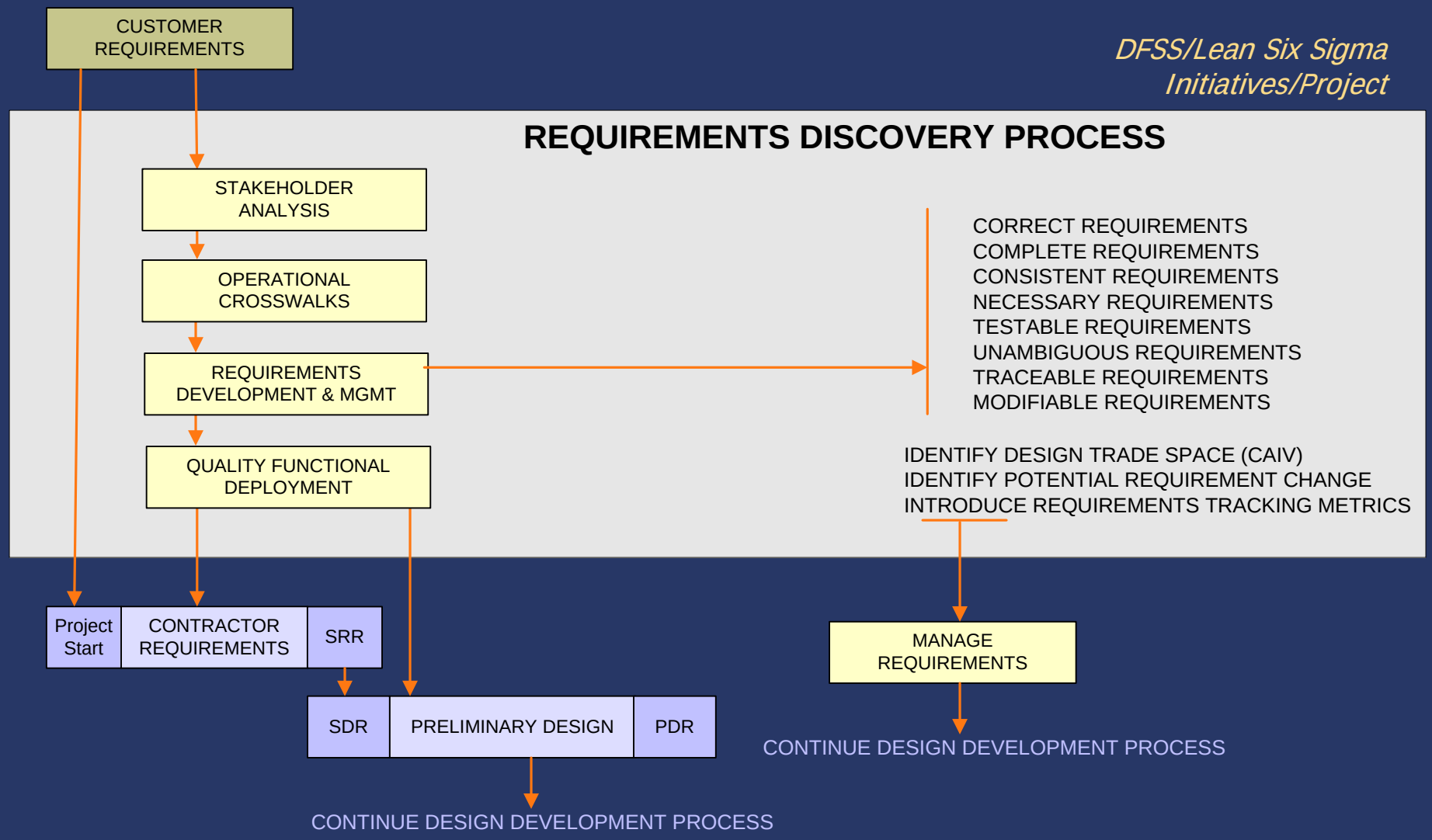
Design for Competitiveness, Advance copy by Bart Huthwaite

