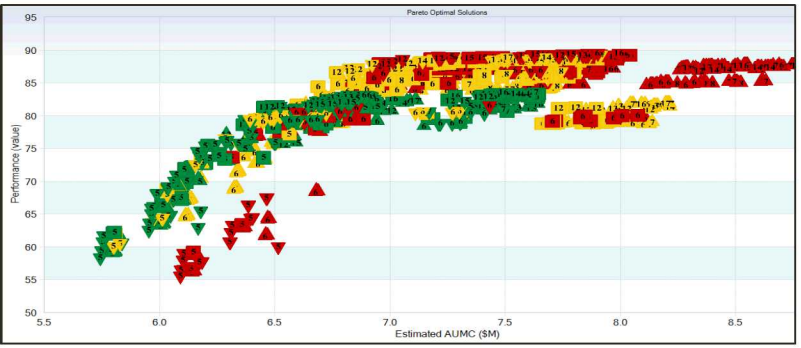
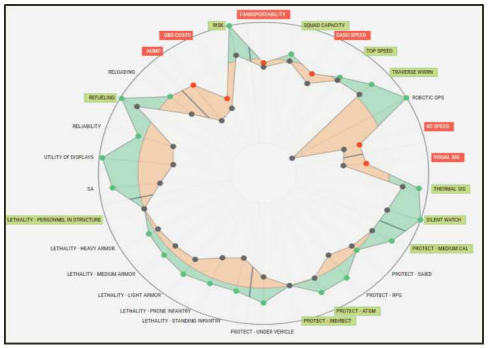
SAND2020-5829C





Tradespace Analytics to Support Major Acquisition Programs

Bruce Thompson
Manager, Advanced Decision Analytics
(505) 284-4949
bmthomp@sandia.gov

Society of Decision Professionals
Decision Analysis Affinity Group (DAAG)
Conference
June 24, 2020

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND-XXXXX

Outline

Sandia National Laboratories

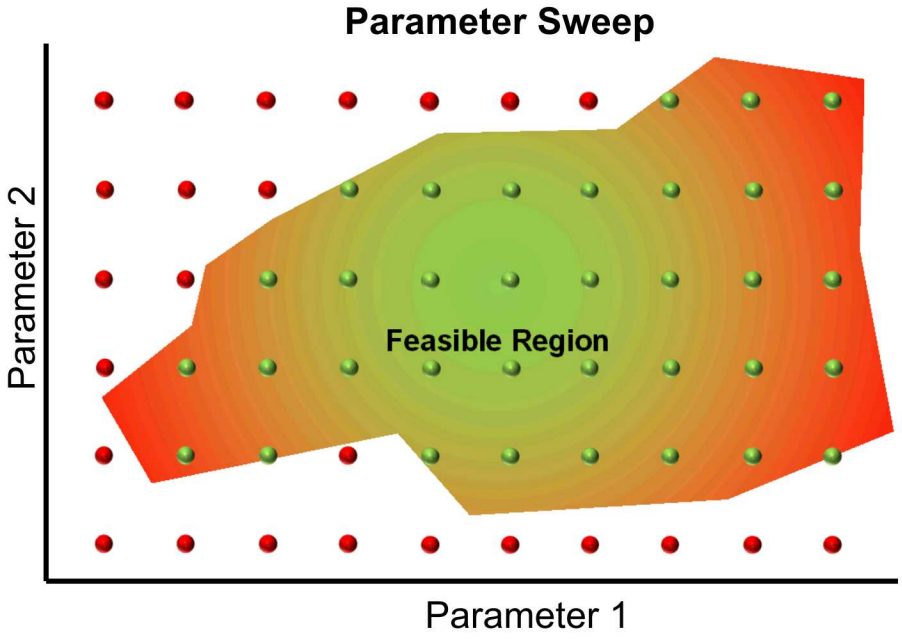
- Tradespace Terminology
- Acquisition Process
- Advanced Requirements Integration & Exploration System (ARIES) Overview
  - Optimal Requirements Trade Space
- Whole System Trades Analysis Tool (WSTAT) Overview
  - Optimal System Design Trade Space
- Summary

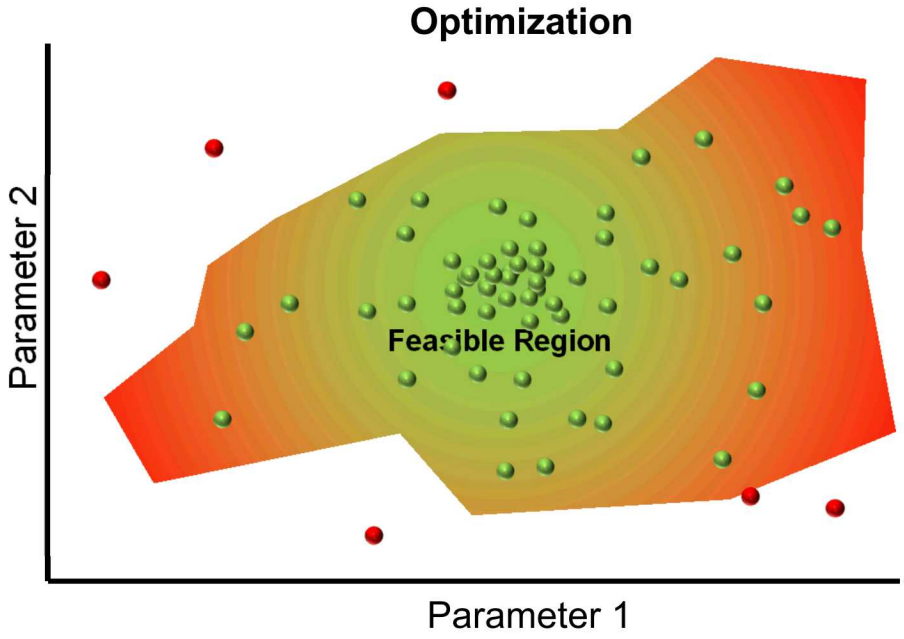
Trade Space Terminology: Optimization vs. Parameter Sweep

Sandia National Laboratories

Over time, we've noticed that the idea of a "trade space study" can mean different things to different people. Generally speaking, this difference often boils down to the difference between a ***parameter sweep*** and an ***optimization***.

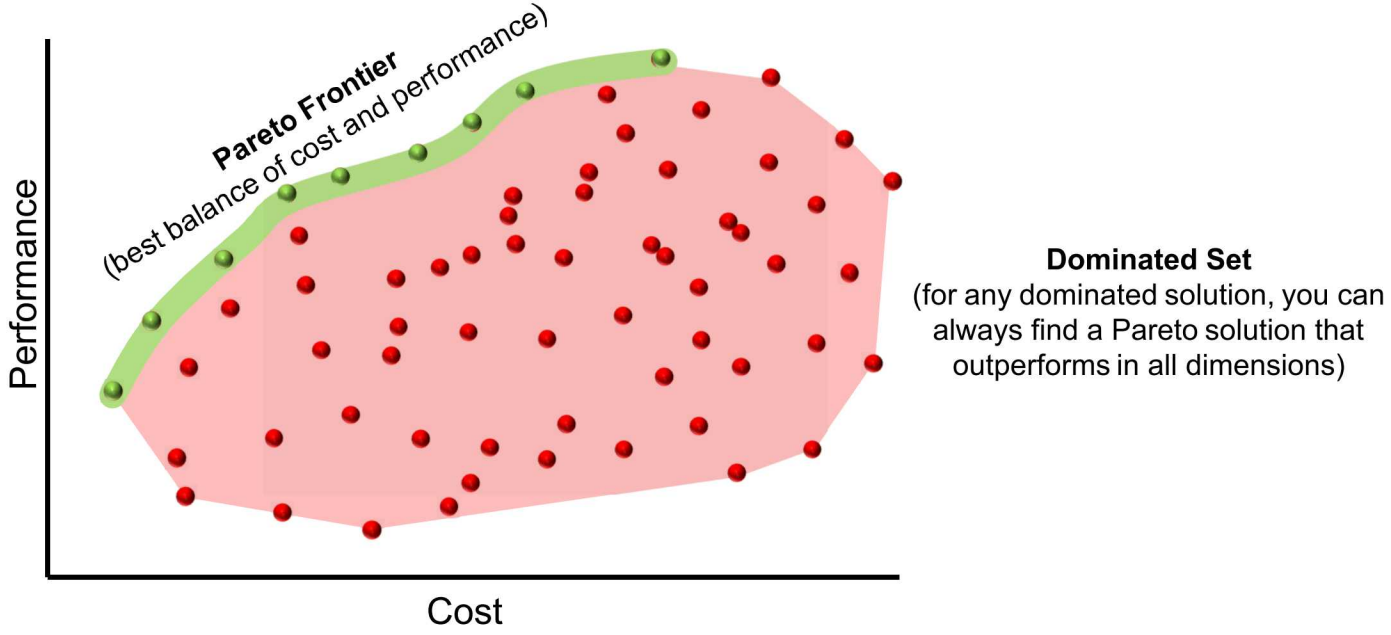
Given the problem context and search space size, BOTH approaches can be perfectly appropriate, and both techniques may entail various pros and cons.





Optimization Trade Space

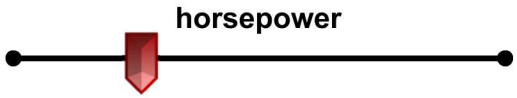
- Many of our decision analytics tools focus on an ***optimization trade space***
  - Capture not just one best answer, but instead a **set of best answers** that balance competing objectives in different ways
  - Advanced Requirements Integration & Exploration System (ARIES) and Whole System Trades Analysis Tool (WSTAT) both focus on capturing this optimal trade space (or a Pareto Frontier)



Generating Solutions from Technologies

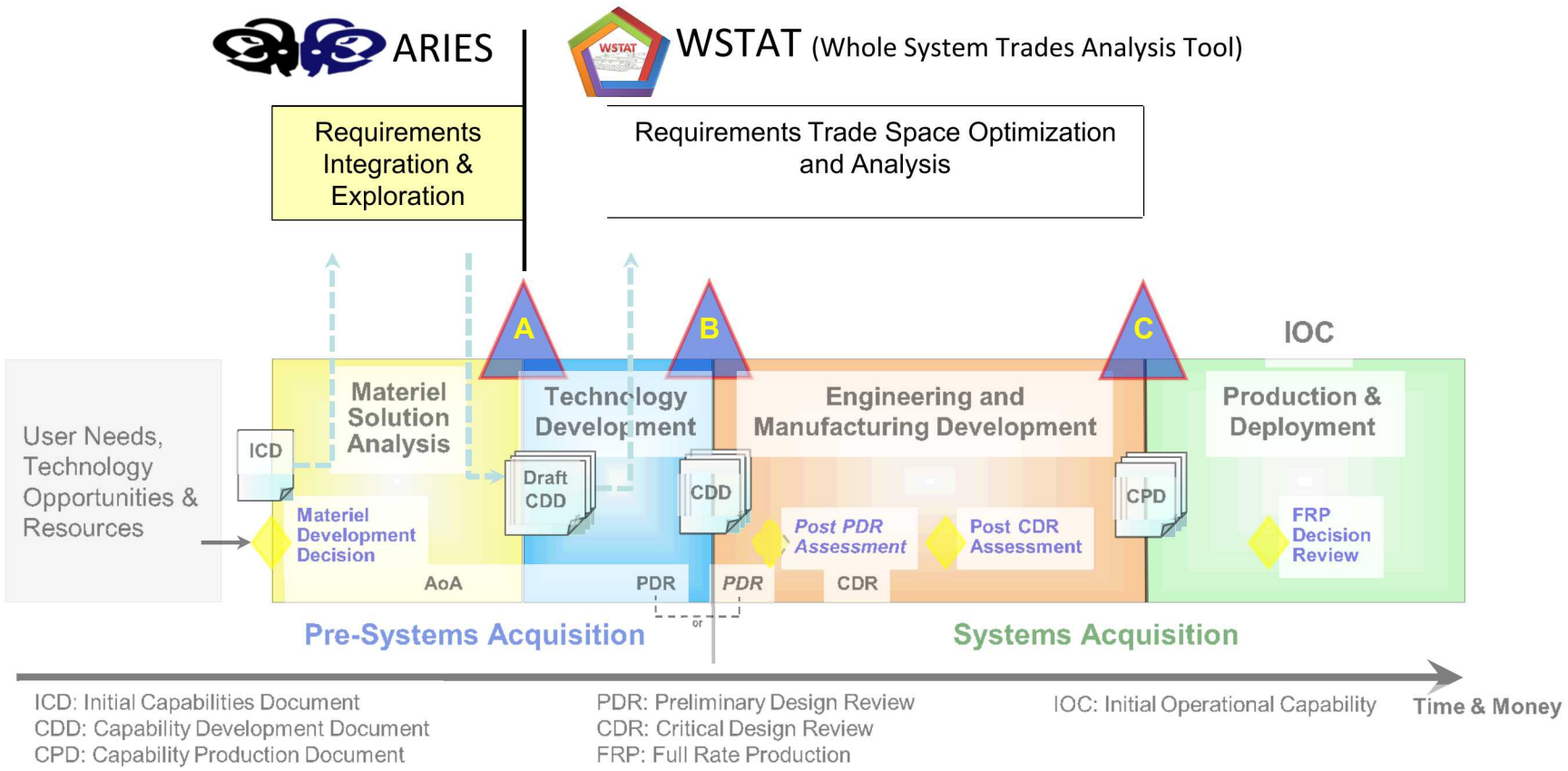
ARIES and WSTAT generate solutions via combinations of discrete subsystems (with inherent properties) rather than by directly setting system parameters

