



25th anniversary
annual INCOSE
international symposium
Seattle, WA
July 13 - 16, 2015



Whole System Trades Analysis

“Making an informed decision”

Shatiel Edwards (PEO GCS)

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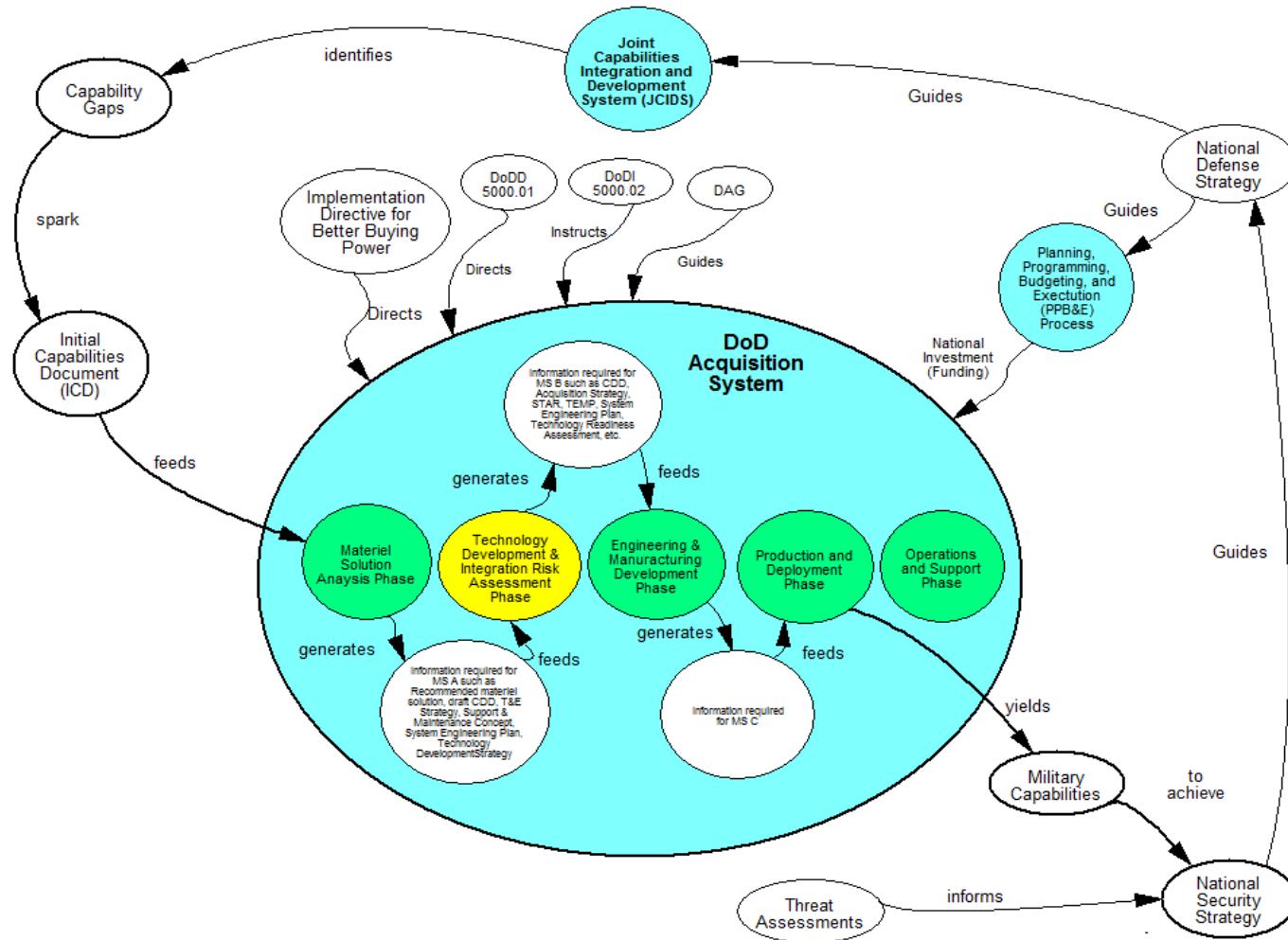
Troy Peterson (Booz Allen Hamilton)

Matt Cilli (ARDEC)

Liliana Shelton (Sandia National Labs)

Mike Zabat (Booz Allen Hamilton)

Context... DoD Acquisition Process



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Product Development in Defense Domain is Complex



Decision Objectives	The number of fundamental objectives is large. At the very least cost, schedule, and performance as competing objectives – most often decomposed into several sub-objectives each.
Stakeholders	The number of stakeholders is high and access is limited as the stakeholders are often high level decision makers sprawled across the DoD enterprise, Government and Industry. Stakeholders do not often speak with one voice yet only one decision will be made.
Uncertainty	The degree of uncertainty is high as decision makers are often dealing with a wide variety of threats (details regarding what must be countered are often lacking), diverse combat environments (urban/rural, forest/desert, hot/cold, night/day, sun/clouds, rain/snow, sand/mud/pavement) emerging requirements (how a change in capability will translate to overall mission effectiveness is difficult to quantify across the mission types), technology (performance of immature technologies is difficult to predict), costs (the only thing more difficult to predict than performance of an immature technology is the lifecycle cost of an immature technology)
Stakes	The stakes are high with decision consequences on the order of millions or billions of dollars with nothing less than National Security at stake.
Accountability	Accountability is certainly high as such decisions are often reviewed by several independent review boards.
Subject Matter	Decision subject matter itself is often novel and cutting edge, sometimes creating a barrier to full understanding for all but a small element of the scientific and engineering community.

**Product development is difficult in any industry,
but perhaps especially so in the defense industry.**

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Shortcomings in Current Process

United States Government Accountability Office
GAO Report to Congressional Committees

September 2006 BEST PRACTICES Stronger Practices Needed to Improve DOD Technology Transition Processes

GAO Accountability • Integrity • Reliability

GAO-06-583

United States Government Accountability Office
GAO Report to the Committee on Armed Services, U.S. Senate

March 2007 BEST PRACTICES An Integrated Portfolio Management Approach to Weapon System Investments Could Improve DOD's Acquisition Outcomes

GAO Accountability • Integrity • Reliability

GAO-07-388



Getting to Best: Reforming the Defense Acquisition Enterprise

A Business Imperative for Change from the Task Force on Defense Acquisition Law and Oversight

July 2009

United States Government Accountability Office
GAO Report to the Chairman, Subcommittee on National Security and Foreign Affairs, Committee on Oversight and Government Reform, House of Representatives

September 2009 DEFENSE ACQUISITIONS Many Analyses of Alternatives Have Not Provided a Robust Assessment of Weapon System Options

GAO Accountability • Integrity • Reliability

GAO-09-665

The services' annual senior-level project portfolio reviews "do not include formal assessment of many of the technical and business criteria...such as determining if the costs, benefits, and risks are well understood and technology is affordable."

