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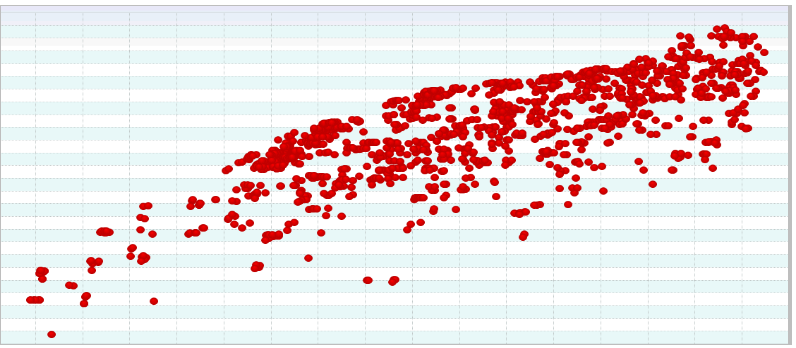

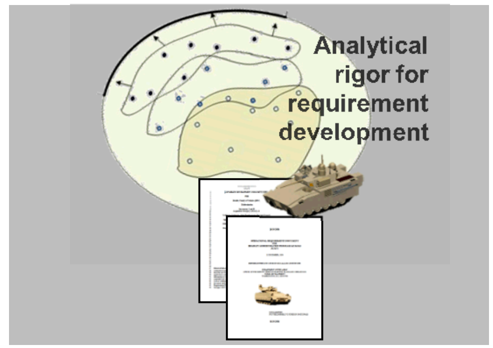


LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

# An Optimization Approach to Integrated Requirements Development for Acquisition Programs

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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# Overview

Sandia National Laboratories

**Purpose of this briefing is to provide an overview of a research project funded by Sandia National Laboratories that aims to develop a tool to aid future requirements development efforts**

- Background on Current Analytic Capability
- Challenge
  - Current Requirements Development Approach
  - Proposed Approach
- Integrated Requirements Development Concept
- Technical Challenges
- What Does Success Look Like?
- Example Applications
- Significance of Capability
- Status and Next Steps

# Background on Current Analytic Capability

- Sandia developed and has significant experience applying the Whole System Trades Analysis Tool (WSTAT)
  - Evaluates system concepts against existing requirements
- WSTAT Origins
  - Acquisition Decision Memorandum:
    - On November 3, 2010 the Under Secretary of Defense for Acquisition, Technology and Logistics signed the Directive for obtaining greater efficiency in defense spending
      - "The ability to successfully develop, build, and field a capable IFV within the department's cost and schedule constraints is strongly dependent on ***aggressive exploration of the capabilities trade-space and the full range of alternatives*** prior to finalizing requirements…"
- Motivation
  - Requirement for all new acquisitions (Milestone B)
    - "You will present a ***systems engineering trade off analysis showing how cost varies as the major design parameters and time to complete are traded off*** against each other."


OFFICE OF THE UNDER SECRETARY OF DEFENSE
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ACQUISITION, TECHNOLOGY AND LOGISTICS

SEP 14 2010

MEMORANDUM FOR ACQUISITION PROFESSIONALS

SUBJECT: Better Buying Power: Guidance for Obtaining Greater Efficiency and Productivity in Defense Spending

On June 28, I wrote to you describing a mandate to deliver better value to the taxpayer and warfighter by improving the way the Department does business. I emphasized that, next to supporting our forces at war on an urgent basis, this was President Obama's and Secretary Gates' highest priority for the Department's acquisition professionals. To put it bluntly: we have a continuing responsibility to procure the critical goods and services our forces need in the years ahead, but we will not have ever-increasing budgets to pay for them. We must therefore strive to achieve what economists call productivity growth: in simple terms, to DO MORE WITHOUT MORE. This memorandum contains specific Guidance for achieving the June 28 mandate.

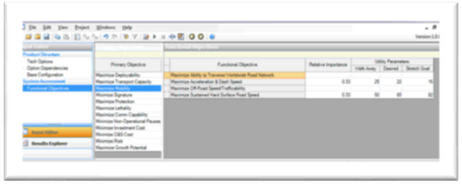
Secretary Gates has directed the Department to pursue a wide-ranging Efficiencies Initiative, of which this Guidance is a central part. This Guidance affects the approximately $400 billion of the $700 billion defense budget that is spent annually on contracts for goods (weapons, electronics, fuel, facilities etc., amounting to about $200 billion) and services (IT services, knowledge-based services, facilities upkeep, weapons system maintenance, transportation, etc., amounting to about another $200 billion). We estimate that the efficiencies targeted by this Guidance can make a significant contribution to achieving the $100 billion redirection of defense budget dollars from unproductive to more productive purposes that is sought by Secretary Gates and Deputy Secretary Lynn over the next five years.