1

Project

CONTRACTOR

New Approach to Product Development

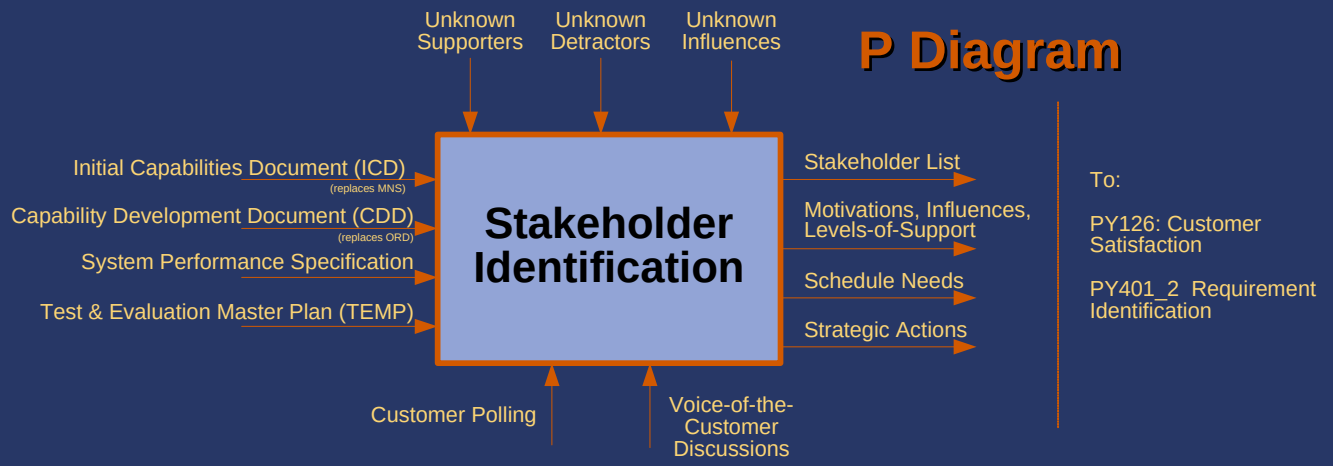


ATK Technical Standard

Requirements Defined and Tracked

Stakeholder Analysis

P Diagram



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

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

Operational Crosswalks

Requirements Development and Management

CUSTOMER REQUIREMENTS

DFSS/Lean Six Sigma Initiatives/Project

REQUIREMENTS DISCOVERY PROCESS

STAKEHOLDER ANALYSIS

OPERATIONAL CROSSWALKS

REQUIREMENTS DEVELOPMENT & MGMT

QUALITY FUNCTIONAL DEPLOYMENT

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

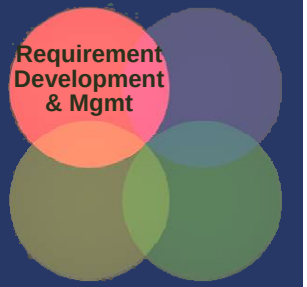
Project Start | CONTRACTOR REQUIREMENTS | SRR

SDR | PRELIMINARY DESIGN | PDR

CONTINUE DESIGN DEVELOPMENT PROCESS

MANAGE REQUIREMENTS

CONTINUE DESIGN DEVELOPMENT PROCESS



ATK Technical Standard

Requirements Defined and Tracked

Performance Requirements Walkthrough

Requirements Walkthough

Consolidated Walkthrough Review

3.3.5.2 KPP 2 - Lethality

Verbatim from Customer Performance Specification

REFERENCE: System Performance Specification Draft 31-Jan-03

OWNER: USAIC

DESCRIPTION:

3.3.5.2 KPP 2 – Lethality. The XM395 cartridge SHALL have the ability to incapacitate or fractionally casualtize personnel protected within and by point…

EVALUATION:

X	INCOMPLETE		INFEASIBLE		UNTESTABLE
	INCONSISTENT		UNMODIFIABLE		UNTRACEABLE
	INCORRECT		UNNECESSARY		AMBIGUOUS

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

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?

PRIORITY:

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

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)?