"While DoD's JCIDS process provides a framework for reviewing and validating the initial need for proposed capabilities, it does not focus on the cost and feasibility of acquiring the capability to be developed and fielded...Milestone A are often skipped...this practice eliminates a key opportunity for decision makers to assess the early product knowledge needed to establish a business case that is based on realistic cost, schedule, and performance expectations.

The principle shortcomings of the existing requirements process are that: 1) it does not couple needs for specific future systems to an overall national defense strategy; and 2) requirements are largely determined by the military services without realistic input as to what is technically feasible from an engineering perspective...

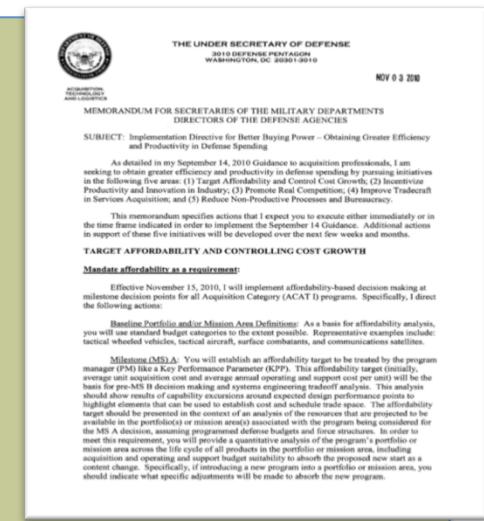
Although an AOA is just one of several inputs required to initiate a weapon system program, a robust AOA can be a key element to ensure that new programs have a sound, executable business case. Many of the AOAs that GAO reviewed did not effectively consider a broad range of alternatives for addressing a warfighting need or assess technical and other risks associated with each alternative.

Recent reports in the defense domain call for more robust assessments of a broader range of alternatives across a more thorough set of stakeholder value criteria earlier in the lifecycle.

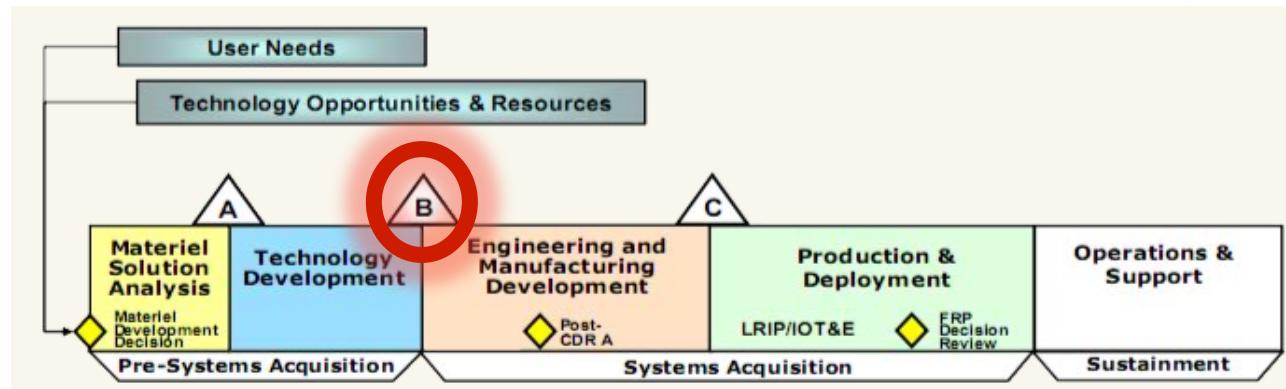
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Directive



Directive for Better Buying Power – Obtaining Greater Efficiency and Productivity in Defense Spending. NOV 3, 2010. Under Secretary of Defense for Acquisition, Technology, and Logistics, Dr. Ashton Carter



Milestone B: You will present a **systems engineering tradeoff analysis** showing how cost varies as the major design parameters and time to complete are traded off against each other. The analysis will pay due attention to spiral upgrades. You will recommend for my approval to establish and document, in the Acquisition Decision Memorandum (ADM) and in the program baseline, an 'Affordability Requirement' for acquisition cost and for operating and support cost. This requirement will be the functional equivalent of Key Performance Parameters (KPPs) for baseline establishment and monitoring. You will provide **cost tradeoff curves or trade space around major affordability drivers** (including KPPs when they are major cost drivers) to show how the program has established a cost-effective design point for these affordability drivers."

OSD Directs Systems Engineering Tradeoff Analyses Be Conducted Early in the Lifecycle.

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WSTA Purpose & Goals

- Overview
 - Model the relationship between design decisions & stakeholder value in order to inform and potentially influence requirements documents and associated specifications.
 - Conduct cost informed trades analysis based on holistic design choices, while understanding the opportunity cost of each choice.
- Process Goals
 - Generate many alternatives
 - Stimulate healthy debate
 - Provide foundation for a traceable and defendable decision
 - Build consensus (high level of commitment and shared understanding among team members and stakeholders)