"Choose the part" **vs.** **"Choose the parameter"**



- Advantages of this technology way of thinking
  - Helps ensure analytic insights are grounded in reality
    - Tied to existing or envisioned technologies, their attributes, and interactions
    - Naturally avoids selecting impractical parameter combinations
      - Example – will not consider a very light and powerful alternative that does not exist/cannot be created
  - Easier to define system design constraints
    - Example – designing a vehicle, suspension has maximum weight it can support, can sum all selected component weights and compare to limit for selected suspension
  - Easier to capture technology compatibilities
    - Example – not all engines are compatible with all transmissions for a vehicle (not necessarily tied to specific parameter values)
  - Easier to talk about what a solution means (collection of parts vs. collection of parameters)

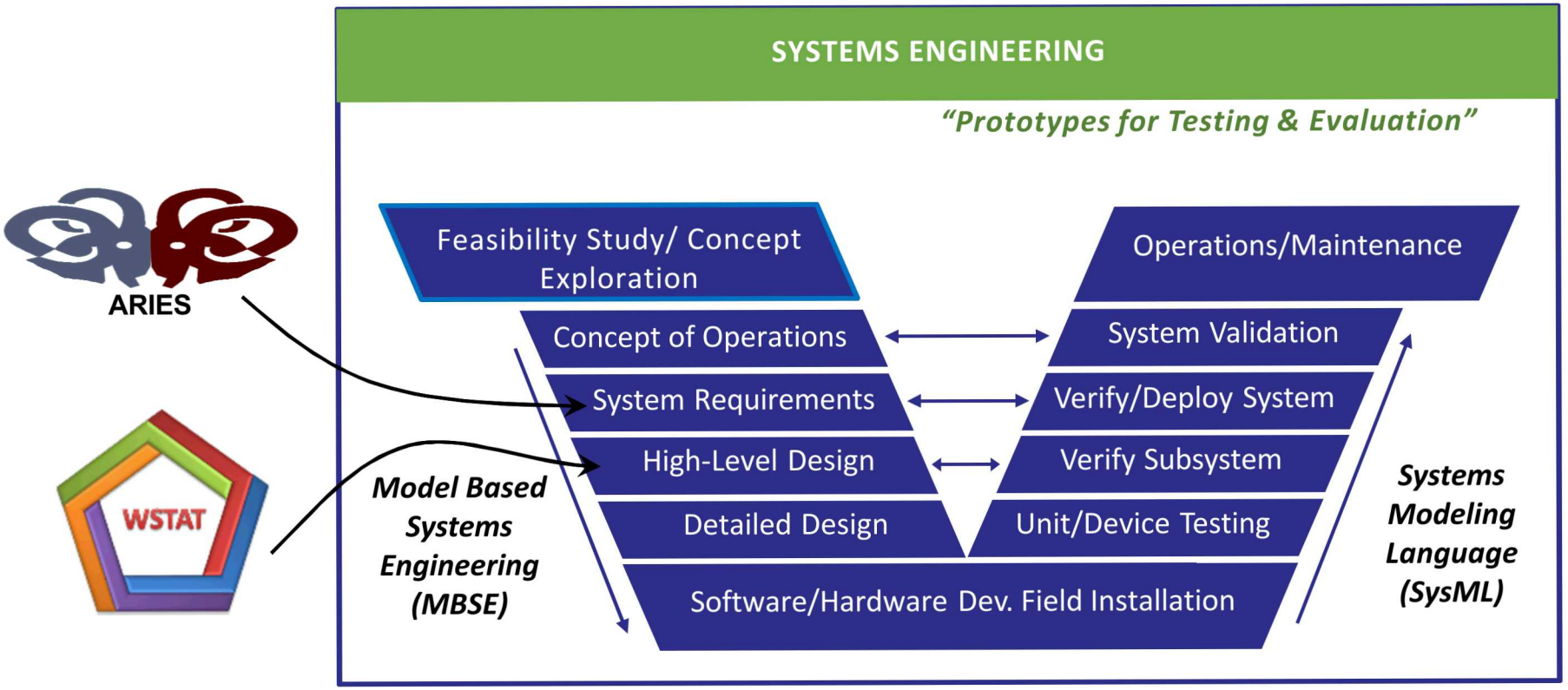
When are ARIES and WSTAT Used?



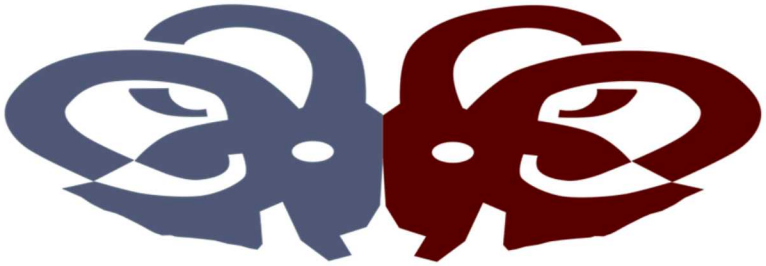
ARIES is used to help establish an achievable set of integrated requirements early in a program

WSTAT explores design trades for combinations of technologies relative to defined requirements