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:

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…

Verbatim from Customer Performance Specification

SUPPORTING ANALYSIS:

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

Performance Requirements Walkthrough

Requirements Walkthough

Consolidated Walkthrough Review

3.3.5.2 KPP 2 - Lethality

Information Capture Directly from Customer

Information Capture Directly from Customer

REFERENCE: System Performance Specification Draft 31-Jan-03	OWNER: USAIC
DESCRIPTION: 3.3.5.2 KPP 2 – Lethality. The XM395 cartridge SHALL have the ability to incapacitate or fractionally casualtize personnel protected within and by point…	EVALUATION: [X] INCOMPLETE [ ] INFEASIBLE [ ] UNTESTABLE [ ] INCONSISTENT [ ] UNMODIFIABLE [ ] UNTRACEABLE [ ] INCORRECT [ ] UNNECESSARY [ ] AMBIGUOUS
CROSS-REFERENCE: CTP 9. Draft ORD Para. 4.1.1.1.1, 4.1.1.1.2	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?
[9] MISSION/SAFETY CRITICAL [X] NON-NEGOTIABLE [X] UNLIKELY TO CHANGE [ ] USEFUL [ ] NEGOTIABLE (CAIV) [ ] MAY CHANGE [ ] DESIRABLE [ ] FLEXIBLE [ ] MOST LIKELY TO CHANGE	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)?
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: 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…
SUPPORTING ANALYSIS:	*Note: Since we are verifying performance through modeling, we are most interested in validating our models. Further discussion needed.*

Performance Requirements Walkthrough

Requirements Walkthough

Consolidated Walkthrough Review

3.3.5.2 KPP 2 - Lethality

REFERENCE: System Performance Specification Draft 31-Jan-03

OWNER: USAIC

DESCRIPTION:

3.3.5.2 KPP 2 – Lethality. The XM395 cartridge SHALL have the ability to incapacitate or fractionally casualtize personnel protected within and by point…

EVALUATION:

X	INCOMPLETE		INFEASIBLE		UNTESTABLE
	INCONSISTENT		UNMODIFIABLE		UNTRACEABLE
	INCORRECT		UNNECESSARY		AMBIGUOUS

Feedback To Customer From Contractor

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

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?

Notes to Formulate Action Plan

PRIORITY:

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

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)?

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:

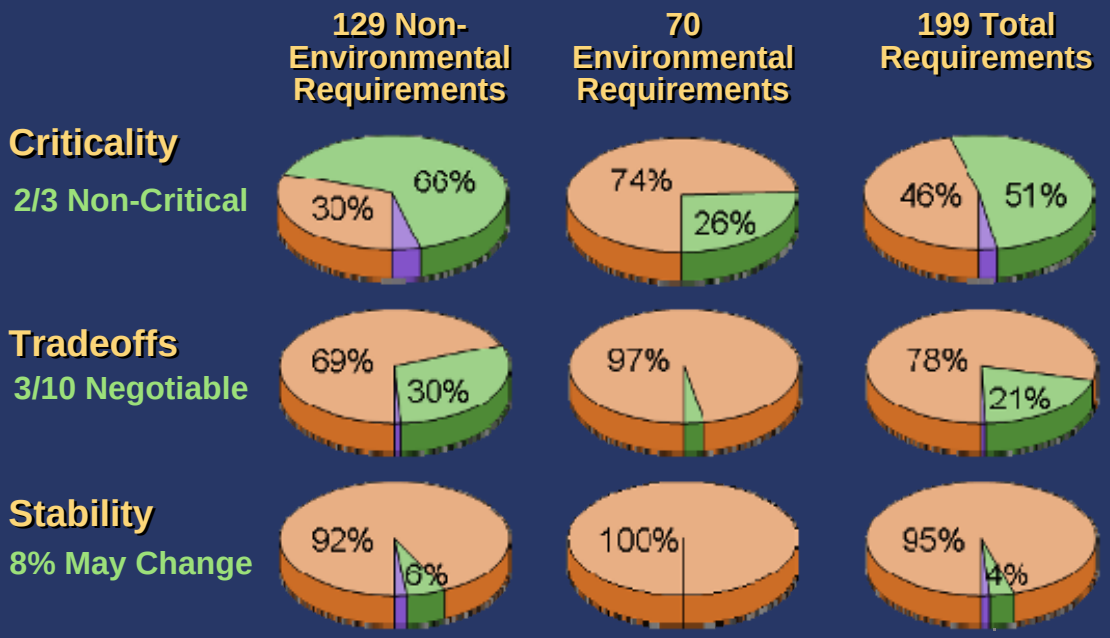
4.3.5.2 Lethality. To be verified via analysis and test of XM395 subsystem and system flight hardware against all targets specified in section…