Whole System Trade Analysis Model Definition and Motivation



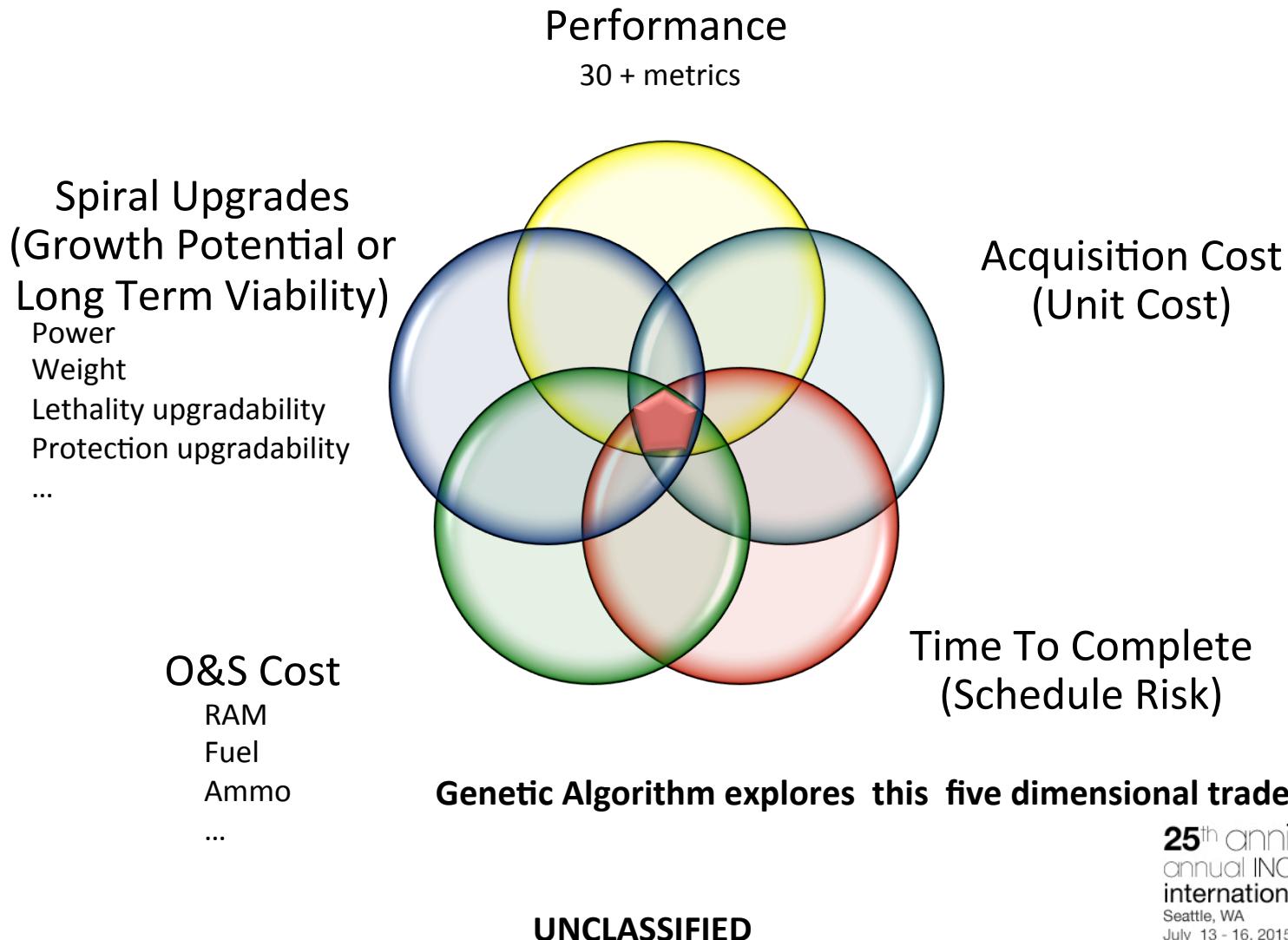
The image shows a screenshot of the Whole System Trade Analysis software interface, divided into four panels:

- Input Stakeholder Objectives:** A table showing various stakeholder objectives such as Primary Objective, Functional Objective, Relative Importance, Utility Parameters, and Weight.
- Input design choices and relationships:** A table showing system components like System Group, Subsystem, and their associated metrics such as Cost (in M\$), O&M Cost, Weight, TRL, Electrical Load (kW), Gross HP, Net Rejection (kW), Transformation Efficiency, and Fan Efficiency.
- View Holistic System Consequences in terms of stakeholder value:** A scatter plot showing the relationship between different system parameters, with a legend for various data series.
- Detailed Data Table:** A large table showing detailed data for each system component, including sub-components and their specific values.

- **What:** The whole system trade analysis model integrates otherwise separate subsystem models into a holistic system view mapping critical design choices to consequences relevant to stakeholders.
- **Why:** Avoid oversimplification, avoid sub-optimization, find balance across competing objectives.

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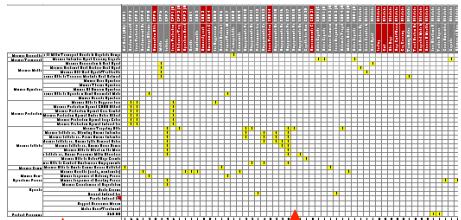
Shaping Requirements to Balance Stakeholder Value



The Whole System Trade Analysis Process



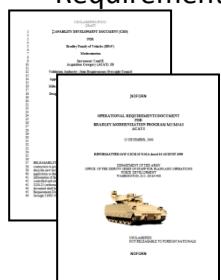
Map Requirements to Functional Objectives



Develop Functional Objectives

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

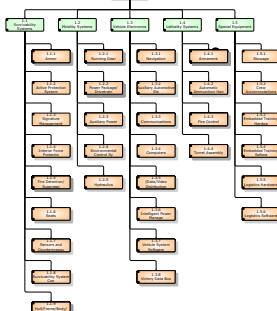
Understand Requirements



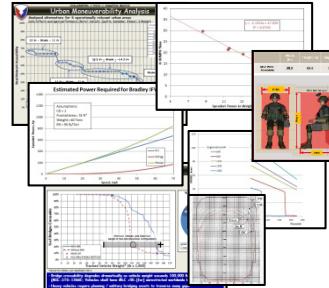
Map Functional Objectives to Product Structure