Decision Analytics & Systems Engineering



Sandia National Laboratories

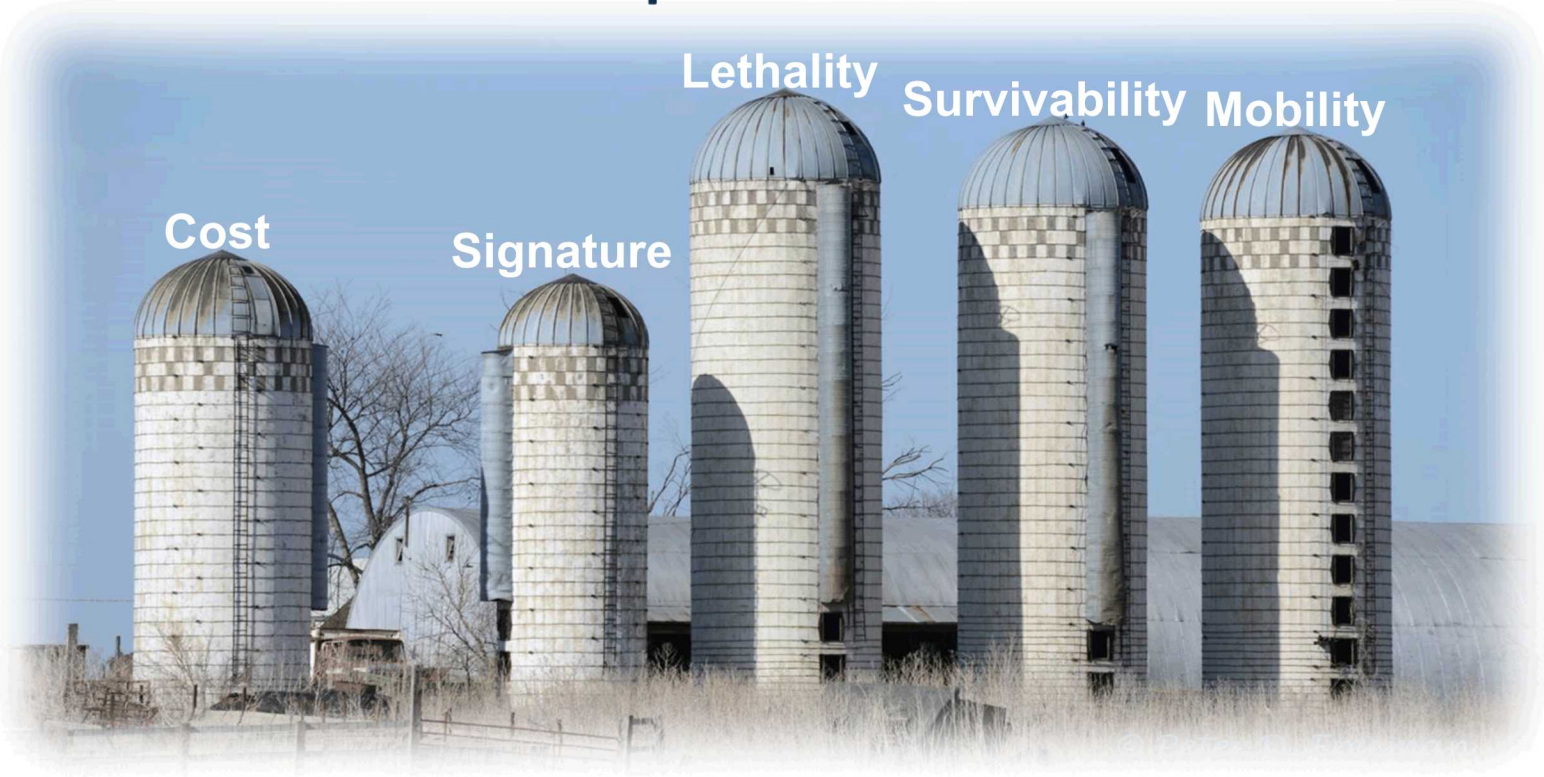


ADVANCED REQUIREMENTS INTEGRATION & EXPLORATION SYSTEM (ARIES) OVERVIEW

ARIES: Optimal Requirements Trade Space

ARIES Problem Space

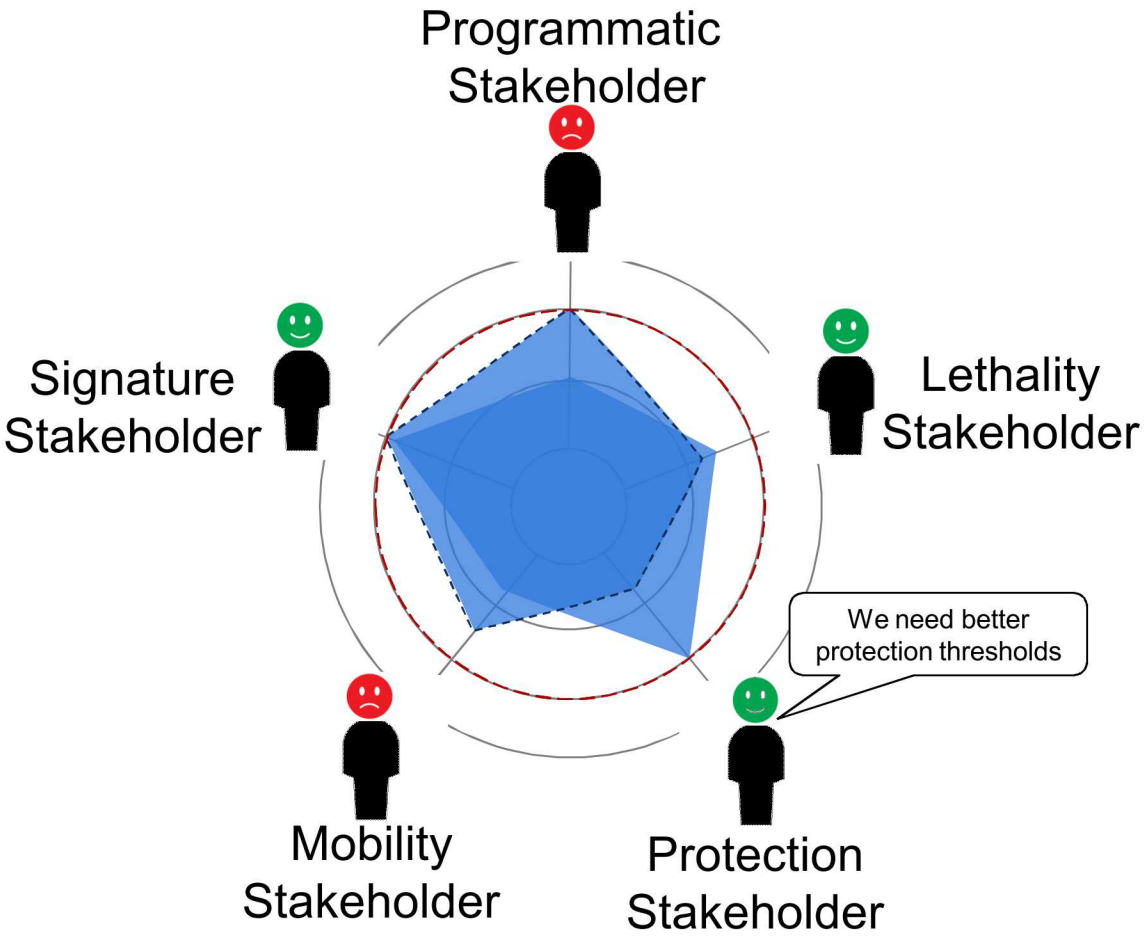
Sandia National Laboratories



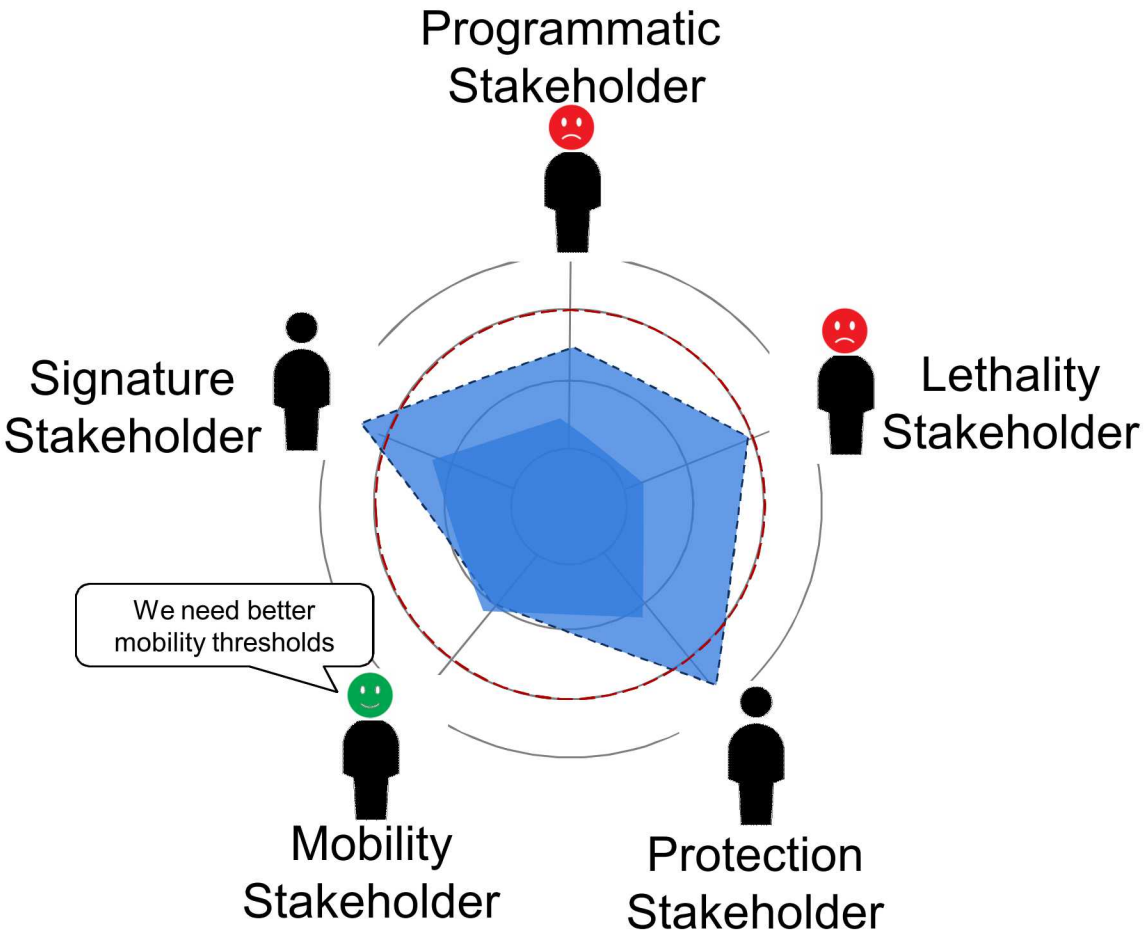
- Early in defense acquisition programs, an increasingly complex set of requirements is developed
- Each individual requirement possesses solid rationale and analytical backing
- However, different groups of requirements (lethality, mobility, etc.) are sometimes incompatible or unachievable when programmatic constraints are applied

ARIES provides unique analytic capability to foster communication and compromise across potential requirements silos, resulting in a simultaneously achievable set of requirements

Real-Time Stakeholder Collaboration



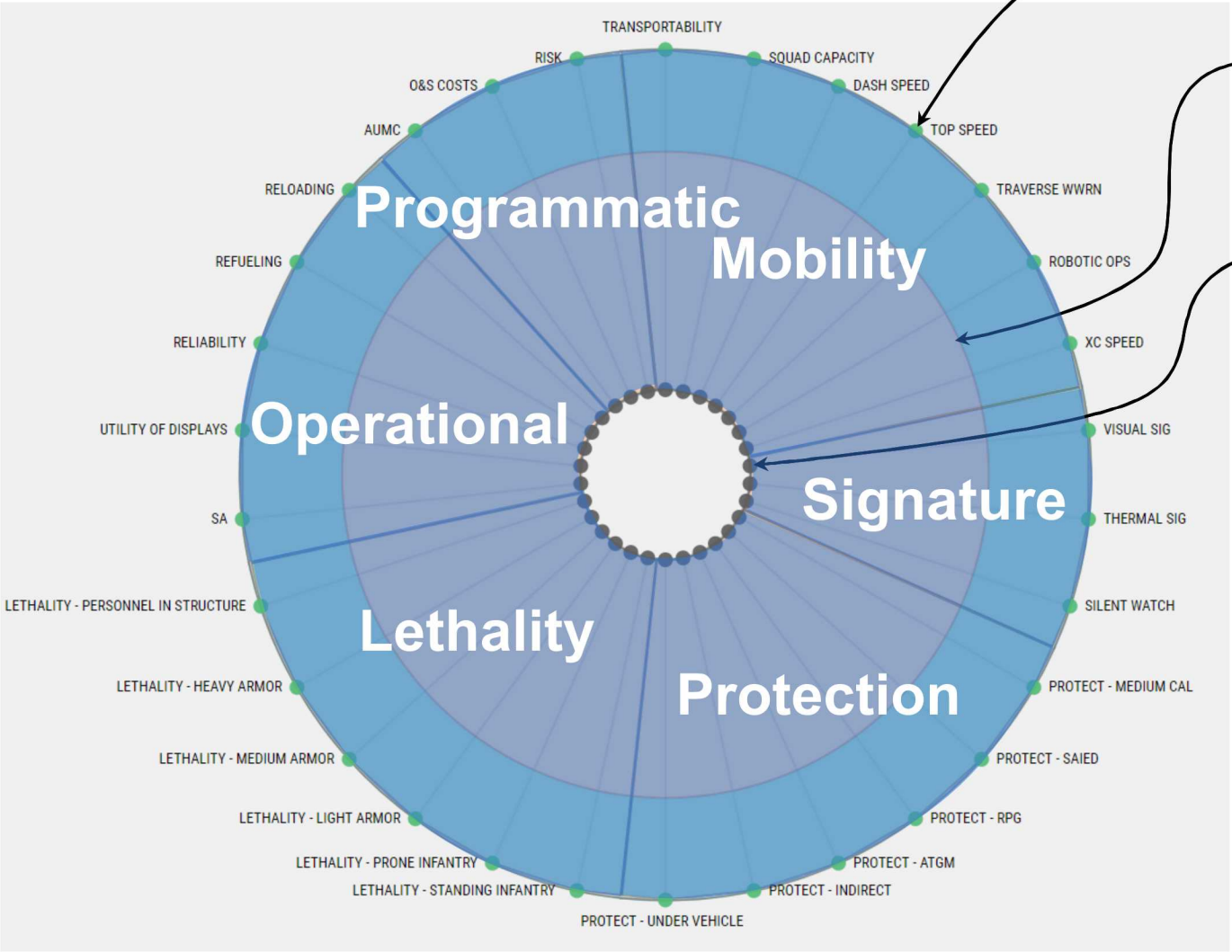
Real-Time Stakeholder Collaboration



ARIES Radar Chart

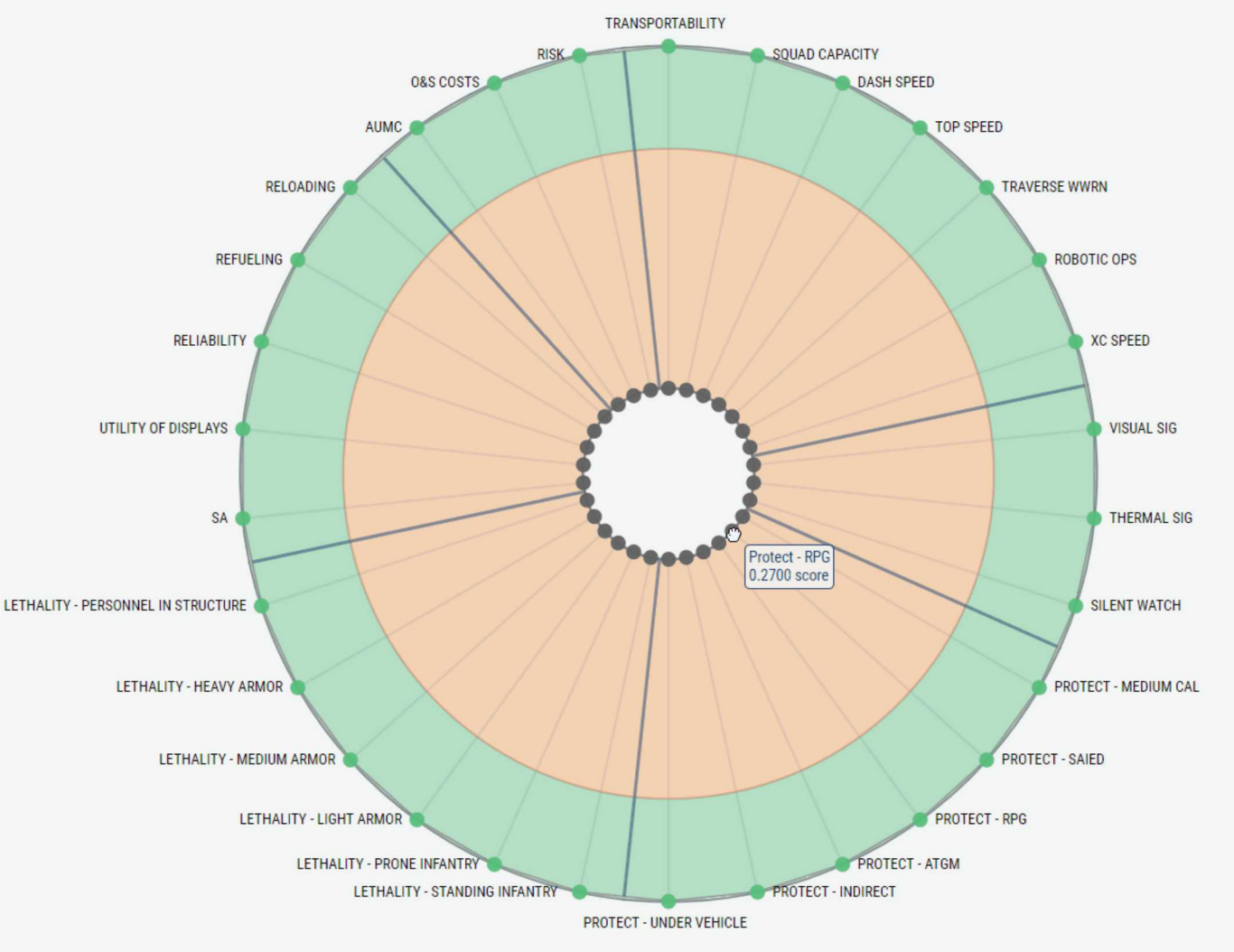
- Each spoke represents a system requirement
- The orange/green ring represents the **desired** threshold for each requirement
- The grey dot represents the current filter setting for each requirement

ARIES Radar Chart



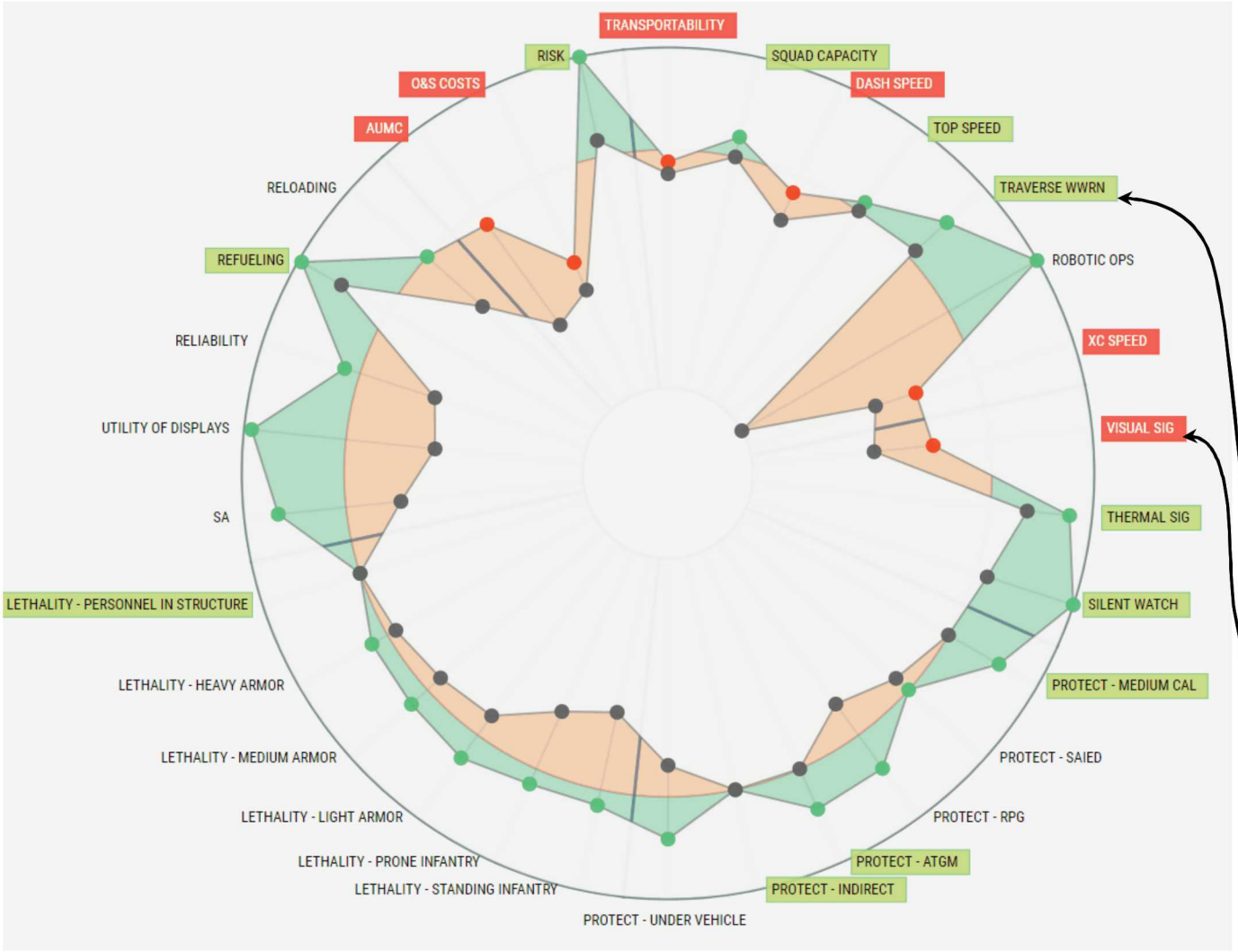
- Each spoke represents a system requirement
- The orange/green ring represents the **desired** threshold for each requirement
- The grey dot represents the current filter setting for each requirement
- Related requirements are grouped around the circle