SUPPORTING ANALYSIS:

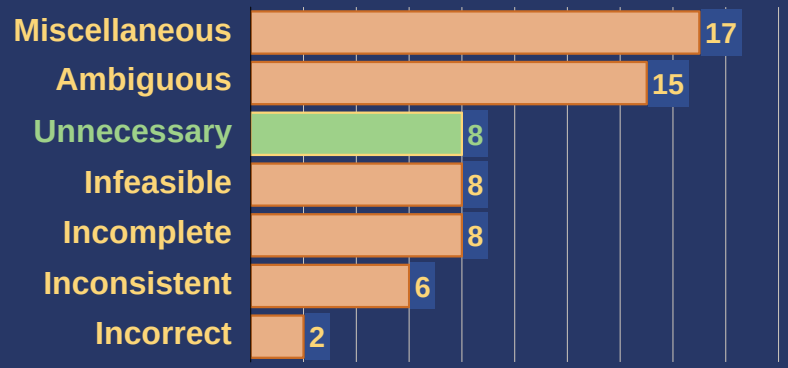
Note: Since we are verifying performance through modeling, we are most interested in validating our models. Further discussion needed.

Requirements Walkthrough Statistics

Customer Priorities	129 Non-ENV REQ	70 ENV REQ	199 Total REQ
Mission/Safety Critical	39	52	91
Useful	85	18	103
Desireable	5	0	5
Non-Negotiable	89	68	157
Negotiable	39	2	41
Flexible	1	0	1
Unlikely to Change	118	72	190
May Change	7	0	7
Most Likely to Change	2	0	2



Contractor Feedback (64 Issues)



- 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).

Accomplishment - Requirement Reduction

Reduced Customer Requirements

- 199 "SHALL" requirements in US Army SPS (System Performance Specification)
- Deleted 17 requirements (8.5%)
- Relaxed another 5 requirements (2.5%)

} 11%

Significance

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

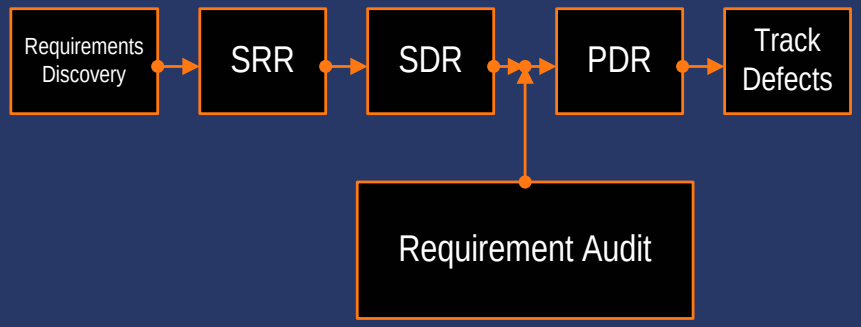
- Avoided fuze redesign cost of ~$300K to safely reset after exposure to the second environment

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

Process



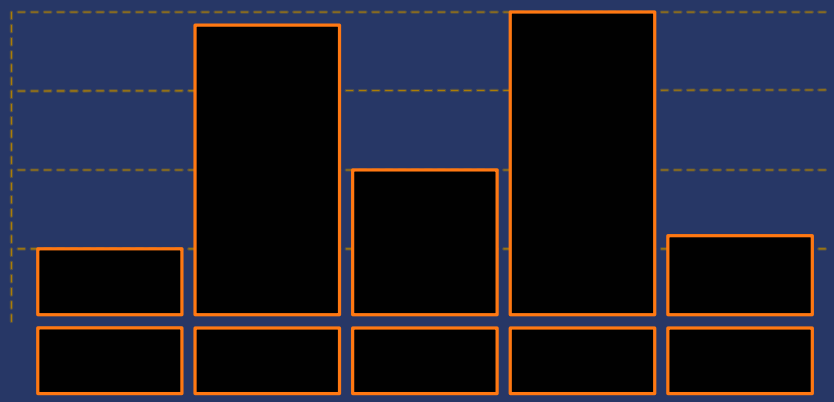
Requirement Defects	Examples
Incorrect Information	Incorrect Test Standard Incorrect Paragraph Reference Incorrect Environmental Levels
Omissions	Missing Test Standard Missing Requirement Missing Verification
Ambiguities	More Than One Interpretation
Poorly Written	Multiple “Shalls” In One Requirement Spelling and Grammar Requirement Not Clear
Misplaced	Requirement in Wrong Section Requirement Applied to Wrong Subsystem