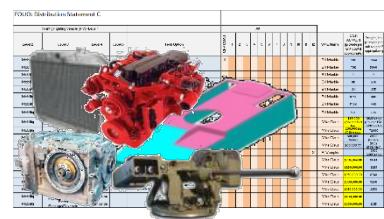
Establish Product Structure



Define Metrics

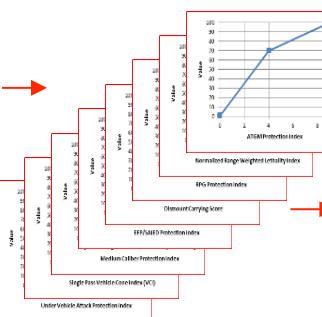


Identify Technology Options

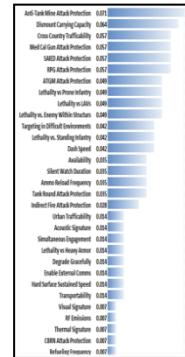


Design Rules Necessitations & Obyiations

Craft Value Functions



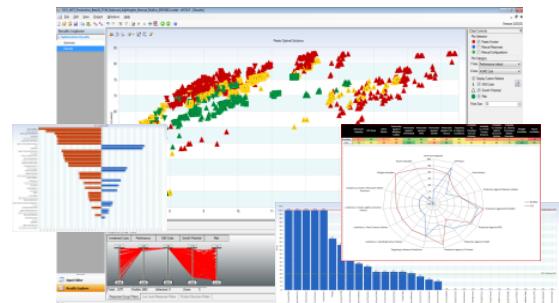
Determine Priority Weightings



Optimization

Pareto Set

Generate Graphical Output



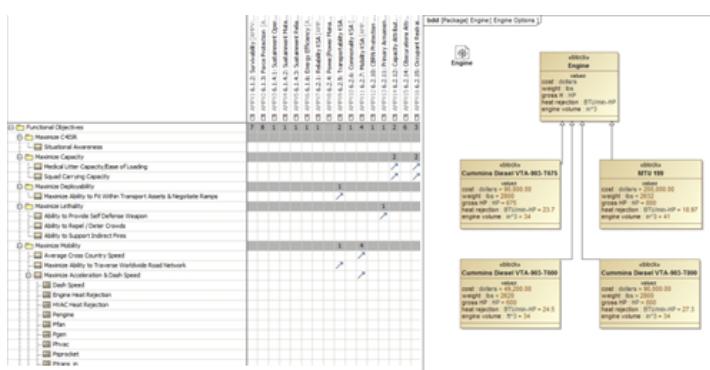
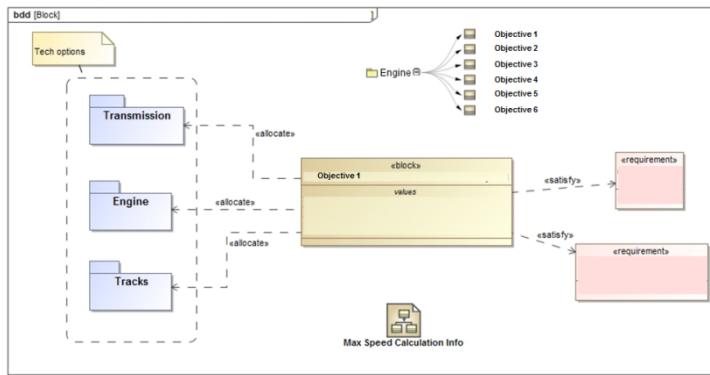
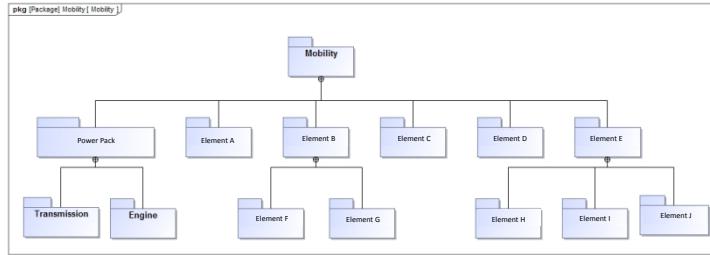
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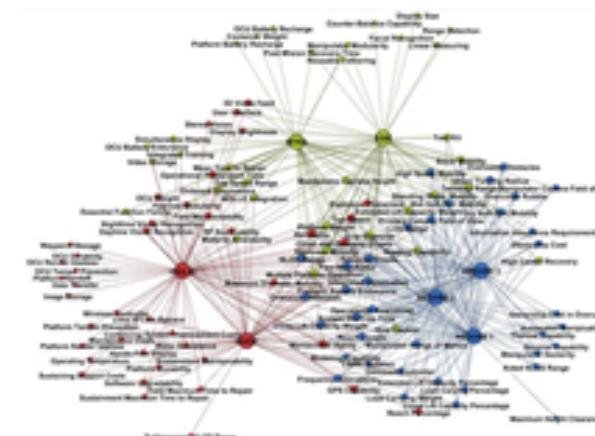
The Whole System Trade Analysis Byproducts



Use Model Based Systems Engineering Tools to create system descriptive models



Robotic Platform to Requirements Map

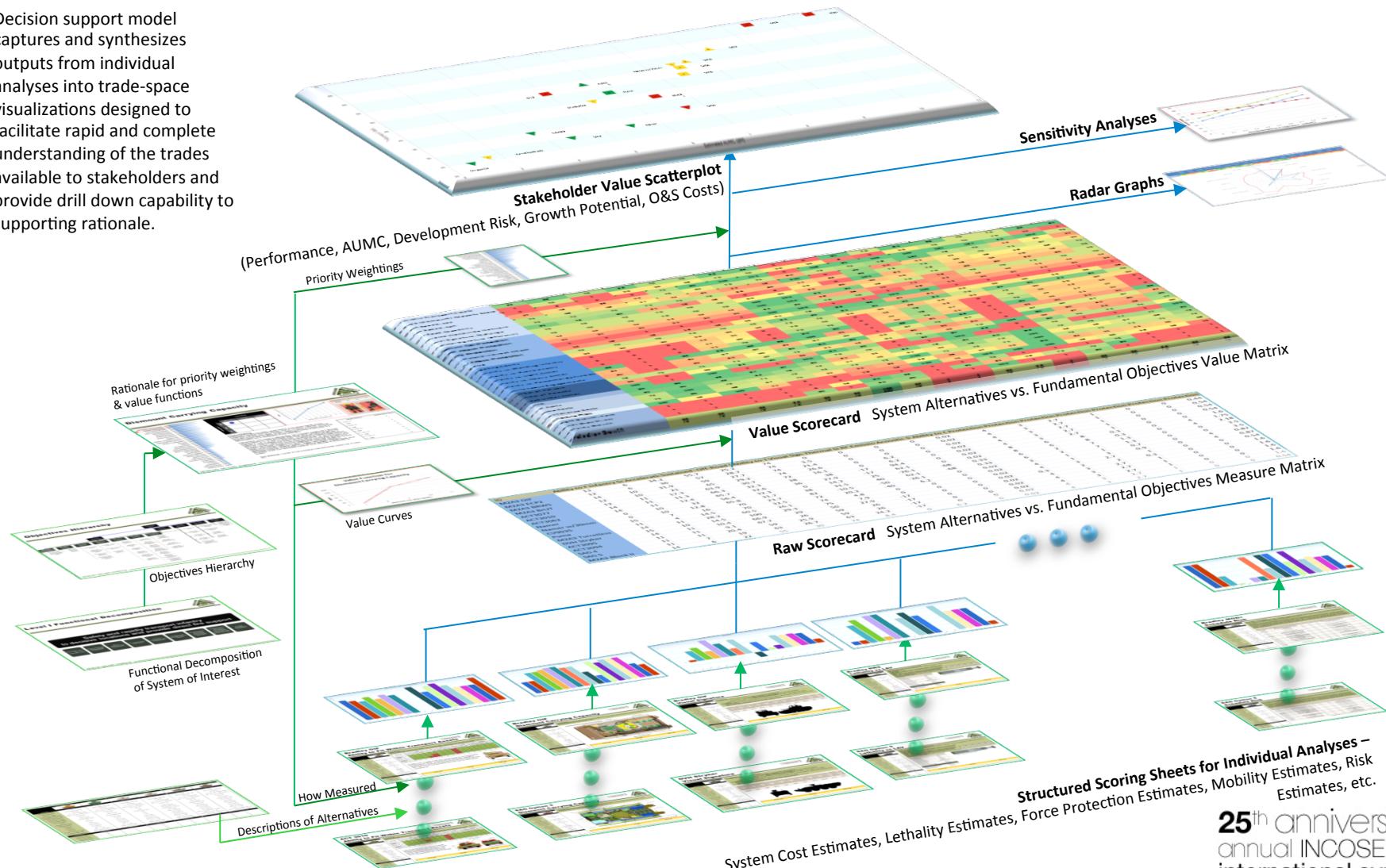


Product Structure Interrelationships

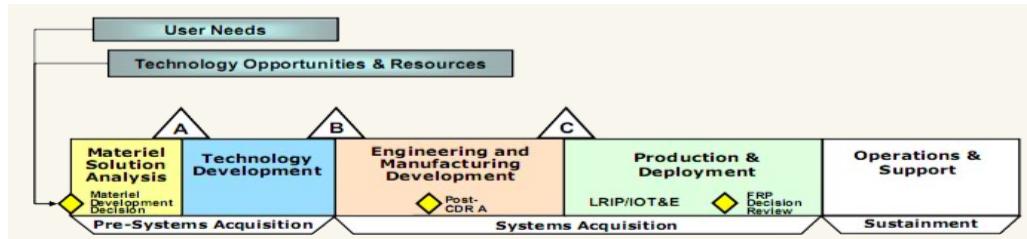
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Decision Support Model Construct