ARIES Radar Chart



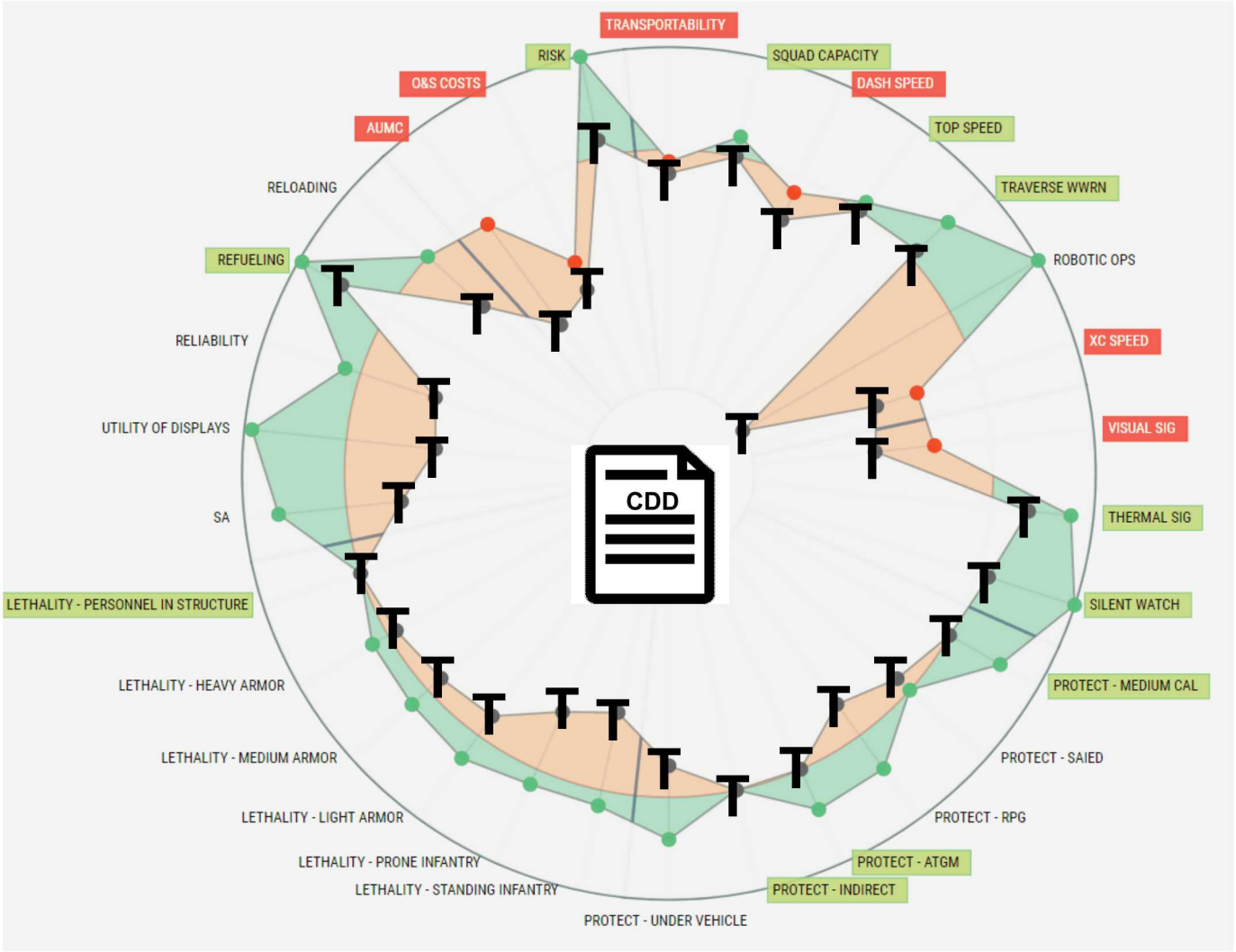
- Each spoke represents a system requirement
- The orange/green ring represents the **desired** threshold for each requirement
- The grey dot represents the current filter setting for each requirement
- Related requirements are grouped around the circle

ARIES Radar Chart



- Each spoke represents a system requirement
- The orange/green ring represents the **desired** threshold for each requirement
- The grey dot represents the current filter setting for each requirement
- Related requirements are grouped around the circle
- Green means good: all remaining solutions meet desired threshold
- Red means bad: no remaining solutions can meet desired threshold

ARIES Radar Chart



- Each spoke represents a system requirement
- The orange/green ring represents the **desired** threshold for each requirement
- The grey dot represents the current filter setting for each requirement
- Related requirements are grouped around the circle
- Green means good: all remaining solutions meet desired threshold
- Red means bad: all remaining solutions cannot meet desired threshold

ARIES Result - a complete set of achievable requirement values

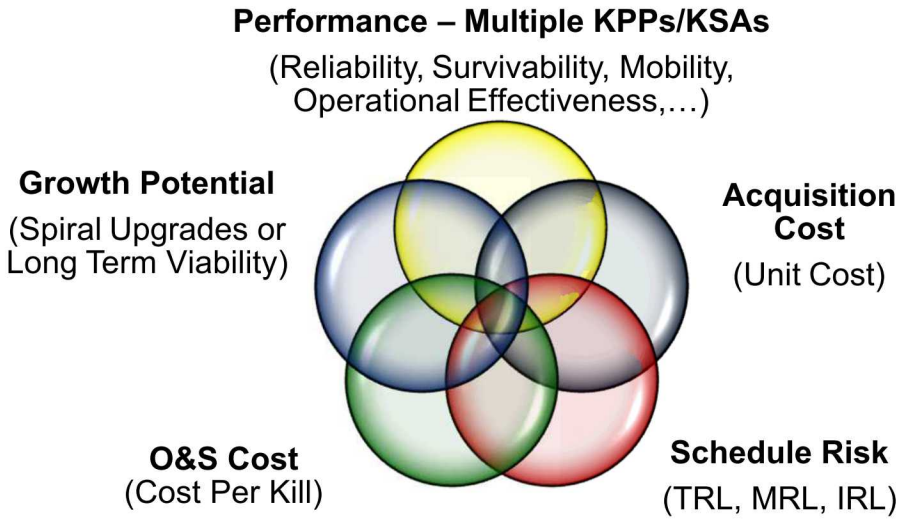
Sandia National Laboratories

WHOLE SYSTEM TRADES ANALYSIS TOOL (WSTAT) OVERVIEW

WSTAT: Optimal System Design Trade Space

WSTAT Purpose and Goals

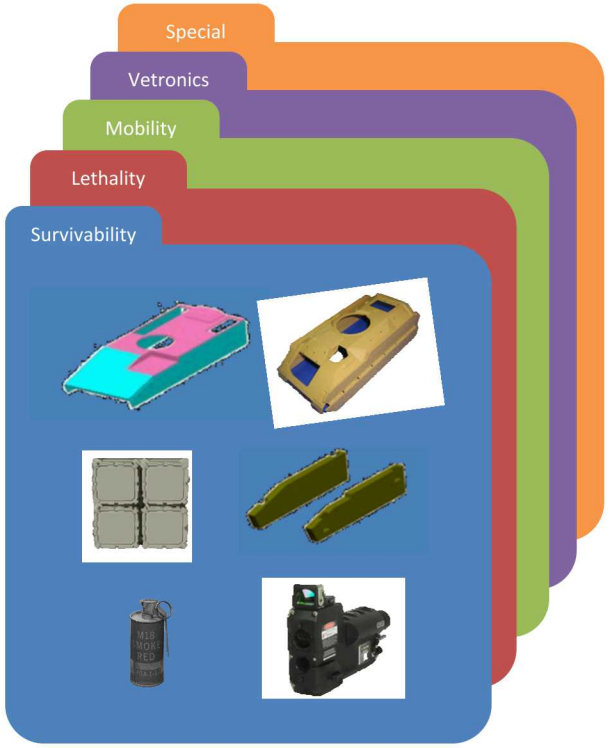
- Purpose
  - Identify efficient technology combinations
  - Model relationships between design decisions & stakeholder value to inform and potentially influence requirements and technology investments
  - Provide insights to help decision makers understand holistic system-level impacts of technology choices
- Process Goals
  - Generate many good alternatives
  - Stimulate conversation
  - Provide foundation for traceable and defendable decisions
  - Build consensus (high level of commitment and shared understanding among team members and stakeholders)



Like ARIES, WSTAT does not provide a single answer. It's is a decision support tool, providing insights and facilitating conversation and exploration of many possible answers

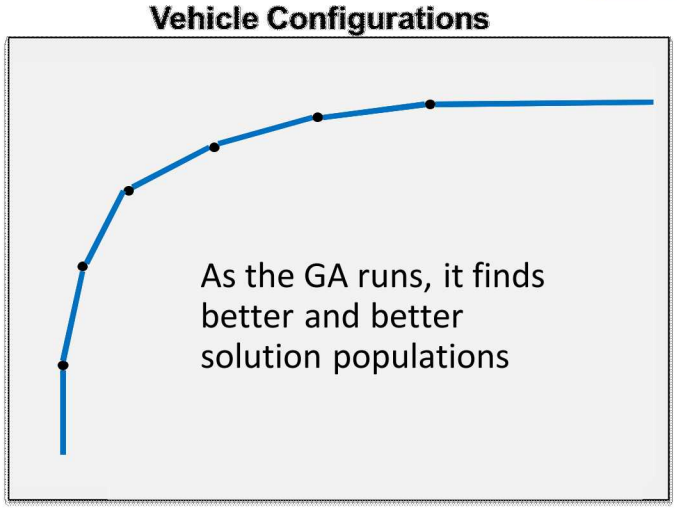
How WSTAT Works

- WSTAT combines compatible technology options into a system configuration, keeping those configurations that best balance competing objectives



Collection of Available Technology Options

Technologies are selected to create configurations

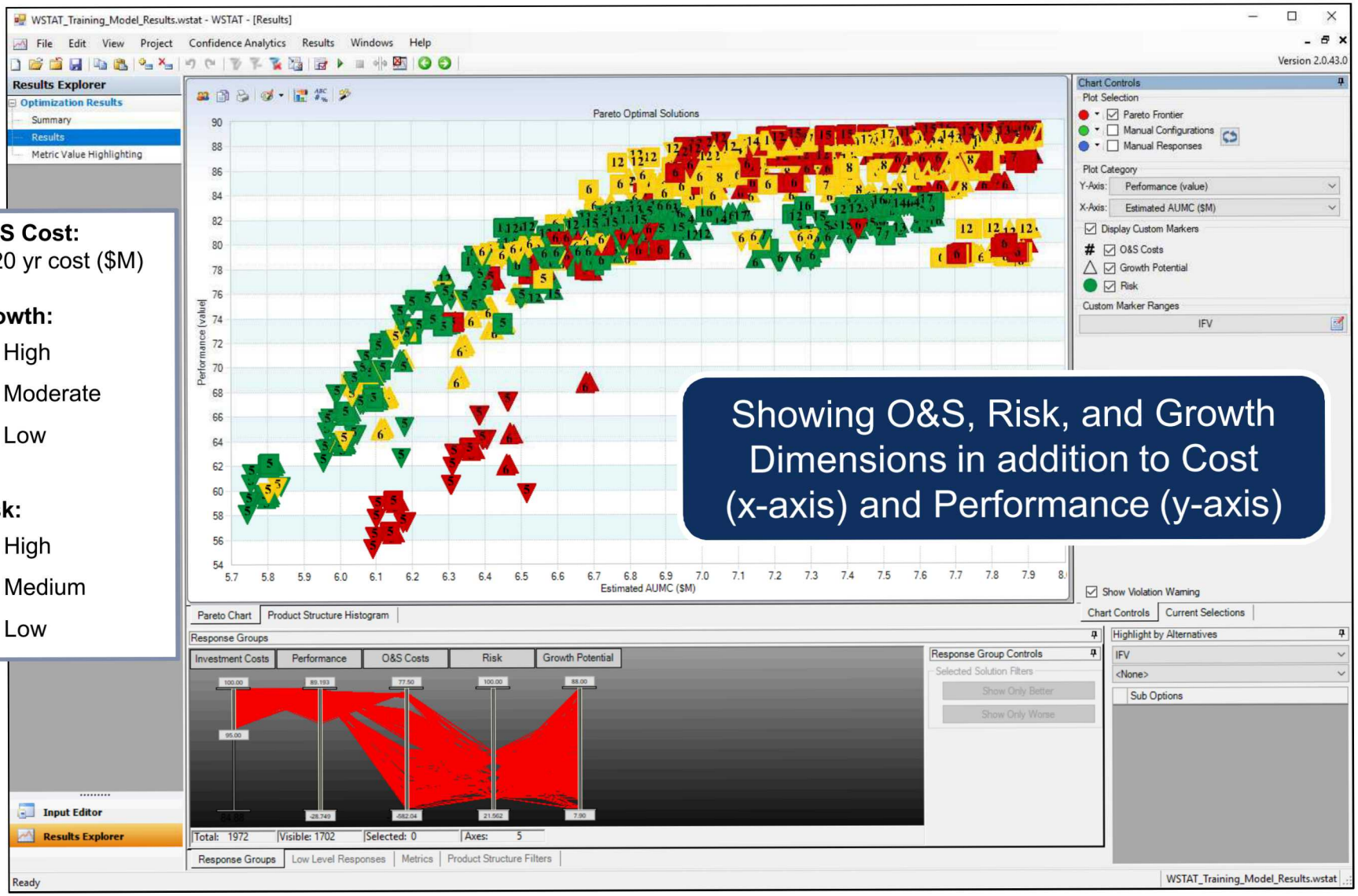


Configurations are scored in multiple value dimensions (tailorable to problem):