Since June, the senior leadership of the acquisition community – the Component Acquisition Executives (CAEs), senior logisticians and systems command leaders, OSD officials, and program executive officers (PEOs) and program managers (PMs) – has been meeting regularly with me to inform and craft this Guidance. We have analyzed data on the Department's practices, expenditures, and outcomes and examined various options for changing our practices. We have sought to base the specific actions I am directing today on the best data the Department has available to it. In some cases, however, this data is very limited. In these cases, the Guidance makes provision for future adjustments as experience and data accumulate so that unintended consequences can be detected and mitigated. We have conducted some preliminary estimates of the dollar savings anticipated from each action based on reasonable and gradual, but steady and determined, progress against a clear goal and confirmed that they can indeed be substantial.

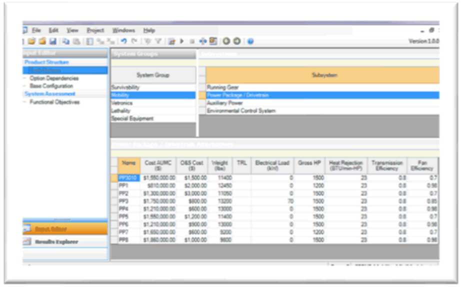
Changing our business practices will require the continued close involvement of others. We have sought out the best ideas and initiatives from industry, many of which have been adopted in this Guidance. We have also sought the input of outside experts with decades of experience in defense acquisition.

# What is WSTAT and Why is it Needed?

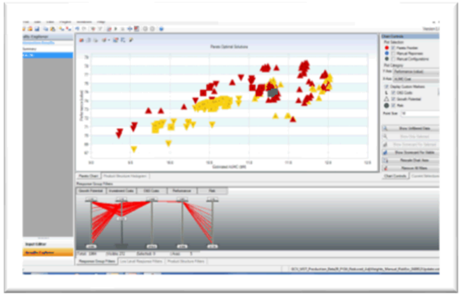
**Input Stakeholder Objectives**



**Input design choices and relationships**



**View holistic system consequences in terms of stakeholder value**



**Columns represent functional objectives: cooler colors are easy to meet requirements while warmer colors are more difficult to meet**

- **What**
  - Decision support tool
  - Integrates otherwise separate subsystem models into a holistic system view
  - Maps critical design choices to consequences relevant to stakeholders

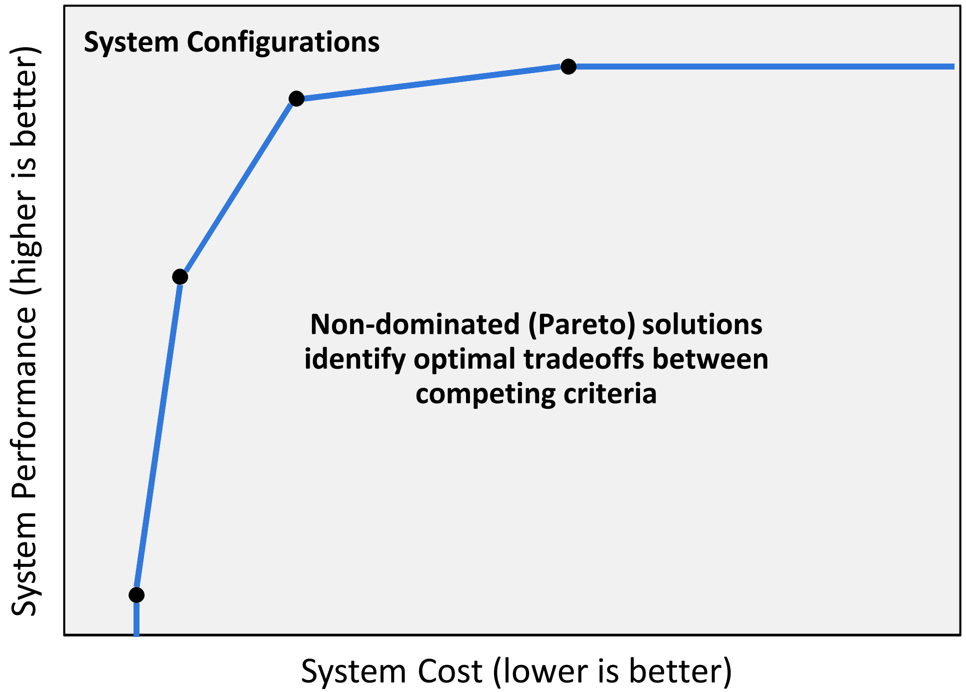
- **Why**
  - Military designs and fields complex systems with many interrelated subsystems
  - Finding the sweet-spot among competing objectives (performance, cost, schedule risk, etc.) is a non-trivial task

Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect.

(Federal Aviation Administration [USA], *Systems Engineering Manual*, definition contributed by Simon Ramo)

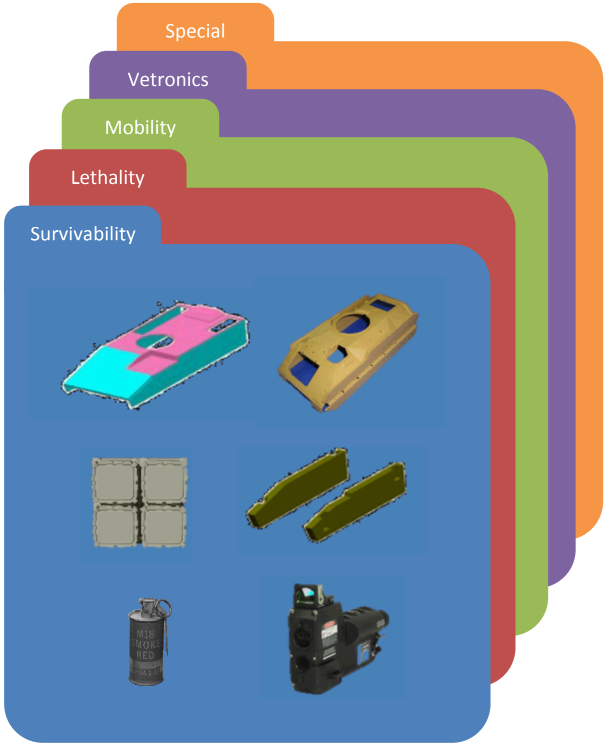
# WSTAT Concept

- WSTAT looks at the design of a system, aggressively examining many potential configurations in an effort to explore tradeoffs between multiple competing objectives
- WSTAT uses a multi-objective genetic algorithm (GA) optimization to find the best designs to satisfy competing criteria
  - Consider only 2 criteria, cost and performance
  - Same idea applies when balancing more criteria, except that higher-dimensional spaces are required



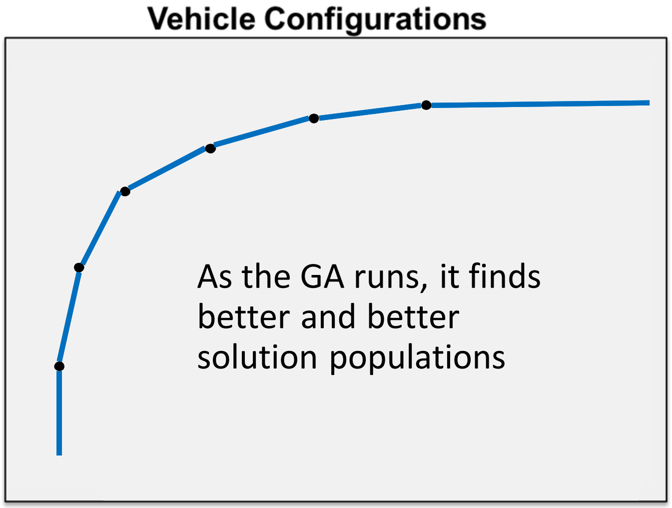
# WSTAT Concept

- The WSTAT GA 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



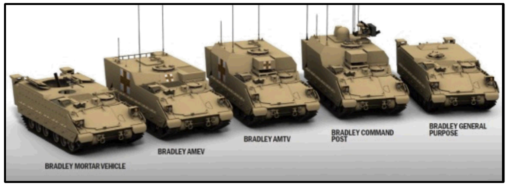

Configurations are scored in multiple value dimensions (tailorable to problem):