Decision support model captures and synthesizes outputs from individual analyses into trade-space visualizations designed to facilitate rapid and complete understanding of the trades available to stakeholders and provide drill down capability to supporting rationale.



WSTA Applied...



Capability Gap Assessments: What current platform gaps can be mitigated by material solutions and which ones require other DOT_LPF options.

Technology Exploitation: Quantify dominated solutions between subsystems (% of time a subsystem is selected from the Pareto frontier)

Requirements Definition: Collaborating with the USER community to understand contextually the implications of established Threshold and Objective values. Early emphasis on realistic trade space allows for improved contractor proposals, because of stability in the requirement.

Early Cost Informed Trades: Affordability is an important metric, WSTA will work to ensure that capability is optimized given a specific price point.

Requirements Analysis: Support CDD refinement activity. Provide analytical underpinnings to KPPs and KSAs. Holistically run cost informed trades analysis .

Analysis of Alternatives: Provide alternatives options for the AoA, Work with Adv Concepts on integration. Ensures total trade space explored during the AoA process.

Contractor Trades: Used by the program office to understand the subsystem trades from the contractor proposals throughout EMD.

Technology Trade Options: Analyze different technology options that meet the same functional objective, providing alternative solutions to the contractor and PM for capability enhancements.

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Why WSTA...

- Decision analysis has become rapidly more important as strategic choices are being made in a dynamic global, economic, and social environment
- Trusted tools and processes are going to need to be embedded to synthesize the data. WSTAT is under-going V&V through AMSAA
- Investigate many alternatives through the use of the genetic algorithm
- Understanding the complex interrelationships of a ground vehicle requires high computing capabilities and a rigorous use of Army technical professionals (Technologists and USERs)



WSTA Examples

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Example: Using Tool to Find Some Interesting Low Cost Alternatives



Complete Solution Set:

1,375,398 evaluations
2153 solutions

Remove any solutions that do not meet performance walk away points (2076 solutions)

Look at solutions under \$8 M (821 solutions)

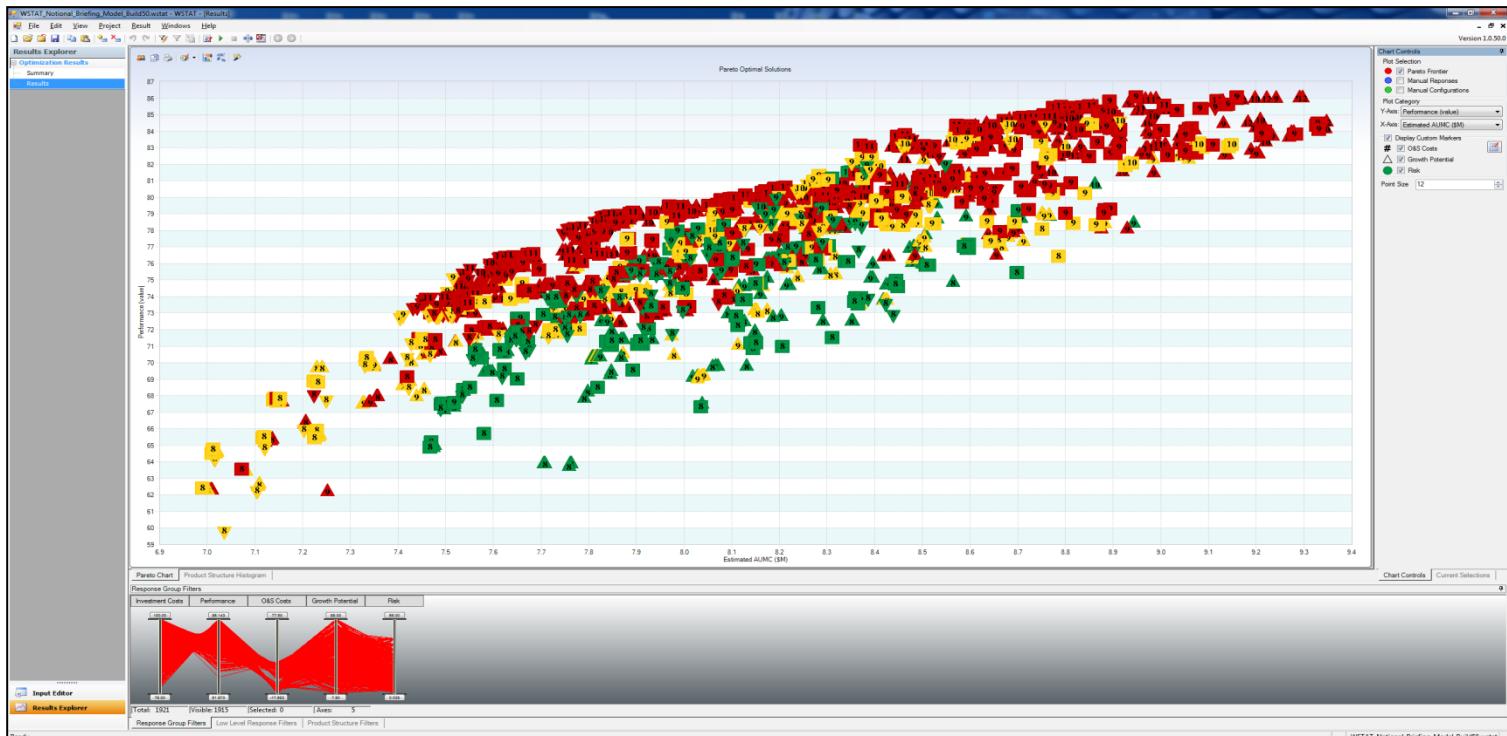
Filter out solutions with high risk, low growth potential, and high O&S cost



Selection procedure is used to identify two representative configurations

Exploration of the capabilities trade-space

How do we balance requirements? Payload vs Protection vs Mobility



WSTA complements AoA and NDV Assessment by generating
100s of non-dominated creative alternatives