- Performance (top speed, lethality, etc.)
- Acquisition Cost
- O&S Cost
- Risk (immaturity of technologies)
- Growth (future upgrade potential)

WSTAT uses a multi-objective genetic algorithm to efficiently explore the spectrum of possible configurations and examine tradeoffs between multiple competing objectives

Results – Multiple Dimensions



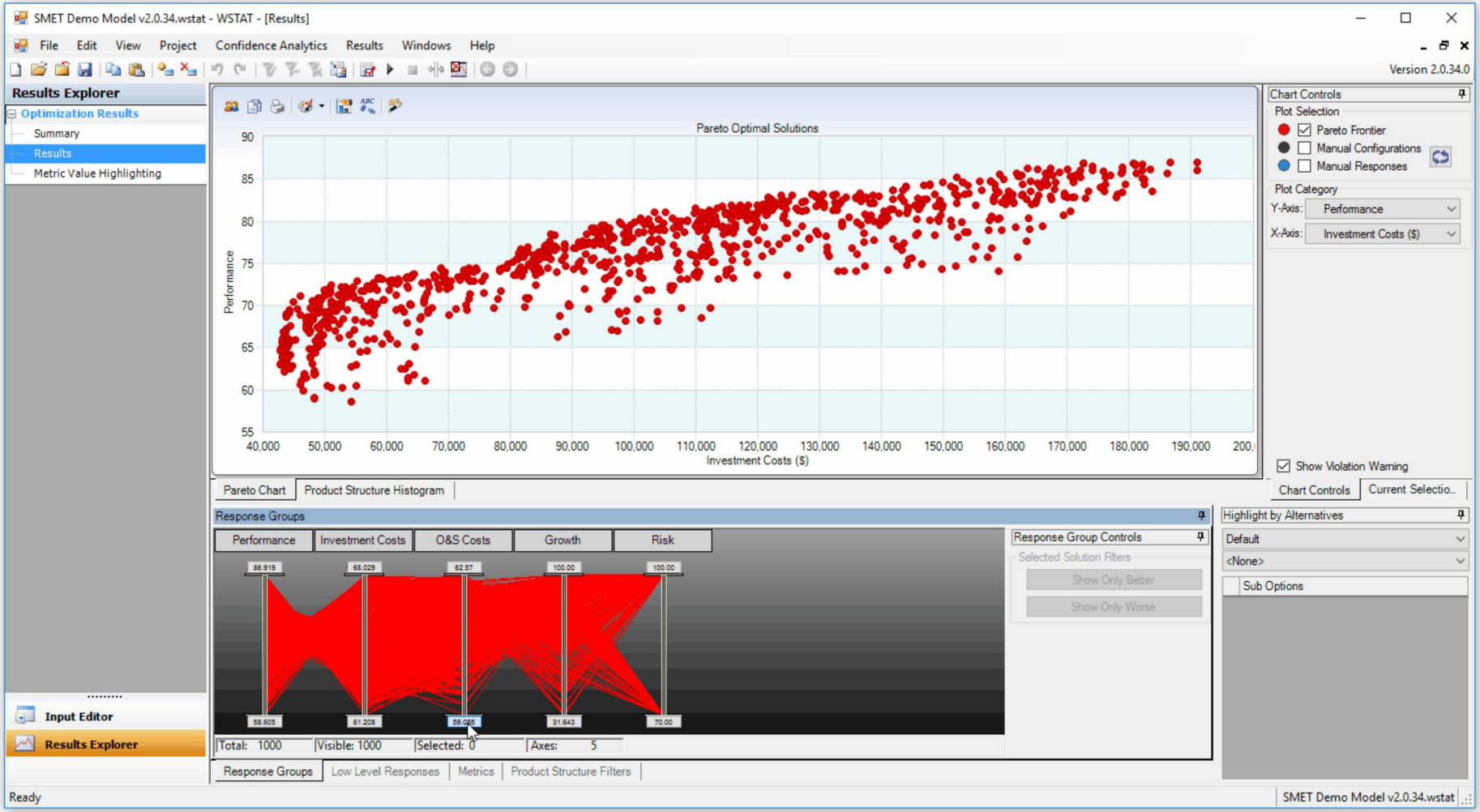
O&S Cost:
20 yr cost ($M)

Growth:
△ High
□ Moderate
▽ Low

Risk:
● High
● Medium
● Low

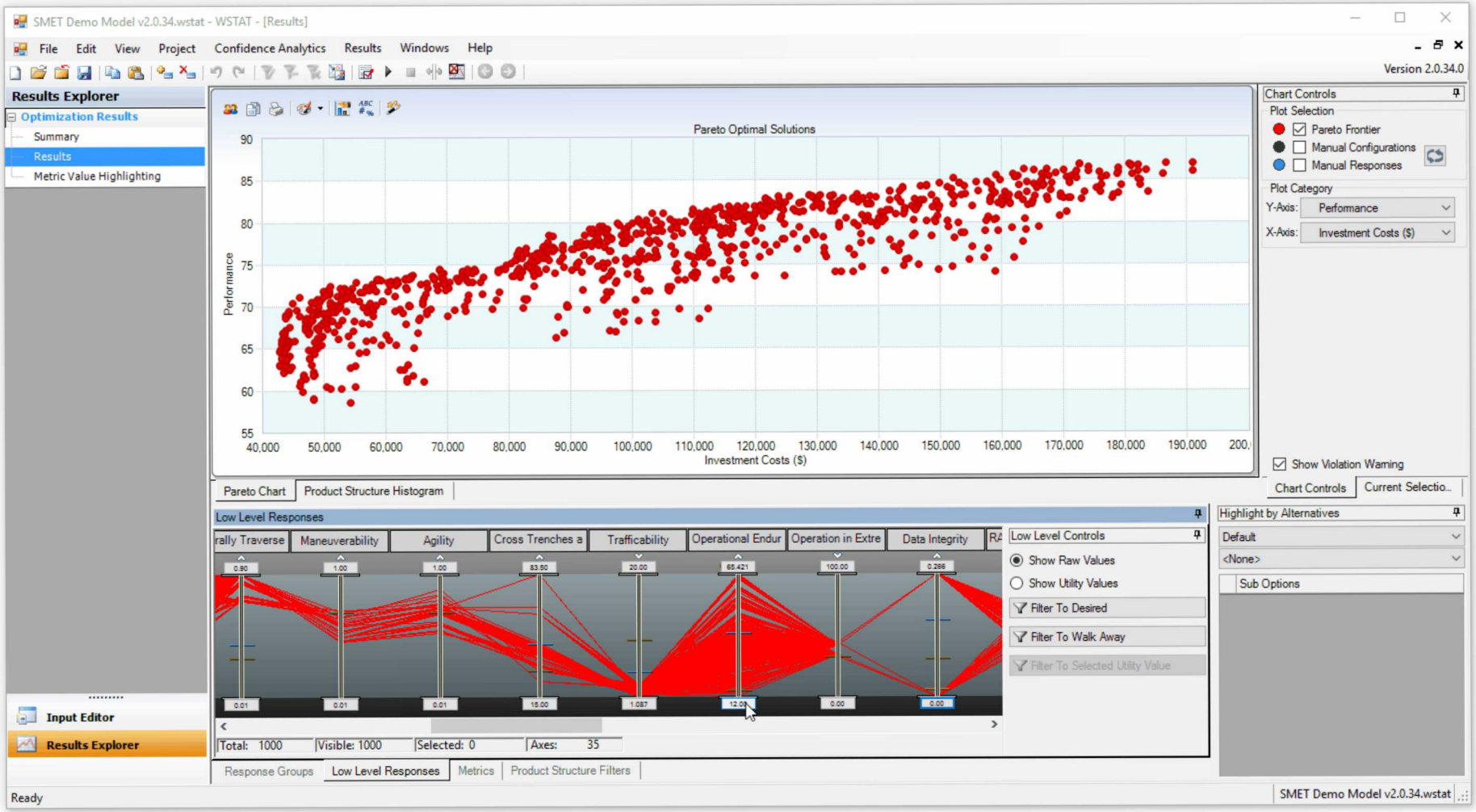
Showing O&S, Risk, and Growth Dimensions in addition to Cost (x-axis) and Performance (y-axis)

High-Level Filtering



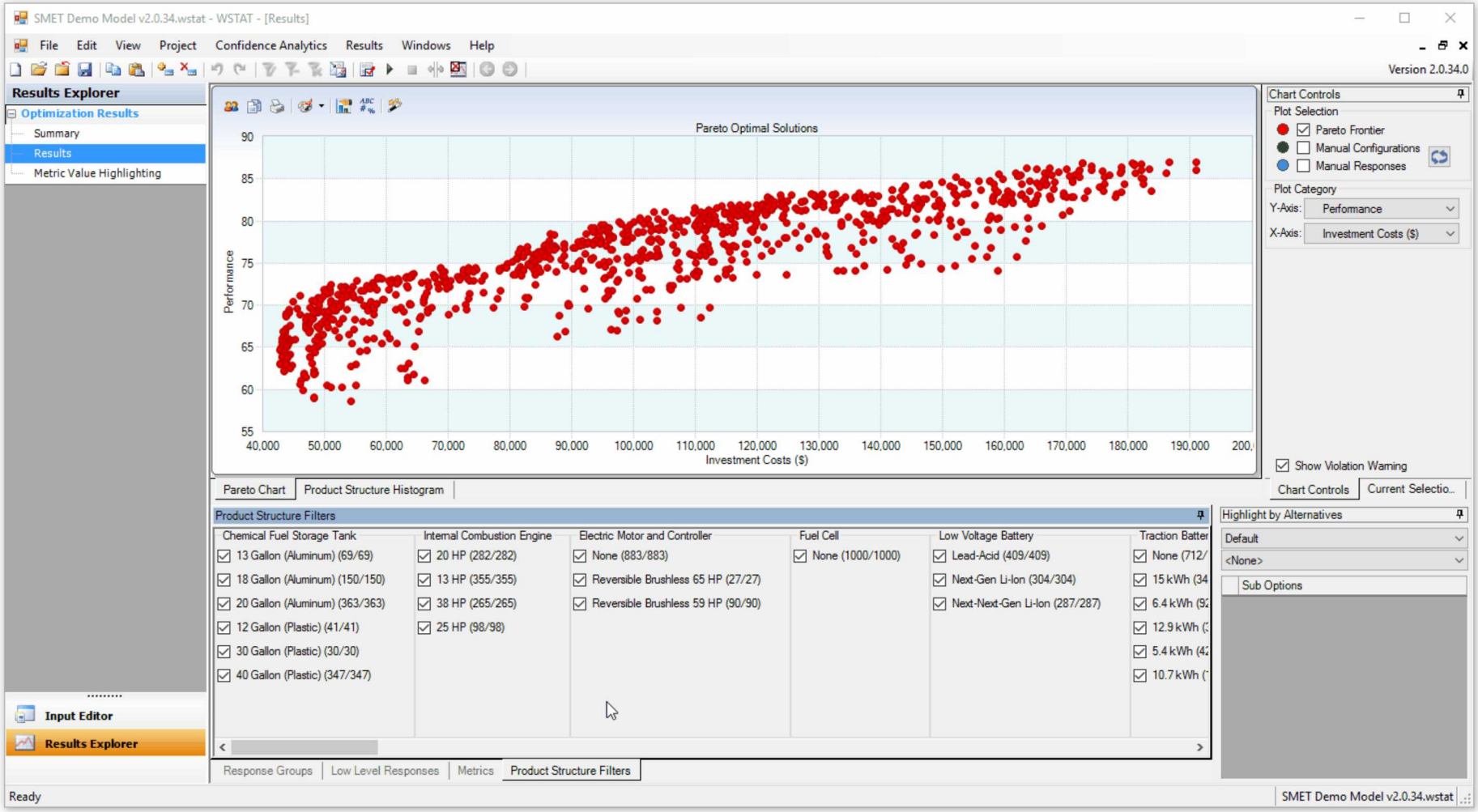
Solutions can be filtered by high-level stakeholder criteria
(Cost, Risk, Growth, etc.)