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

# Past WSTAT Applications

- The WSTAT methodology has been successfully applied to the design of a single platform…
  - Ground Combat Vehicle (GCV)
  - Bradley Fighting Vehicle
  - Paladin Integrated Management (PIM)
  - Maneuver Support Vessel - Light (MSV-L)
- WSTAT has also been successfully applied to…
  - Optimizing a family of platforms (Armored Multi-Purpose Vehicle, Robotic Systems)
    - Taking commonality across mission roles into account
    - AMPV included simultaneous analysis of both wheeled and tracked concepts
  - Optimizing a cluster of contingency base camps
    - Taking commonality within a single base and across multiple different size bases into account

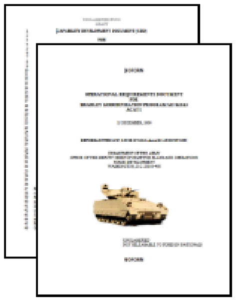





- Experience led to an observation
  - When examining existing requirements, *<u>no program met all stated requirements with the available technologies at a feasible cost</u>*
  - Motivated us to try to come up with a way to help

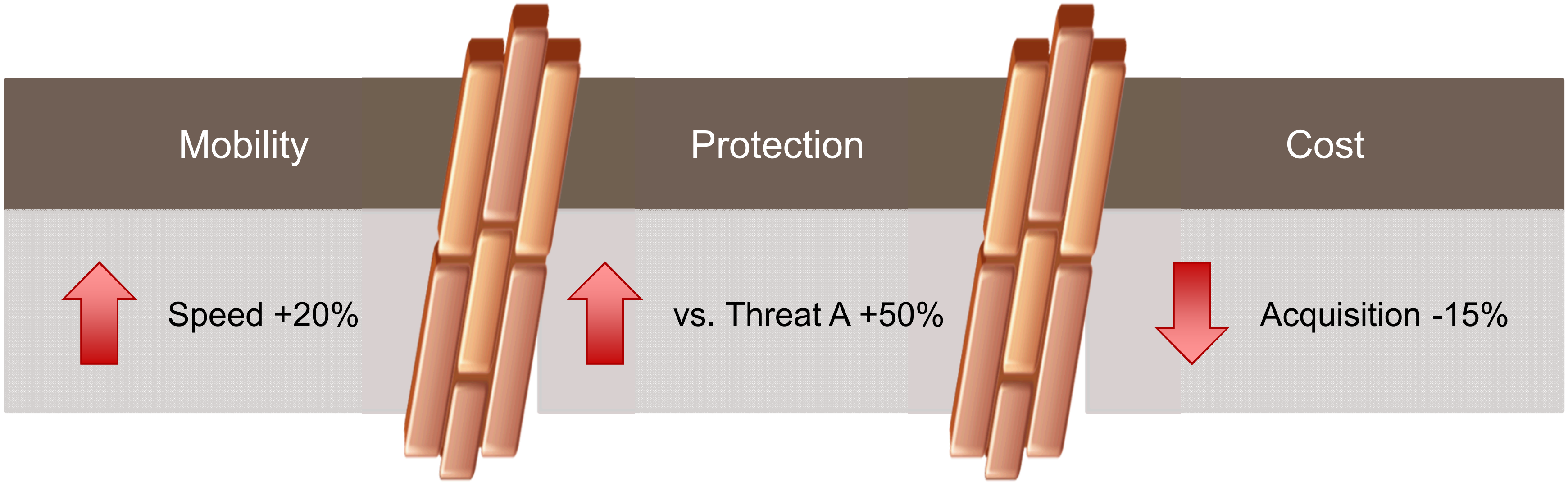
# Requirements Development Challenge

- From outside perspective, defense acquisition process possesses a fundamental flaw
- Flaw is frequent inability to meet stated requirements
  - *Future Combat Systems (FCS)* required levels of situational awareness unattainable with available technologies
  - *Ground Combat Vehicle (GCV)* required increased seating capacity while simultaneously having a smaller visual signature
- Missing requirements can increase likelihood of program cancellation
- Every time a program is cancelled
  - Money is spent with little return on investment
  - Delivery of vital capability to the warfighter is delayed



- Apparent Cause
  - Requirements traditionally developed without ability to understand complex interactive effects
  - Often results in unattainable, unaffordable, and/or mutually incompatible requirements that put a program at risk from the start