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Ten Configurations Across FCC Weight Spectrum

FCC Weight Class (tons)	< 45	45 - 50		50 - 55		55 - 60		60 - 65		> 65
Configuration ID Number	# 0	#306	#6	#200*	#372*	#376*	#799*	#743*	#479*	#972
Dismounts	7L	7M	9L	7M	9L	7M	9L	9L	9L	9L
Hull/Frame/Body/Cab	Al Space frame	RHA Welded	Al Space Frame	Al Space Frame	RHA Welded					
Hull Armor – U kit	Al 2139 (T)	Int. RHA Steel (O)	Al 2139 (T)	Al 2139 (T)	Integral RHA Steel (O)					
Hull Armor – B kit	Ti-6Al-4V (L0)	None (Int. RHA Steel)	Ti-6Al-4V (L0)	7039 Al (L0)	None (Int. RHA Steel)	Integral RHA Steel	Integral RHA Steel	Integral RHA Steel	Integral RHA Steel	Ti-Al Kevlar Laminate
Hull Armor - C kit	none	none	none	none	none	none	Passive ICE (L0)	Passive ICE (L0)	Passive ICE (L0)	Multi-Threat ERA (L1)
Turret Armor – B kit	None (RWS)	None (RWS)	None (RWS)	Ceramic Al Composite (L0)	None (RWS)	7039 Al (L0)	None (RWS)	Ceramic Al Composite (L0)	None (RWS)	7039 Al (L0)
Power Pack / Drivetrain	1500 HP Diesel	1500 HP Diesel	1500 HP Diesel	1200 HP Diesel	1500 HP Diesel	1200 HP Diesel	1500 HP Diesel	1500 HP Diesel	1200 HP Diesel	1500 HP Diesel
Turret & Main Armament	RWS 30mm	RWS 30mm	RWS 30mm	Unmanned 30mm	RWS 30mm	Unmanned 30mm	RWS 30mm	Unmanned 30mm	RWS 30mm	Unmanned 30mm
Secondary Armament	None	None	None	None	7.62 Co-ax	None	7.62 Co-ax	7.62 Co-ax	7.62 Co-ax	7.62 Co-ax
CIWS	None	None	None	CROWS w/ 7.62mm	CROWS w/ .50 cal	None	None	CROWS w/ 7.62mm	CROWS w/ .50 cal	CROWS w/ 7.62mm
Missile System	none	None	none	Integrated Javelin	Integrated Javelin	none	None	Integrated Javelin	Integrated Javelin	Integrated Javelin
Fire Control	3 rd Gen FLIR (1280 x 720)									
DAS	none									

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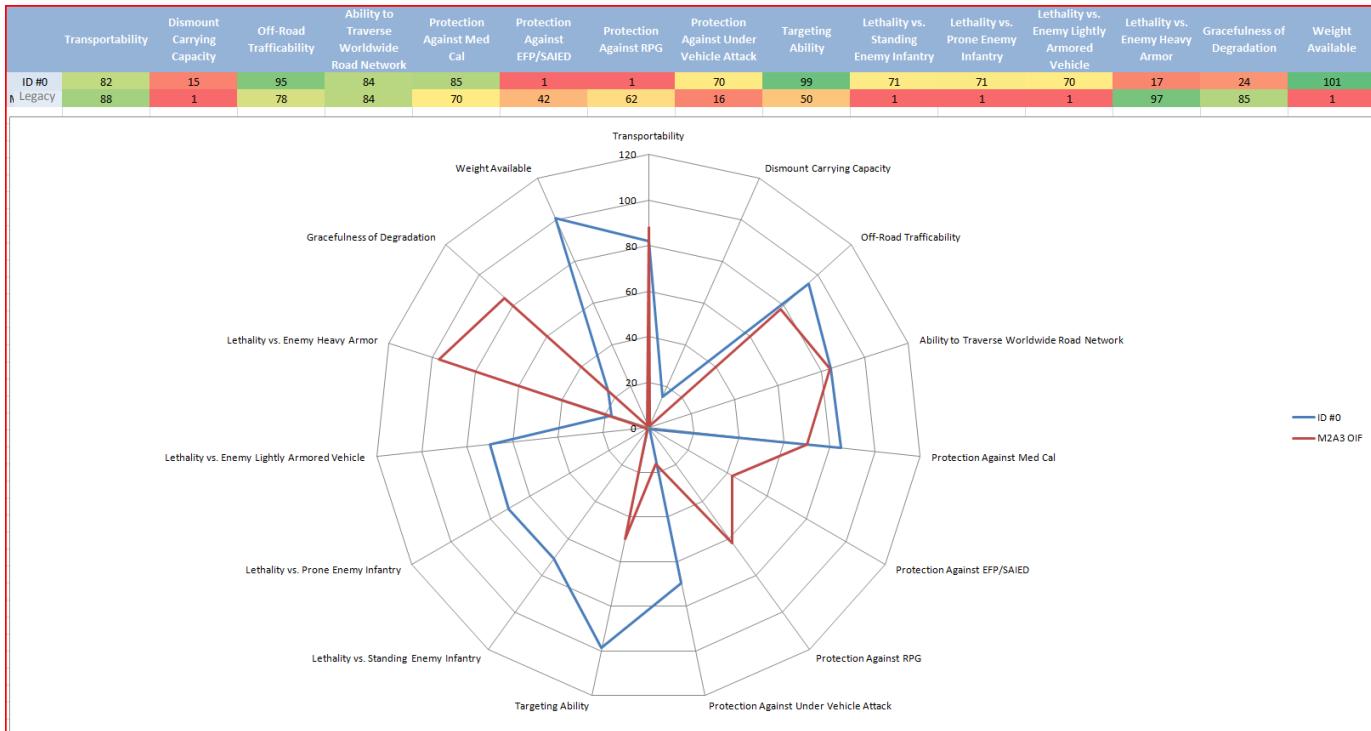
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Trends By Weight Class

- <45 tons – Expect 7 dismounts with no SAIED protection, threshold Under Vehicle protection, and a RWS Turret
- 45-50 tons – Expect no SAIED protection and a RWS Turret, but trades can be made between 7 dismounts with objective Under Vehicle protection or 9 dismounts with threshold Under Vehicle protection (with fewer dismounts, additional Under Vehicle protection is feasible)
- 50-55 tons – Expect no SAIED protection and trades to be made between 7 dismounts with an Unmanned Turret and threshold Under Vehicle protection or 9 dismounts with a RWS Turret and objective Under Vehicle protection (smaller, lighter turret allows for more dismounts and additional Under Vehicle protection)
- 55-60 tons – Expect objective Under Vehicle protection and trades to be between 7 dismounts with no SAIED protection and an Unmanned Turret or 9 dismounts with threshold SAIED protection and a RWS Turret (smaller, lighter turret allows for more dismounts and improved SAIED protection)
- 60-65 tons – Objective Under Vehicle and threshold SAIED protection can be achieved with 9 dismounts for either an Unmanned or RWS Turret
- >65 tons – Objective SAIED and Under Vehicle protection with 9 dismounts and an Unmanned Turret