ATK Technical Standard

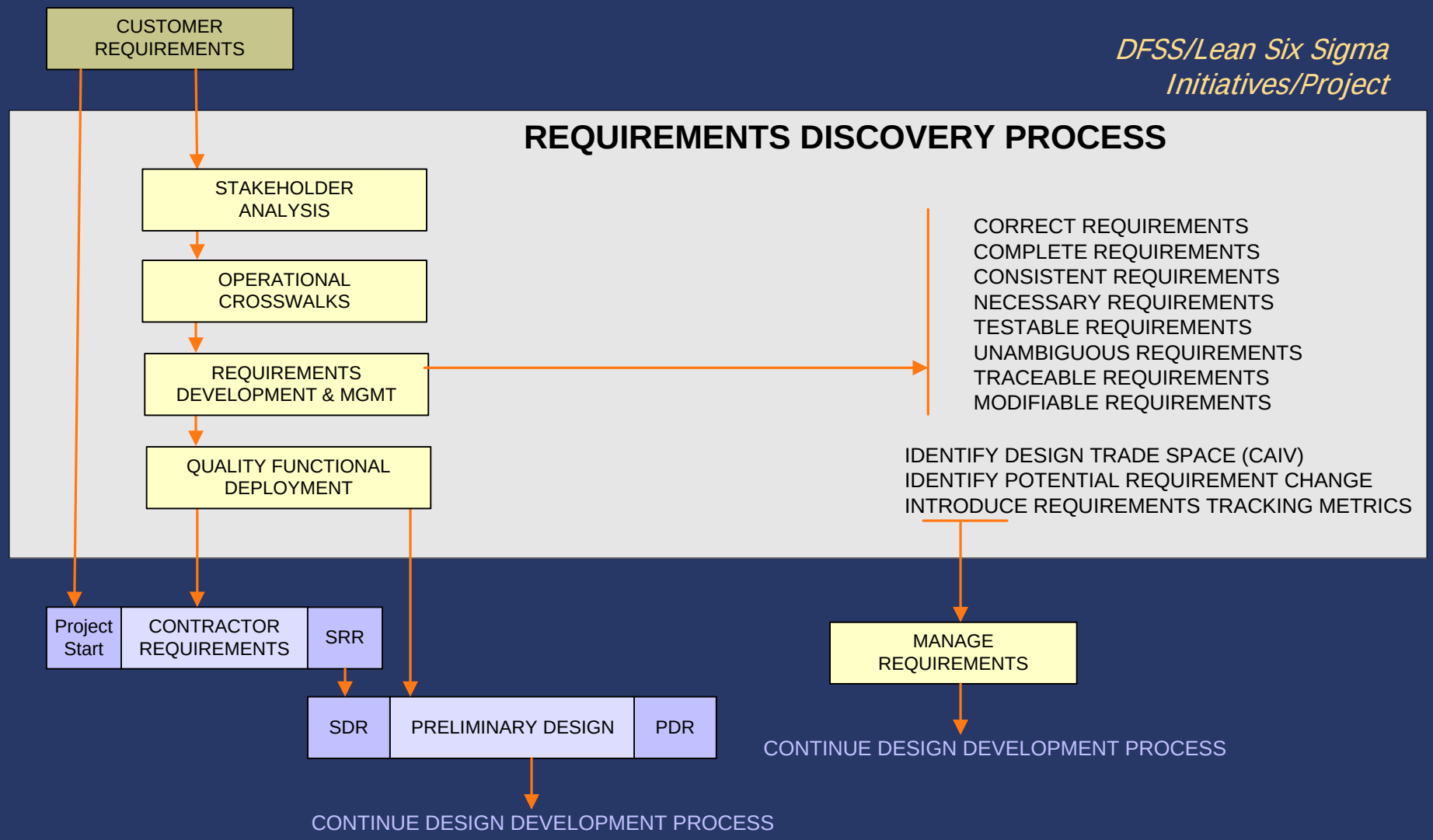
Early elimination of deficiencies

Results

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



Quality Functional Deployment