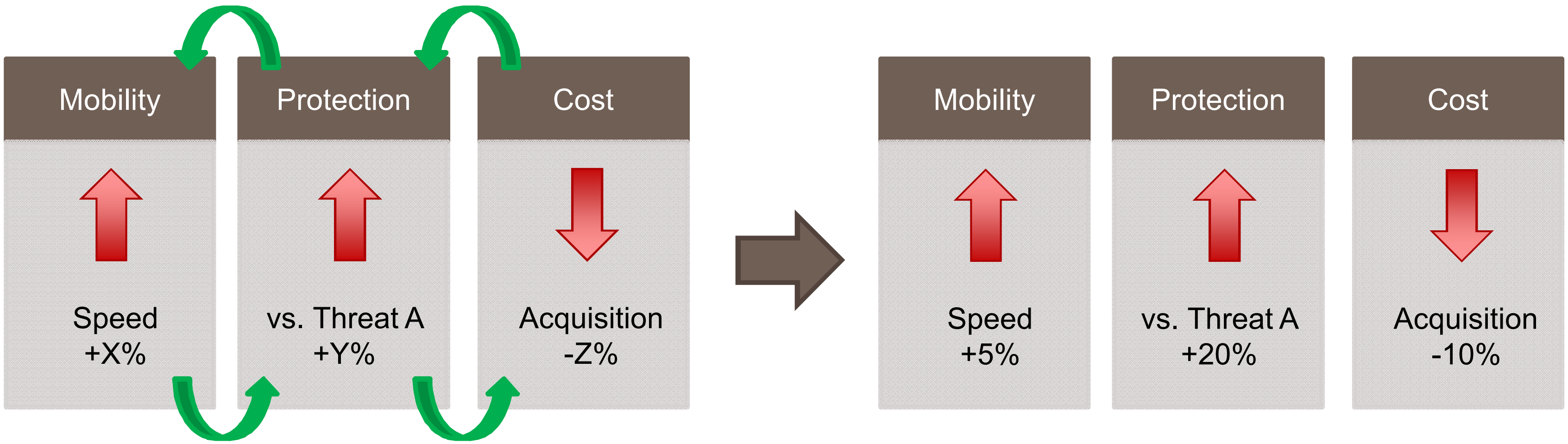
# Current Requirements Development Approach Example




- Mobility and Protection Subject Matter Experts (SMEs) each develop performance goals
- Cost analysts determine feasible unit cost based on budget
- Individual requirements are feasible and well reasoned, but when taken together inconsistencies arise
  - Increased speed requires lighter vehicle or more powerful, expensive engine
  - Increased protection requires heavier armor or exotic, expensive materials
  - Decreased cost precludes use of expensive technologies (e.g., larger engine or exotic materials)

# Proposed Requirements Development Approach Example

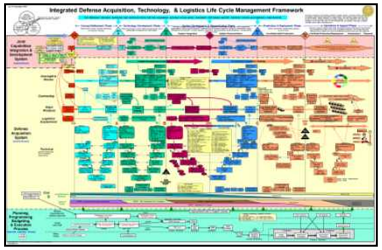


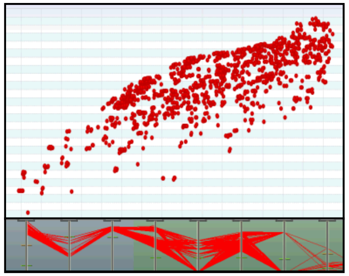



- Goal is to develop requirements in an integrated fashion, considering
  - Interactions between competing criteria
  - Available technologies
  - Most pressing warfighter needs
- Results in set of requirements that are simultaneously attainable for given constraints
- Easy to manually reconcile inconsistencies when looking at *small* number of objectives
  - Significantly more challenging in acquisition programs where large number of requirements might be in conflict
- Complexity necessitates an optimization approach for resolving conflicts
- Provides requirements developers with numerous feasible sets to explore interactions between requirements and tradeoffs amongst them
- Want to enable better understanding of requirements early

# Integrated Requirements Development Concept

- Identify performance measures of interest
- Define how to evaluate them with help of SMEs
- Identify ***technologies*** anticipated to be available to program
- Identify best achievable values for each measure given these technologies (provides search bounds)
- Meet with SMEs to verify best achievable values and relationships for individual measures make sense
- Explore full range of possible values for each measure to identify potential requirement sets (collections of values that can be simultaneously achieved)
- Meet with system users to identify limits of ***operational*** utility for each measure (when applicable)
- Meet with decision makers to identify ***programmatic*** constraints (e.g., cost and schedule)
- Populate decision support tool with identified potential requirement sets
  - Provide filtering/visualization capabilities
  - Enable exploration of tradeoffs among requirements while applying known constraints
  - Facilitate discussions by displaying proposed requirement sets compared to identified achievable sets
  - Lead to selection of demanding yet feasible set of requirements but not so strict there are few ways to satisfy them