Low-Level Measure Filtering



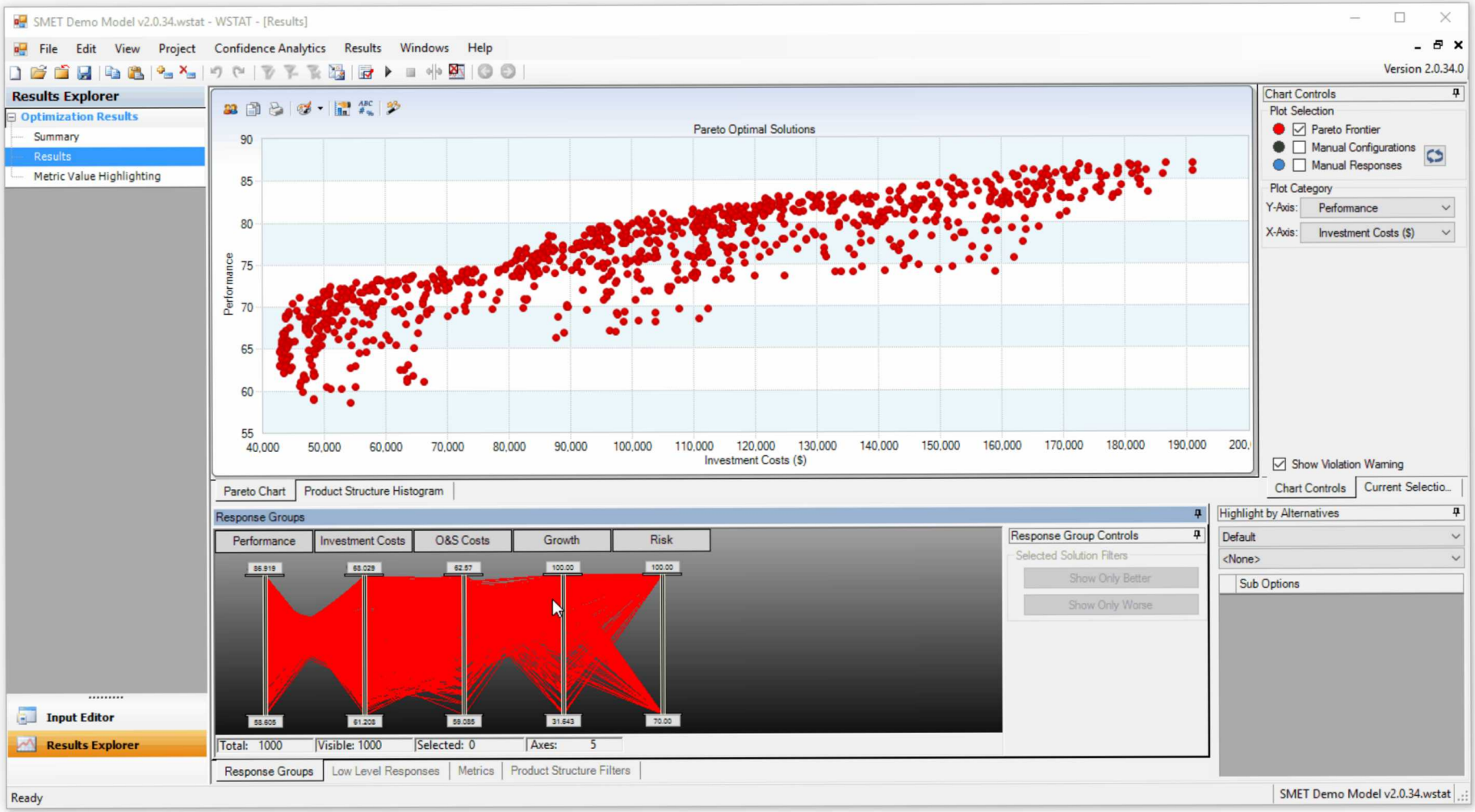
Solutions can be filtered by their low-level characteristics

Subsystem Filtering



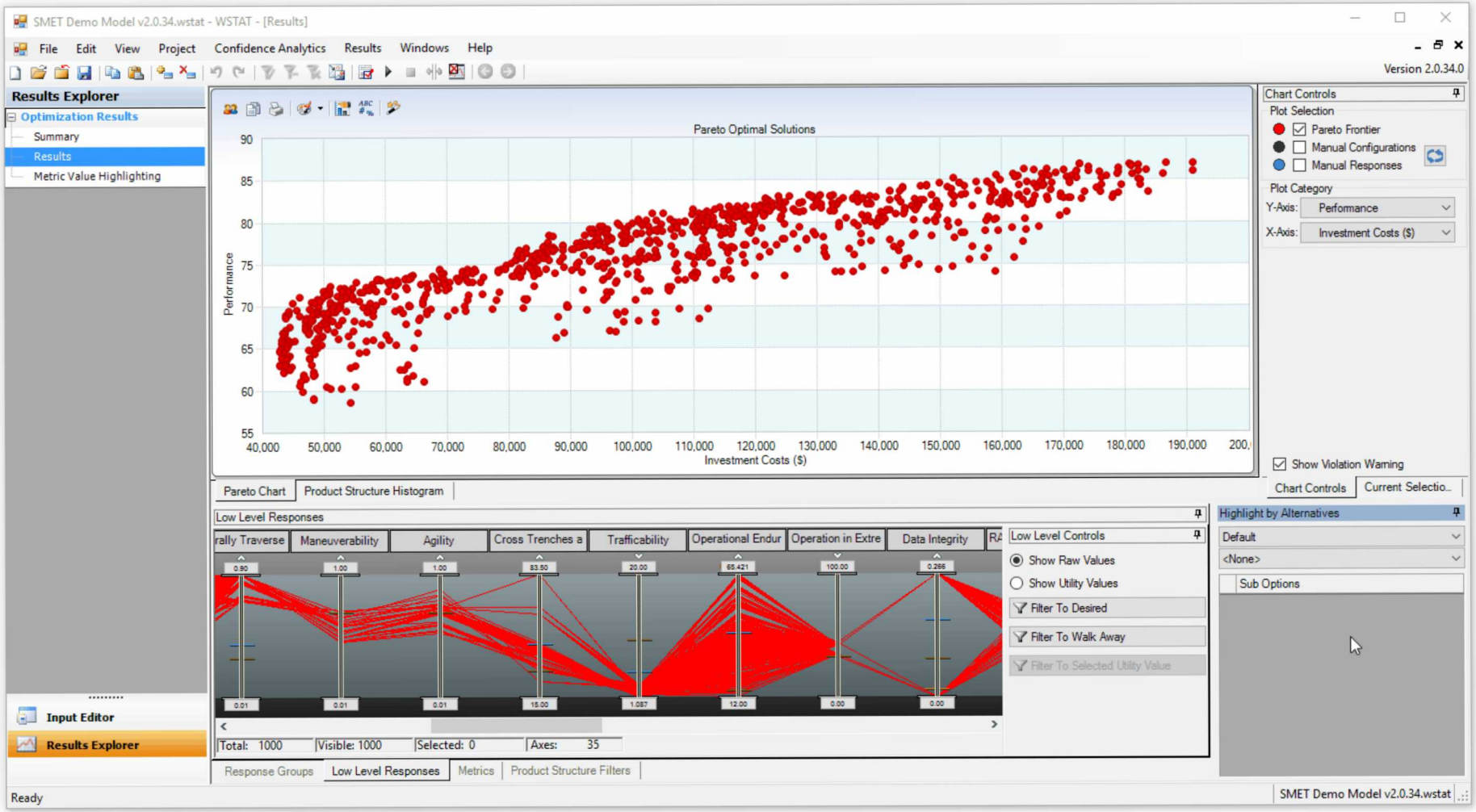
Solutions can also be filtered by their technology choices

Coloring by High & Low-Level Measures



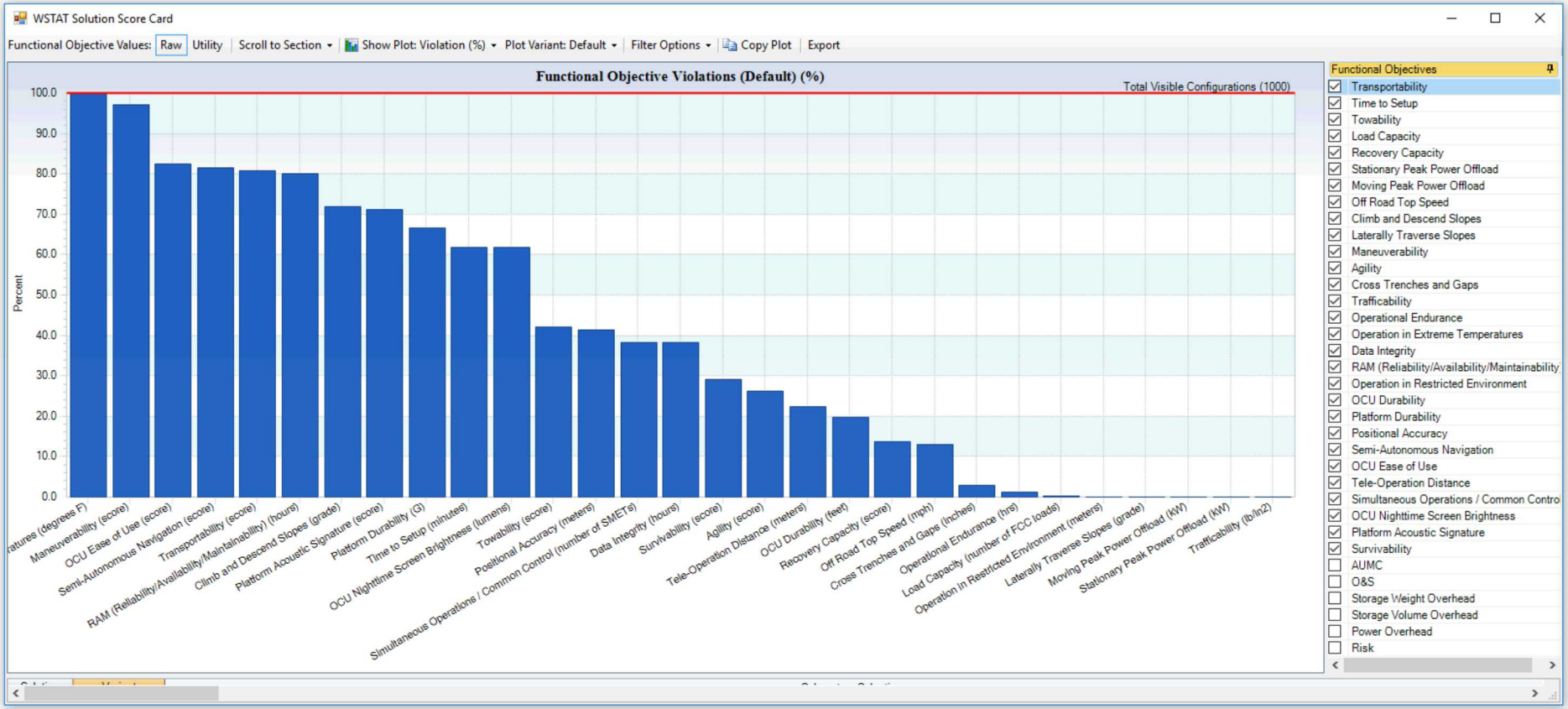
Solutions can be colored (Good=Blue to Red=Bad) by how they score in various high-level design goals and low-level characteristics (“-ilities”)

Coloring by Subsystem Choice



Solutions can also be colored by their technologies selected for a subsystem

Requirements Analysis

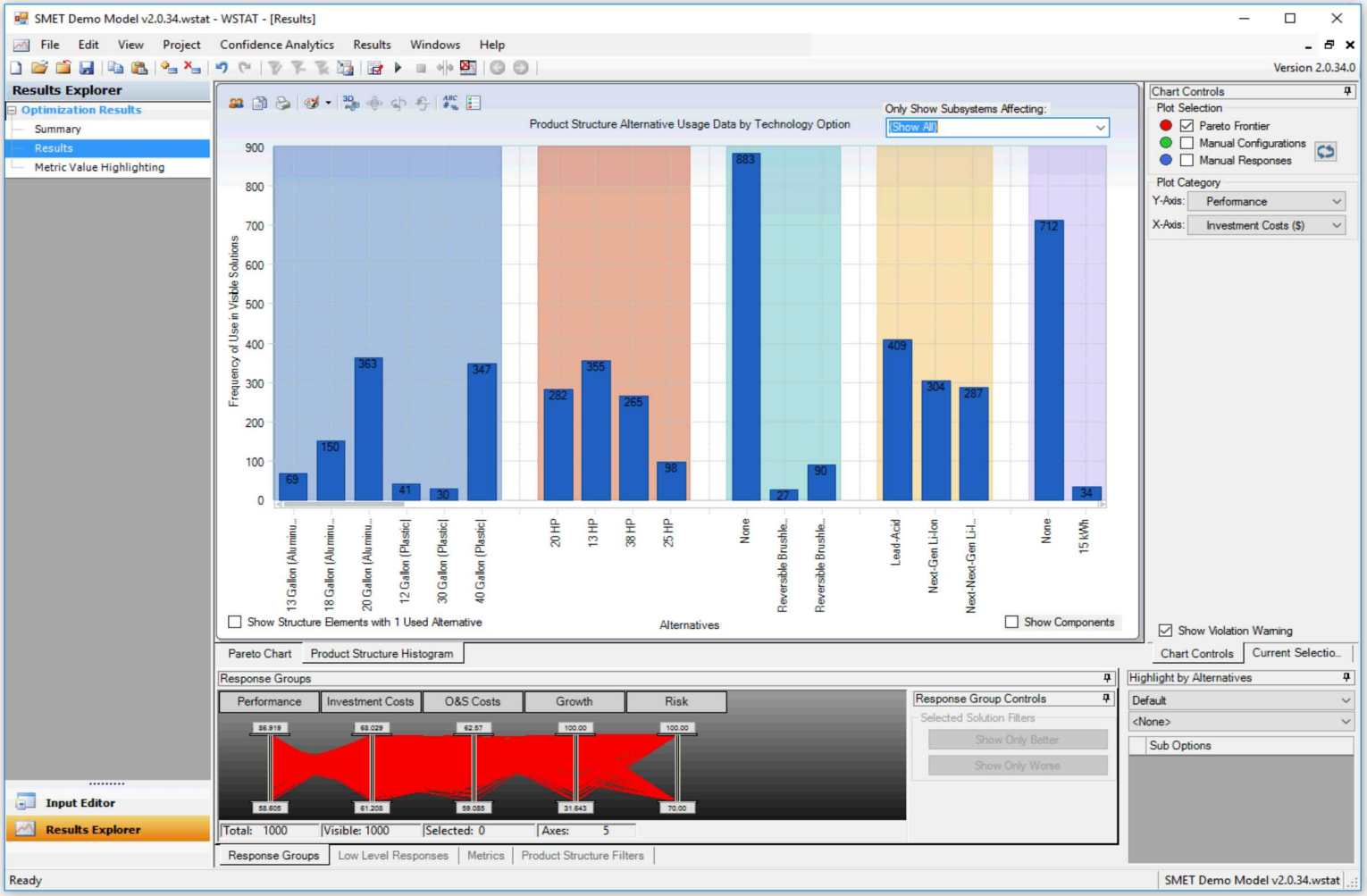


For the optimal solutions, this shows how often Threshold levels for requirements are violated.