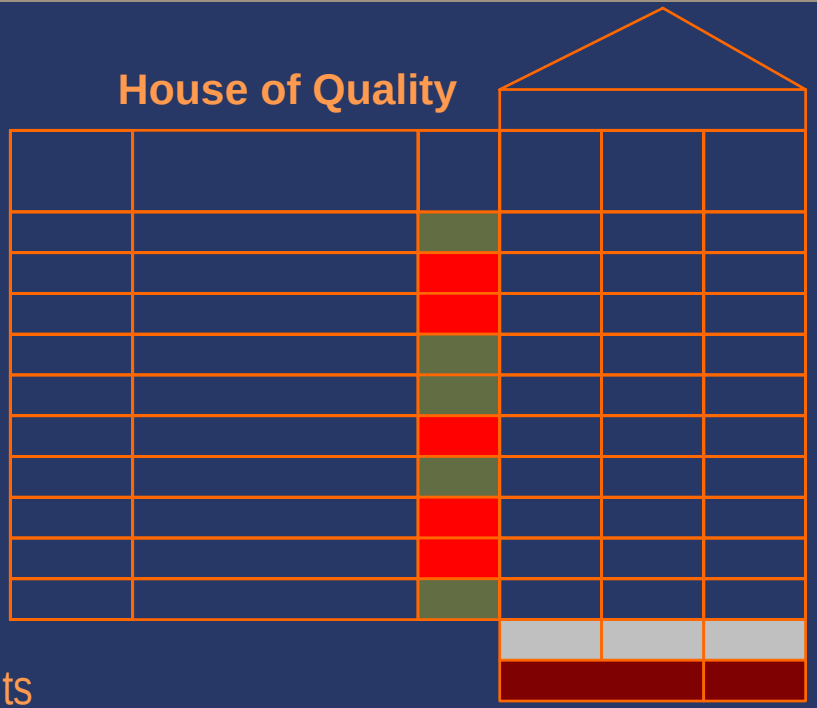
ATK Technical Standard

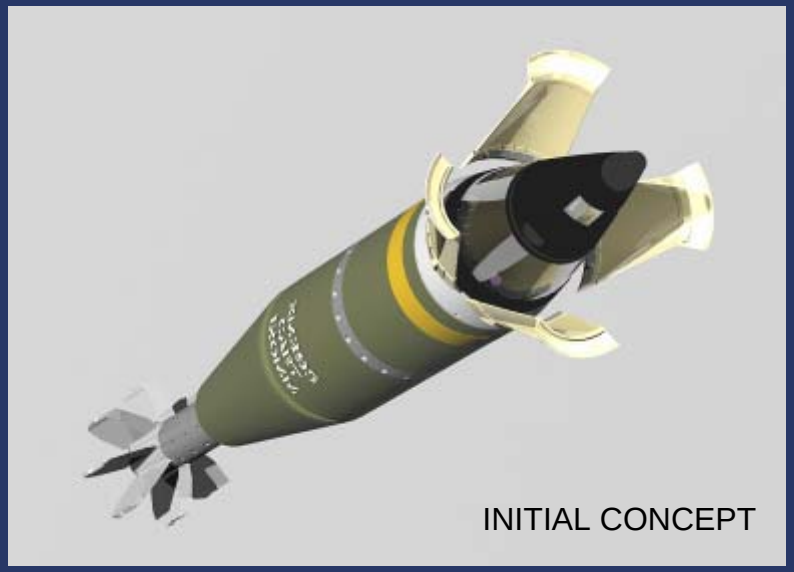
Requirements Defined and Tracked

Quality Functional Deployment (QFD)