Configuration ID # 0

FCC Weight Class (tons)	< 45
Configuration ID Number	# 0
Dismounts	7L
Hull/Frame/Body/Cab	AI Space frame
Hull Armor – U kit	AI 2139 (T)
Hull Armor – B kit	Ti-6Al-4V (L0)
Hull Armor - C kit	none
Turret Armor – B kit	None (RWS)
Power Pack / Drivetrain	1500 HP Diesel
Turret & Main Armament	RWS 30mm
Secondary Armament	None
CIWS	None
Missile System	none
Fire Control	3 rd Gen FLIR (1280 x 720)
DAS	none

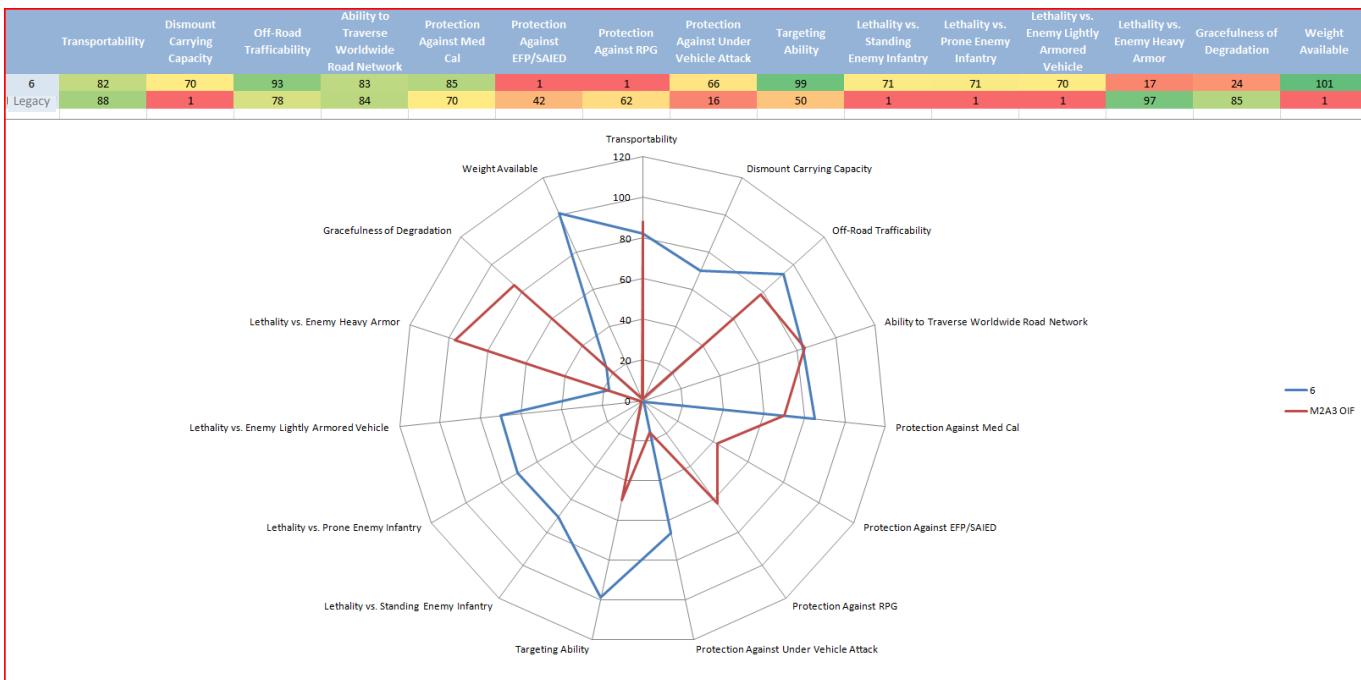


This < 45 ton configuration offers some improvement relative to Legacy Platforms in the areas of lethality of primary armament, weight available for growth, targeting ability, & UV protection.

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Configuration ID #6

FCC Weight Class (tons)	45-50
Configuration ID Number	#6
Dismounts	9L
Hull/Frame/Body/Cab	AI Space Frame
Hull Armor – U kit	AI 2139 (T)
Hull Armor – B kit	TI-6AI-4V (L0)
Hull Armor - C kit	none
Turret Armor – B kit	None (RWS)
Power Pack / Drivetrain	1500 HP Diesel
Turret & Main Armament	RWS 30mm
Secondary Armament	None
CIWS	None
Missile System	none
Fire Control	3 rd Gen FLIR (1280 x 720)
DAS	none