--Requirements on the left are always or almost always violating Threshold level

--Requirements on the right are always or almost always satisfying Threshold level

Subsystem Histograms



Shows the prevalence of various subsystem alternatives, which can highlight “no brainer” technologies that are always picked

Summary

Sandia National Laboratories

- Many of our decision analytics tools focus on an ***optimized trade space***
  - Capture not just one best answer, but instead a **set of best answers** that balance competing objectives in different ways
  - Advanced Requirements Integration & Exploration System (ARIES) and Whole System Trades Analysis Tool (WSTAT) both focus on capturing this optimal trade space (or a Pareto Frontier)
- Advanced Requirements Integration & Exploration System (ARIES) Overview
  - Optimal Requirements Trade Space
- Whole System Trades Analysis Tool (WSTAT) Overview
  - Optimal System Design Trade Space

Thank You!

Questions & Discussion

Sandia National Laboratories

BACKUP

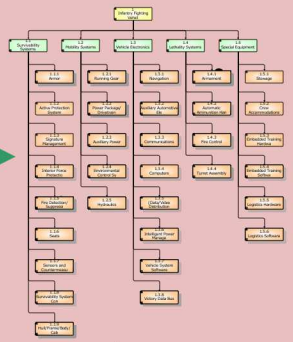
ARIES Methodology

Sandia National Laboratories

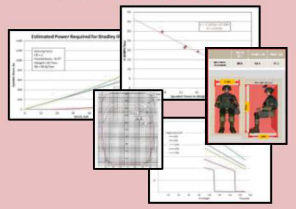
Develop Metrics

Safely and rapidly transport infantry to decisive locations and provide direct fire support

Establish Product Structure



Define Metric Evaluations



Identify Technology Options

Trade Space Analysis

ARIES

Explore Results & Reach Consensus

Understand Needs/Desired Capabilities

ICD

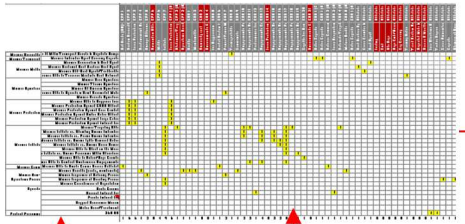
Similar to WSTAT

ARIES is an extension of proven WSTAT methodology, facilitating data reuse

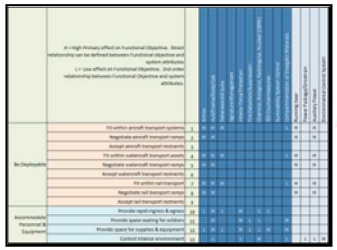
WSTAT Methodology

Sandia National Laboratories

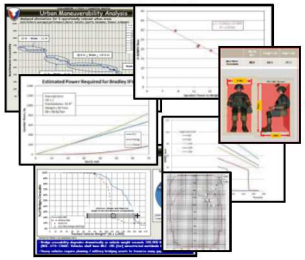
Map Requirements to Functional Objectives



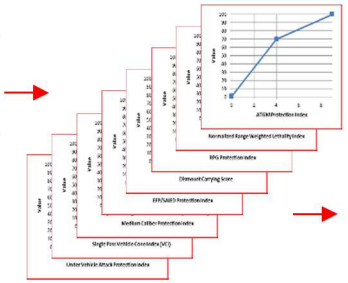
Map Functional Objectives to Product Structure



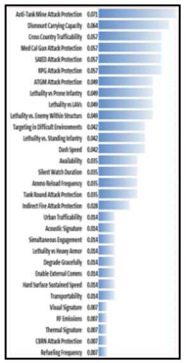
Define Metrics



Craft Value Functions



Determine Priority Weightings

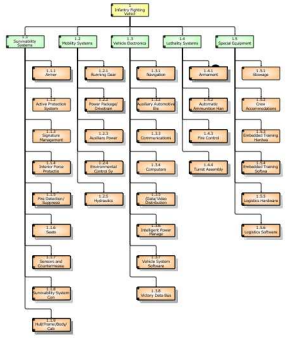


Develop Functional Objectives

Safely and rapidly transport infantry to decisive locations and provide direct fire support

Be Deployable | Accommodate Personnel & Equipment | Move Personnel & Equipment | Avoid Enemy Detection | Protect Personnel and Equipment | Acquire and Defeat Enemy Targets | Synthesize & Securely Exchange Information within IFV | Synthesize & Securely Exchange Information with Elements External to IFV | Enable Sustained Operations

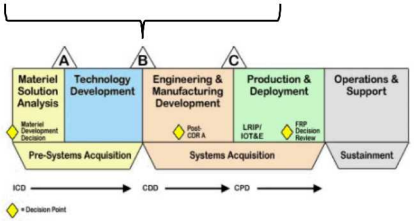
Establish Product Structure



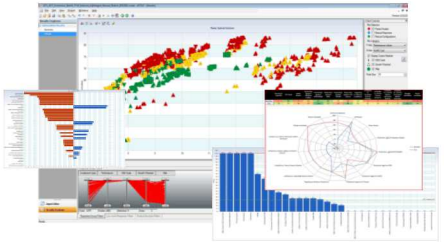
Identify Technology Options

Multi-objective Optimization

Understand Needs/Requirements



Generate Results & Conduct Analysis

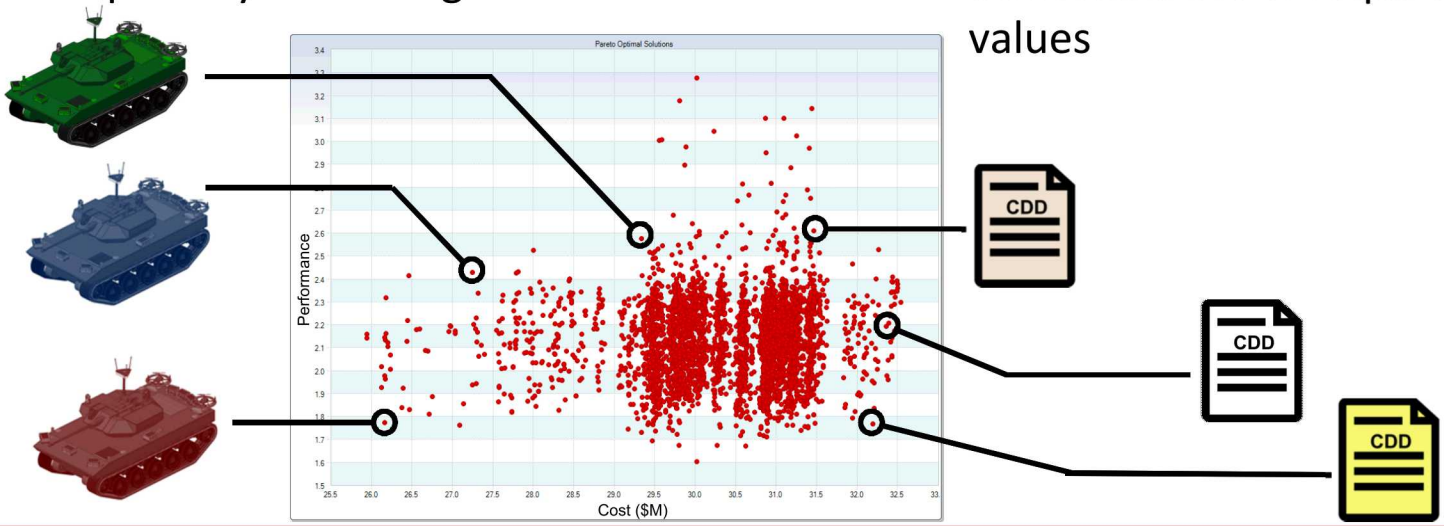


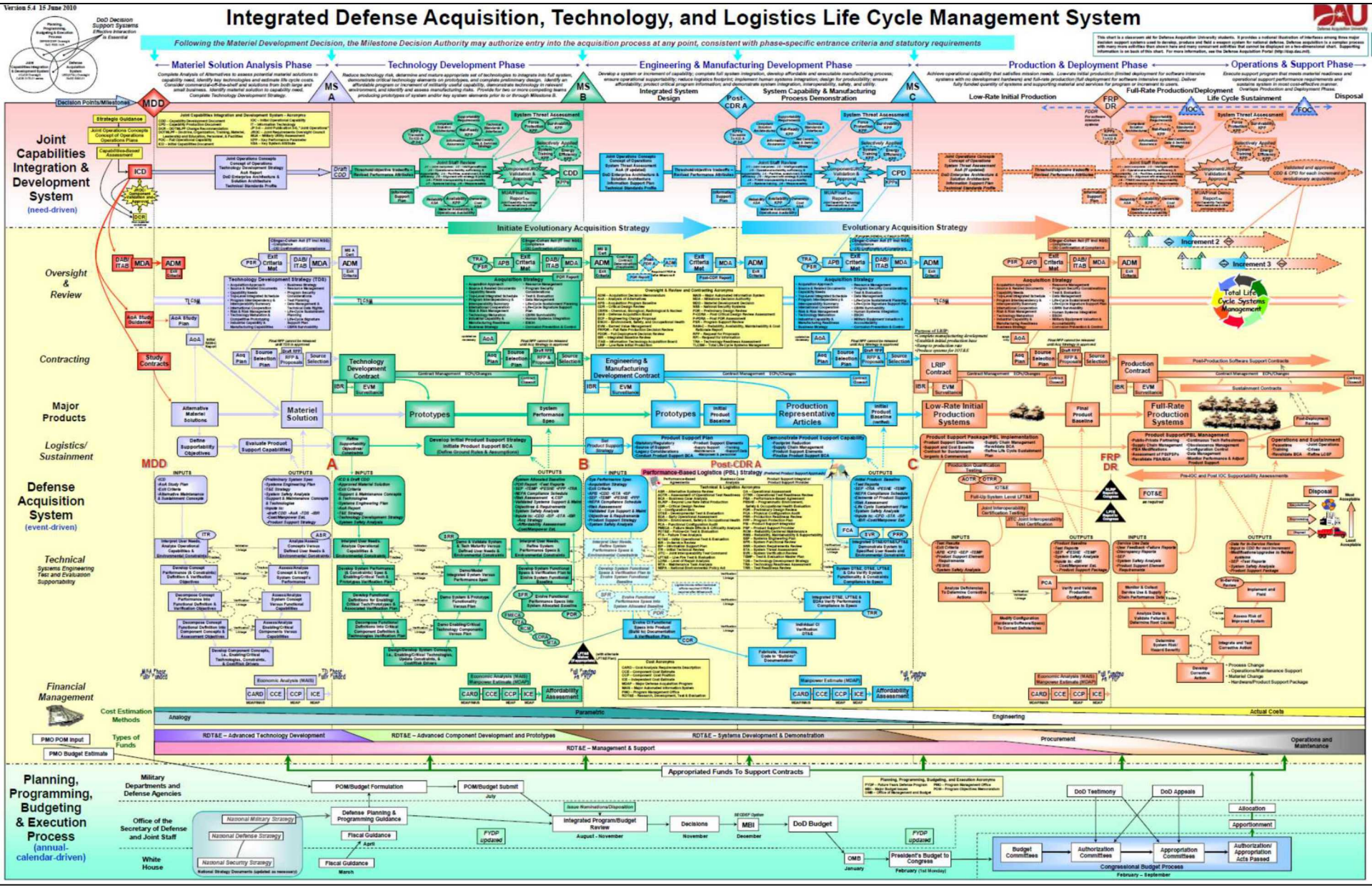
Difference Between WSTAT & ARIES

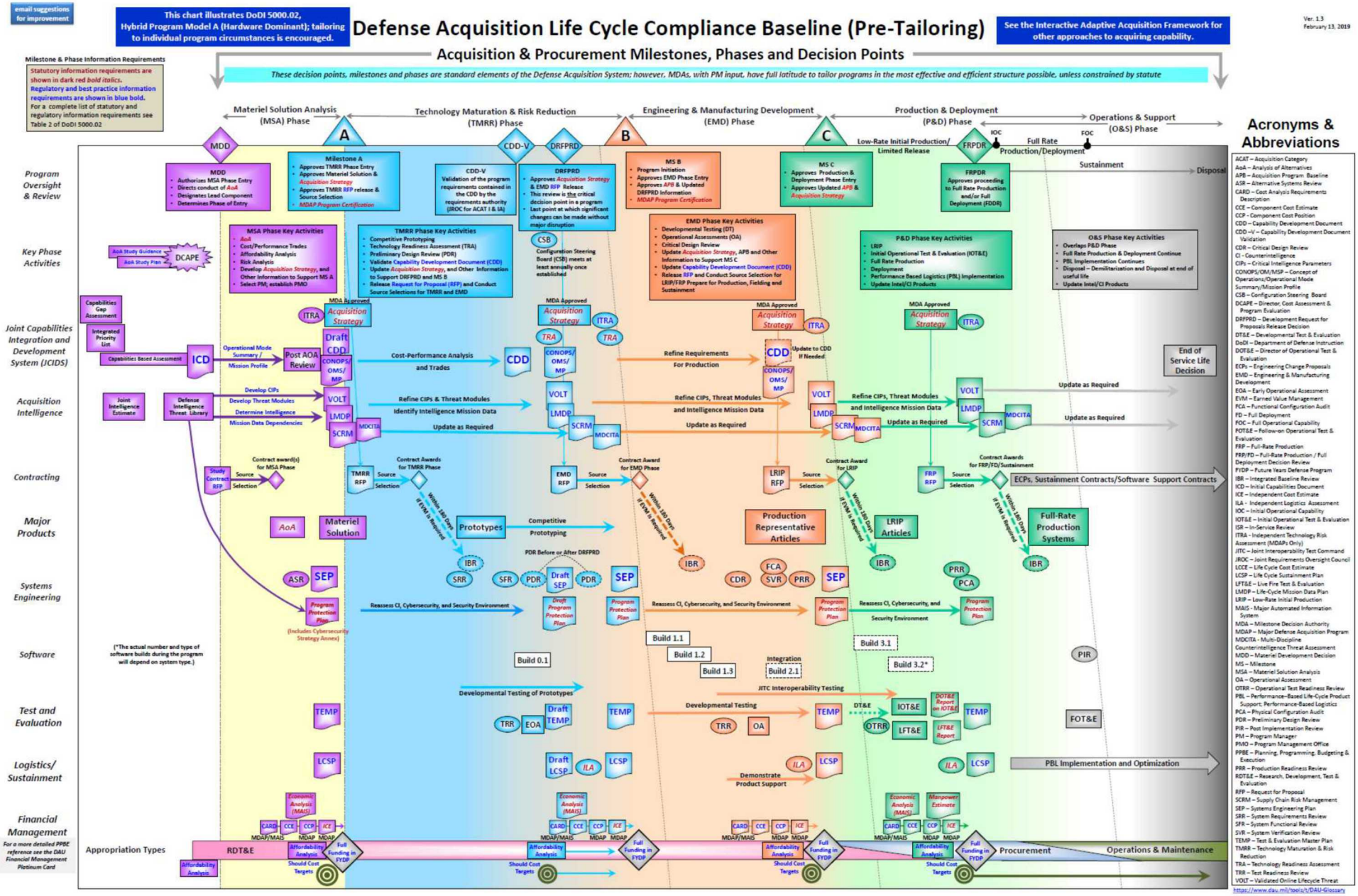
- Both generate solutions by selecting combinations of technology options
  - Ensures feasible concepts are being considered
    - Technology compatibility
    - Physical limitations (such as component weight limits)