Requirement Priority X Correlation

9	Mission/Safety Critical	±9	Critical
3	Useful	±3	Necessary
1	Desirable or Deleted	±1	Helps Satisfy

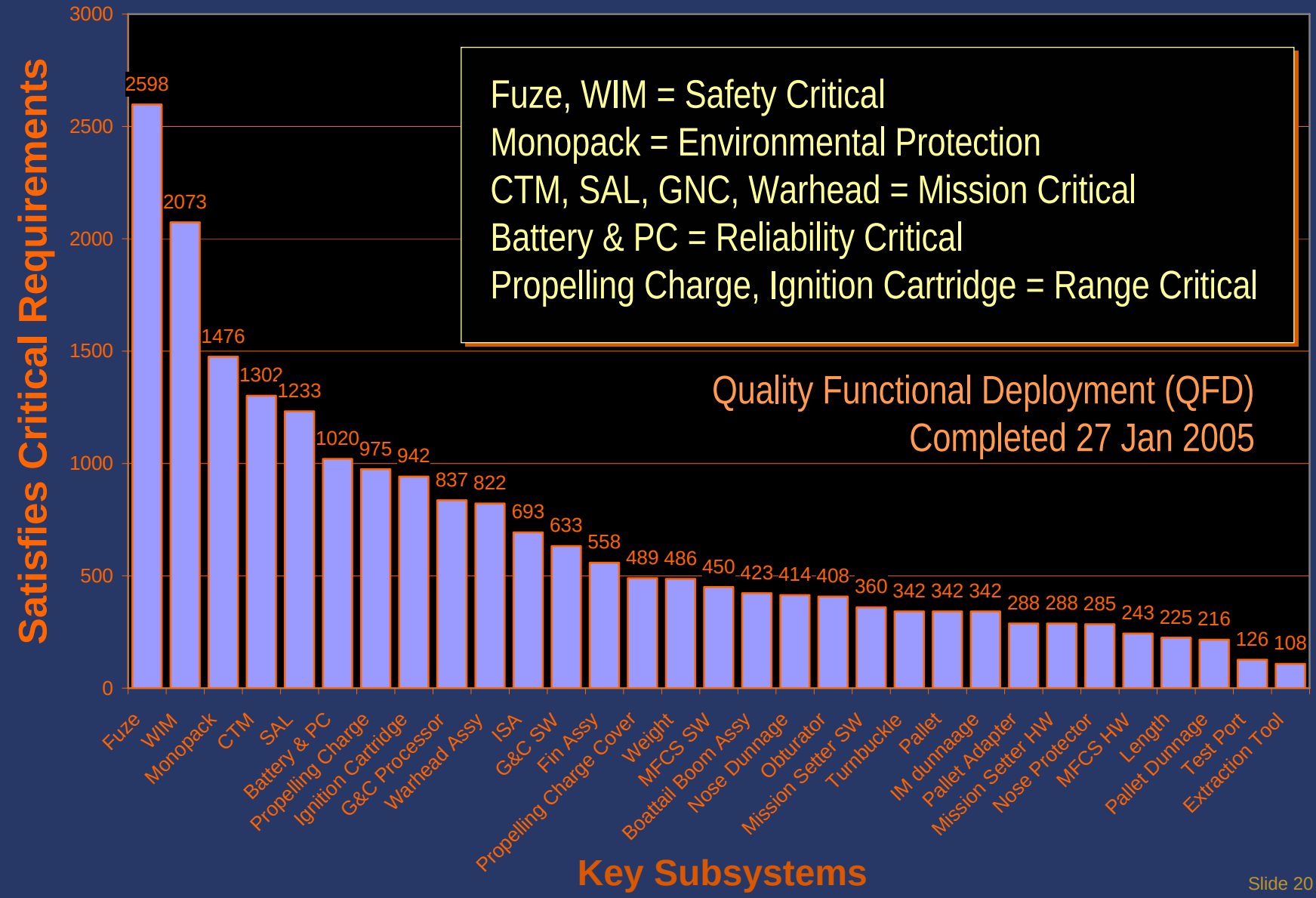




Results

- 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

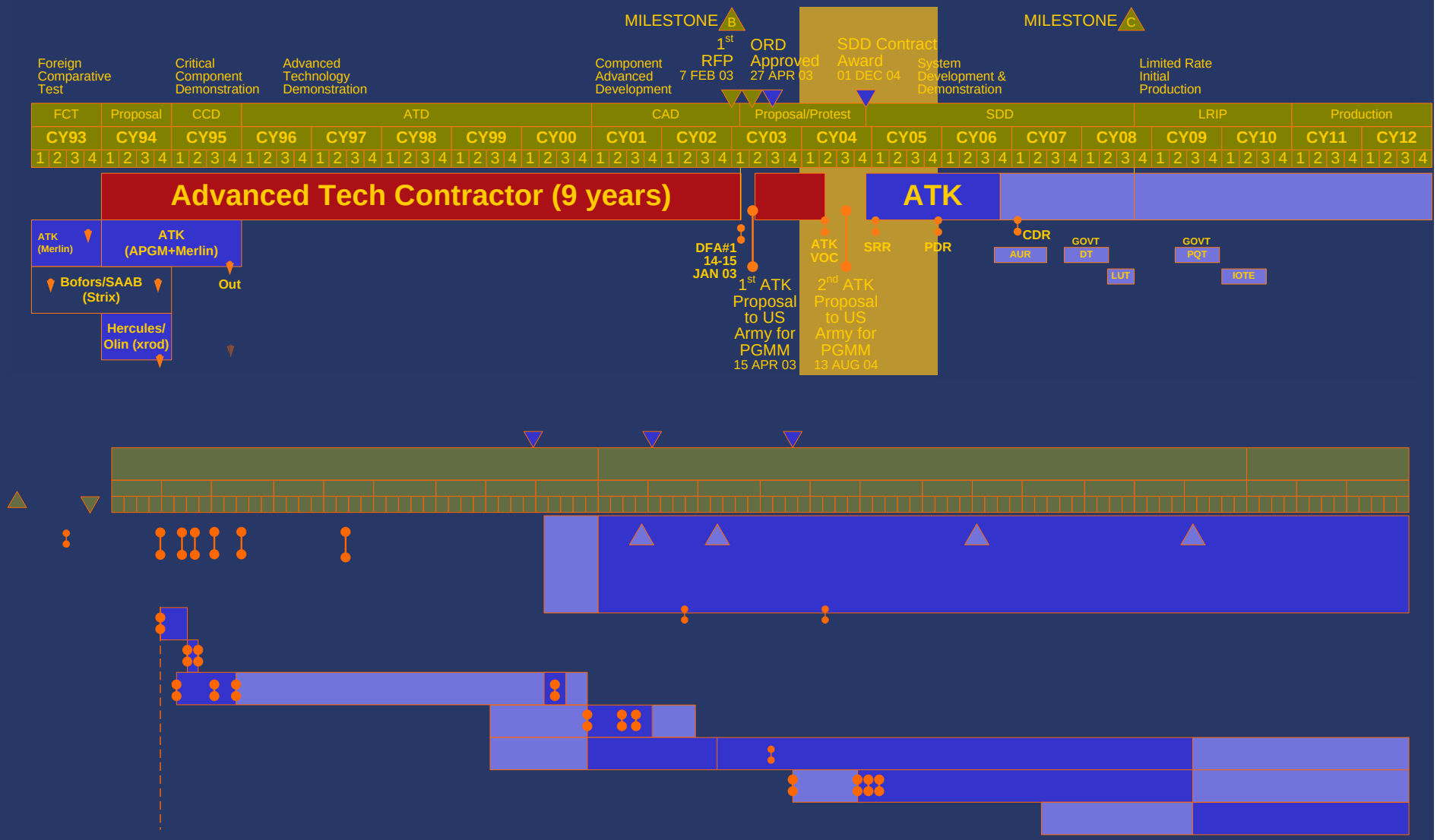
Quality Functional Deployment (QFD) - Results



Design for Six Sigma Tool Implementation

Project Summary

An advanced weapon and space systems company



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

Developed Product = User Need

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

DFSS Project Investment

Program Cost Savings of 5x to 10x DFSS Investment

CONTACT INFORMATION

An advanced weapon and space systems company

James Kalberer

ATK Advanced Weapons Division

4700 Nathan Lane North

Plymouth, MN 55442

763-744-5406

james.kalberer@atk.com