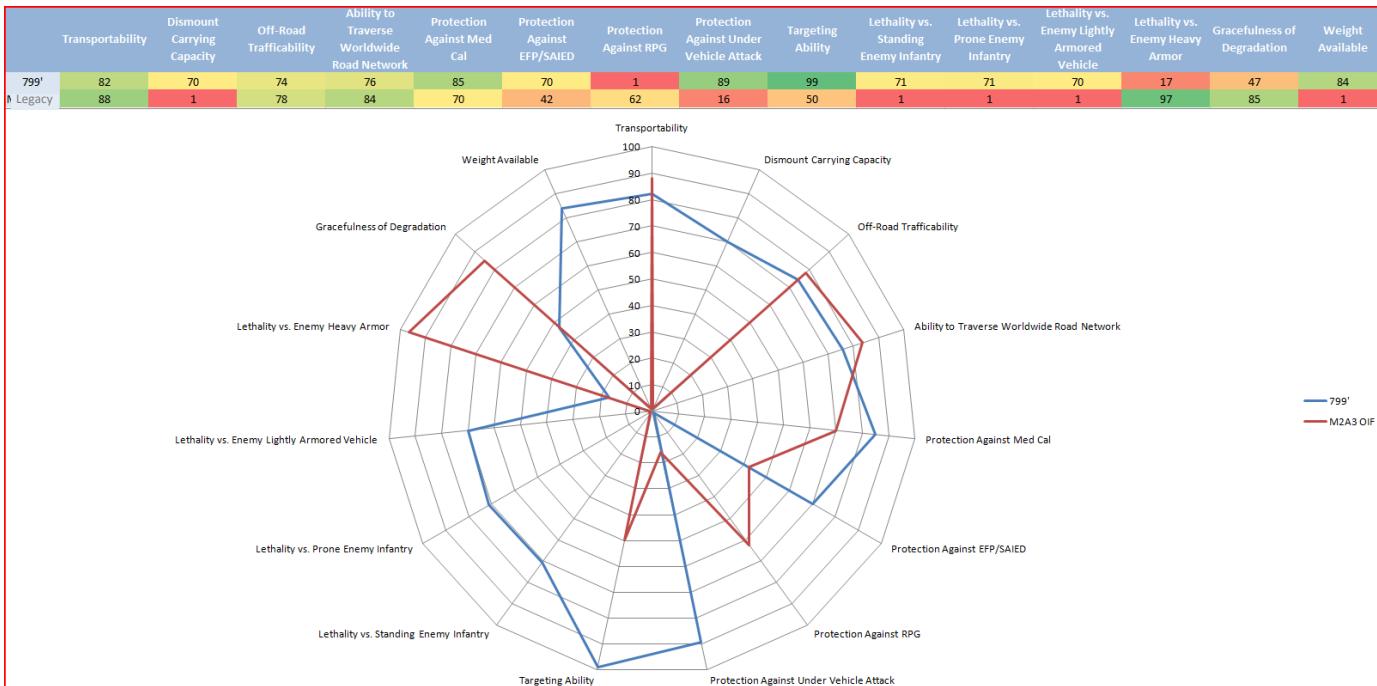


This 45 – 50 ton FCC configuration can carry 9 dismounts and offers some improvement relative to Legacy Platforms in the area of lethality of primary armament, weight available for growth, targeting ability, & UV protection.

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Configuration ID #799

FCC Weight Class (tons)	55 - 60
Configuration ID Number	#799*
Dismounts	9L
Hull/Frame/Body/Cab	RHA Welded
Hull Armor – U kit	Integral RHA Steel (O)
Hull Armor – B kit	Integral RHA Steel
Hull Armor - C kit	Passive ICE (LO)
Turret Armor – B kit	None (RWS)
Power Pack / Drivetrain	1500 HP Diesel
Turret & Main Armament	RWS 30mm
Secondary Armament	7.62 Co-ax
CIWS	None
Missile System	None
Fire Control	3 rd Gen FLIR (1280 x 720)
DAS	none

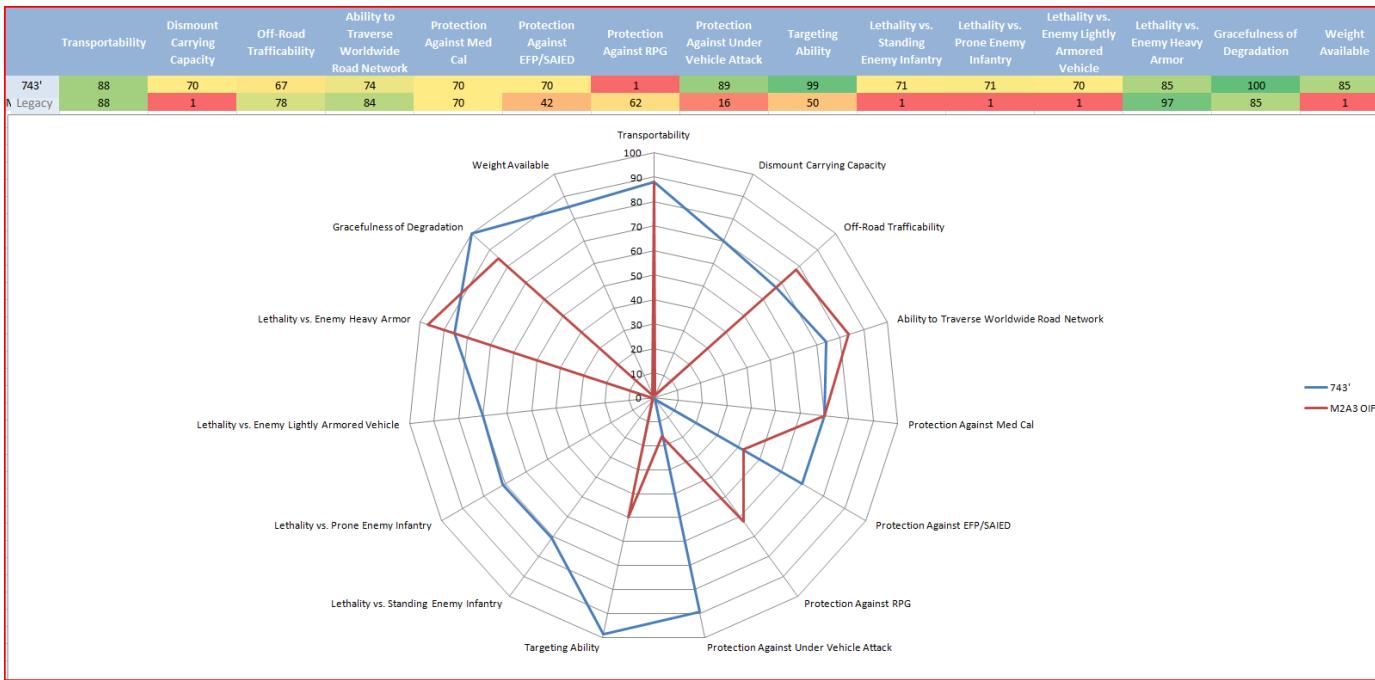


This 55 – 60 ton configuration provides improved EFP / SAIED attack protection, can carry 9 dismounts and offers some improvement relative to Legacy Platforms in the area of lethality of primary armament, weight available for growth, targeting ability, & UV protection

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Configuration ID #743

FCC Weight Class (tons)	60 - 65
Configuration ID Number	#743*
Dismounts	9L
Hull/Frame/Body/Cab	RHA Welded
Hull Armor – U kit	Integral RHA Steel (O)
Hull Armor – B kit	Integral RHA Steel
Hull Armor - C kit	Passive ICE (L0)
Turret Armor – B kit	Ceramic Al Composite (L0)
Power Pack / Drivetrain	1500 HP Diesel
Turret & Main Armament	Unmanned 30mm
Secondary Armament	7.62 Co-ax
CIWS	CROWS w/ 7.62mm
Missile System	Integrated Javelin
Fire Control	3 rd Gen FLIR (1280 x 720)
DAS	none



This 60-65 ton configuration nearly meets or exceeds Legacy Platforms performance in almost every category.

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Summary & Questions

- The Whole Systems Trade Analysis (WSTA) methodology developed within PEO GCS has been applied successfully across several programs to include PM Bradley, PM AMPV and RS JPO. New initiatives are being planned for FY15 and beyond.
- The WSTA methodology directly addresses the Department of Defense's (DoD) request to pursue methods for greater efficiency and productivity in Defense spending (Better Buying Power 2.0 Memorandum - "do more without more.") as well as its Engineered Resilient Systems (ERS) emphasis area directing the use of systems analysis methods, advanced architecture and design analysis techniques and the use of advanced algorithms.