- WSTAT
  - Weighted Sums of FOs, 5-6 optimization dimensions
  - Result exploration focuses on each combination of technologies as a complete system design

- ARIES
  - No FO Weighting, each FO optimized as own dimension (~40)
  - Result exploration focuses on each combination of technologies as an achievable set of requirement values




Version 5.4 15 June 2010
Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System
DAU
Following the Materiel Development Decision, the Milestone Decision Authority may authorize entry into the acquisition process at any point, consistent with phase-specific entrance criteria and statutory requirements
Materiel Solution Analysis Phase
Technology Development Phase
Engineering & Manufacturing Development Phase
Production & Deployment Phase
Operations & Support Phase
MS A
MS B
MS C
Post-CDR A
Integrated System Design
System Capability & Manufacturing Process Demonstration
Low-Rate Initial Production
Full-Rate Production/Deployment
Life Cycle Sustainment
Disposal
FRP DR
IOC
FOC
Decision Points/Milestones
MDD
ICD
CDD
CPD
Joint Capabilities Integration & Development System
(need-driven)
Initiate Evolutionary Acquisition Strategy
Evolutionary Acquisition Strategy
Increment 2
Increment 3
Total Life Cycle Systems Management
Oversight & Review
Contracting
Major Products
Logistics/ Sustainment
Defense Acquisition System
(event-driven)
Technical
Systems Engineering Test and Evaluation Supportability
Financial Management
Technology Development Contract
Engineering & Manufacturing Development Contract
LRIP Contract
Production Contract
Materiel Solution
Prototypes
Production Representative Articles
Low-Rate Initial Production Systems
Full-Rate Production Systems
Performance-Based Logistics (PBL) Strategy
Cost Estimation Methods
Analogy
Parametric
Engineering
Actual Costs
Types of Funds
RDT&E – Advanced Technology Development
RDT&E – Advanced Component Development and Prototypes
RDT&E – Systems Development & Demonstration
RDT&E – Management & Support
Procurement
Operations and Maintenance
PMO POM Input
PMO Budget Estimate
Appropriated Funds To Support Contracts
Planning, Programming, Budgeting & Execution Process
(annual-calendar-driven)
Military Departments and Defense Agencies
Office of the Secretary of Defense and Joint Staff
White House
POM/Budget Formulation
POM/Budget Submit
July
Defense Planning & Programming Guidance
Fiscal Guidance
April
Integrated Program/Budget Review
August - November
Decisions
November
MBI
December
DoD Budget
OMB
January
President's Budget to Congress
February (1st Monday)
FYDP updated
Fiscal Guidance
March
National Military Strategy
National Defense Strategy
National Security Strategy
DoD Testimony
DoD Appeals
Allocation
Apportionment
Budget Committees
Authorization Committees
Appropriation Committees
Authorization/ Appropriation Acts Passed
Congressional Budget Process
February – September


email suggestions for improvement
This chart illustrates DoDI 5000.02, Hybrid Program Model A (Hardware Dominant); tailoring to individual program circumstances is encouraged.
Defense Acquisition Life Cycle Compliance Baseline (Pre-Tailoring)
See the Interactive Adaptive Acquisition Framework for other approaches to acquiring capability.
Ver. 1.3 February 13, 2019
Acquisition & Procurement Milestones, Phases and Decision Points
These decision points, milestones and phases are standard elements of the Defense Acquisition System; however, MDAs, with PM input, have full latitude to tailor programs in the most effective and efficient structure possible, unless constrained by statute
Milestone & Phase Information Requirements
Statutory information requirements are shown in dark red bold italics.
Regulatory and best practice information requirements are shown in blue bold.
For a complete list of statutory and regulatory information requirements see Table 2 of DoDI 5000.02
Materiel Solution Analysis (MSA) Phase
Technology Maturation & Risk Reduction (TMRR) Phase
Engineering & Manufacturing Development (EMD) Phase
Production & Deployment (P&D) Phase
Operations & Support (O&S) Phase
MDD
A
CDD-V
DRFPRD
B
C
FRPDR
IOC
FOC
Low-Rate Initial Production/ Limited Release
Full Rate Production/Deployment
Sustainment
Disposal
Program Oversight & Review
Key Phase Activities
Joint Capabilities Integration and Development System (JCIDS)
Acquisition Intelligence
Contracting
Major Products
Systems Engineering
Software
Test and Evaluation
Logistics/ Sustainment
Financial Management
For a more detailed PPBE reference see the DAU Financial Management Platinum Card
Appropriation Types
RDT&E
Procurement
Operations & Maintenance
MDD
Authorizes MSA Phase Entry
Directs conduct of AoA
Designates Lead Component
Determines Phase of Entry
Milestone A
Approves TMRR Phase Entry
Approves Materiel Solution & Acquisition Strategy
Approves TMRR RFP release & Source Selection
MDAP Program Certification
CDD-V
Validation of the program requirements contained in the CDD by the requirements authority (JROC for ACAT I & IA)
DRFPRD
Approves Acquisition Strategy & EMD RFP Release
This review is the critical decision point in a program
Last point at which significant changes can be made without major disruption
MS B
Program Initiation
Approves EMD Phase Entry
Approves APB & Updated DRFPRD Information
MDAP Program Certification
MS C
Approves Production & Deployment Phase Entry
Approves Updated APB & Acquisition Strategy
FRPDR
Approves proceeding to Full Rate Production and/or Full Deployment (FDDR)
MSA Phase Key Activities
AoA
Cost/Performance Trades
Affordability Analysis
Risk Analysis
Develop Acquisition Strategy, and Other Information to Support MS A
Select PM; establish PMO
TMRR Phase Key Activities
Competitive Prototyping
Technology Readiness Assessment (TRA)
Preliminary Design Review (PDR)
Validate Capability Development Document (CDD)
Update Acquisition Strategy, and Other Information to Support DRFPRD and MS B
Release Request for Proposal (RFP) and Conduct Source Selections for TMRR and EMD
EMD Phase Key Activities
Developmental Testing (DT)
Operational Assessments (OA)
Critical Design Review
Update Acquisition Strategy, APB and Other Information to Support MS C
Update Capability Development Document (CDD)
Release RFP and Conduct Source Selection for LRIP/FRP Prepare for Production, Fielding and Sustainment
P&D Phase Key Activities
LRIP
Initial Operational Test & Evaluation (IOT&E)
Full Rate Production
Deployment
Performance Based Logistics (PBL) Implementation
Update Intel/CI Products
O&S Phase Key Activities
Overlaps P&D Phase
Full Rate Production & Deployment Continue
PBL Implementation Continues
Disposal – Demilitarization and Disposal at end of useful life
Update Intel/CI Products
CSB
Configuration Steering Board (CSB) meets at least annually once established
AoA Study Guidance
AoA Study Plan
DCAPE
Capabilities Gap Assessment
Integrated Priority List
Capabilities Based Assessment
ICD
Operational Mode Summary / Mission Profile
Post AOA Review
Draft CDD
CONOPS/ OMS/ MP
MDA Approved
Acquisition Strategy
ITRA
TRA
Cost-Performance Analysis and Trades
CDD
Refine Requirements For Production
Update to CDD If Needed
End of Service Life Decision
Update as Required
Joint Intelligence Estimate
Defense Intelligence Threat Library
Develop CIPs
Develop Threat Modules
Determine Intelligence Mission Data Dependencies
VOLT
LMDP
SCRM
MDCITA
Refine CIPs & Threat Modules
Identify Intelligence Mission Data
Refine CIPs, Threat Modules and Intelligence Mission Data
Study Contract RFP
Contract award(s) for MSA Phase
Source Selection
TMRR RFP
Contract Awards for TMRR Phase
EMD RFP
Contract Award for EMD Phase
LRIP RFP
Contract Award for LRIP
FRP RFP
Contract Awards for FRP/FD/Sustainment
Within 180 Days if ETM is Required
ECPs, Sustainment Contracts/Software Support Contracts
AoA
Materiel Solution
Prototypes
Competitive Prototyping
Production Representative Articles
LRIP Articles
Full-Rate Production Systems
IBR
ASR
SEP
SRR
SFR
PDR
Draft SEP
PDR Before or After DRFPRD
CDR
FCA
SVR
PRR
PCA
Program Protection Plan
(Includes Cybersecurity Strategy Annex)
Reassess CI, Cybersecurity, and Security Environment
Draft Program Protection Plan
("The actual number and type of software builds during the program will depend on system type.)
Build 0.1
Build 1.1
Build 1.2
Build 1.3
Integration
Build 2.1
Build 3.1
Build 3.2*
PIR
Developmental Testing of Prototypes
JITC Interoperability Testing
Developmental Testing
DT&E
TEMP
Draft TEMP
TRR
EOA
OA
IOT&E
OTRR
LFT&E
DOT&E Report on IOT&E
LFT&E Report
FOT&E
LCSP
Draft LCSP
ILA
Demonstrate Product Support
PBL Implementation and Optimization
Economic Analysis (MAIS)
Manpower Estimate
CARD
CCE
CCP
ICE
MDAP/MAIS
MDAP
Affordability Analysis
Full Funding in FYDP
Should Cost Targets
Acronyms & Abbreviations
ACAT – Acquisition Category
AoA – Analysis of Alternatives
APB – Acquisition Program Baseline
ASR – Alternative Systems Review
CARD – Cost Analysis Requirements Description
CCE – Component Cost Estimate
CCP - Component Cost Position
CDD – Capability Development Document
CDD –V – Capability Development Document Validation
CDR – Critical Design Review
CI - Counterintelligence
CIPs – Critical Intelligence Parameters
CONOPS/OM/MSP – Concept of Operations/Operational Mode Summary/Mission Profile
CSB – Configuration Steering Board
DCAPE – Director, Cost Assessment & Program Evaluation
DRFPRD – Development Request for Proposals Release Decision
DT&E – Developmental Test & Evaluation
DoDI – Department of Defense Instruction
DOT&E – Director of Operational Test & Evaluation
ECPs – Engineering Change Proposals
EMD – Engineering & Manufacturing Development
EOA – Early Operational Assessment
EVM – Earned Value Management
FCA – Functional Configuration Audit
FD – Full Deployment
FOC – Full Operational Capability
FOT&E – Follow-on Operational Test & Evaluation
FRP – Full-Rate Production
FRP/FD – Full-Rate Production / Full Deployment Decision Review
FYDP – Future Years Defense Program
IBR – Integrated Baseline Review
ICD – Initial Capabilities Document
ICE – Independent Cost Estimate
ILA - Independent Logistics Assessment
IOC – Initial Operational Capability
IOT&E – Initial Operational Test & Evaluation
ISR – In-Service Review
ITRA - Independent Technology Risk Assessment (MDAPs Only)
JITC – Joint Interoperability Test Command
JROC – Joint Requirements Oversight Council
LCCE – Life Cycle Cost Estimate
LCSP – Life Cycle Sustainment Plan
LFT&E – Live Fire Test & Evaluation
LMDP – Life-Cycle Mission Data Plan
LRIP – Low-Rate Initial Production
MAIS - Major Automated Information System
MDA – Milestone Decision Authority
MDAP – Major Defense Acquisition Program
MDCITA - Multi-Discipline Counterintelligence Threat Assessment
MDD – Materiel Development Decision
MS – Milestone
MSA – Materiel Solution Analysis
OA – Operational Assessment
OTRR – Operational Test Readiness Review
PBL – Performance–Based Life-Cycle Product Support; Performance-Based Logistics
PCA – Physical Configuration Audit
PDR – Preliminary Design Review
PIR – Post Implementation Review
PM – Program Manager
PMO – Program Management Office
PPBE – Planning, Programming, Budgeting & Execution
PRR – Production Readiness Review
RDT&E – Research, Development, Test & Evaluation
RFP – Request for Proposal
SCRM – Supply Chain Risk Management
SEP – Systems Engineering Plan
SRR – System Requirements Review
SFR – System Functional Review
SVR – System Verification Review
TEMP – Test & Evaluation Master Plan
TMRR – Technology Maturation & Risk Reduction
TRA – Technology Readiness Assessment
TRR – Test Readiness Review
VOLT – Validated Online Lifecycle Threat
https://www.dau.mil/tools/t/DAU-Glossary