# Technical Challenges

- Determine Extreme Values for Measures of Interest
  - Bounds realm of possible values based on available technologies
  - Should be fairly easy to determine with a single objective optimization approach
  - Challenge is finding an efficient and effective technique, initial testing has shown GA to be acceptable
- Explore Realm of Possible Values for Each Measure of Interest to Identify Trades Amongst Objectives
  - Challenge is that approach needs to be able to:
    - Explore full range of values for each measure of interest to provide a comprehensive set of options for decision makers to evaluate (preserve extreme solutions)
    - Identify relationships between measures of interest at various stringency levels so decision makers can see what must be given up or can be gained by changing the level for a particular objective (diverse solutions)
  - Various options, each with pros and cons, exist and were explored
    - Traditional multi-objective optimization with a large number of measures of interest, where related measures are aggregated into a smaller number of optimization dimensions (< 6) – aggregation obscures trades
    - High dimensional optimization, where each measure of interest (can be more than 40 in typical acquisition problems) is given to the algorithm as an optimization dimension – selected approach

# Technical Challenges

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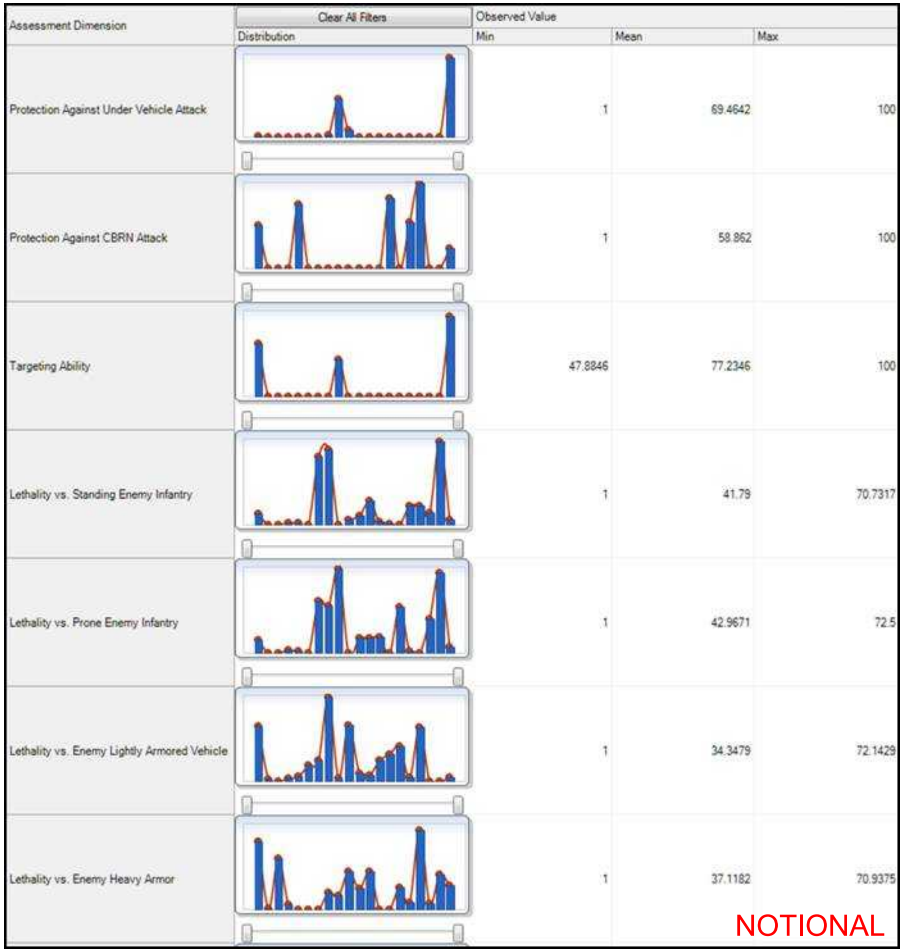
- Develop Structure for Requirements Development Process
  - Question is how to explore and interpret a high-dimensional trade space to provide actionable insight
  - Large amount of information could overwhelm decision makers if not presented effectively
  - Began brainstorming visualization and data analysis techniques to improve understanding of output

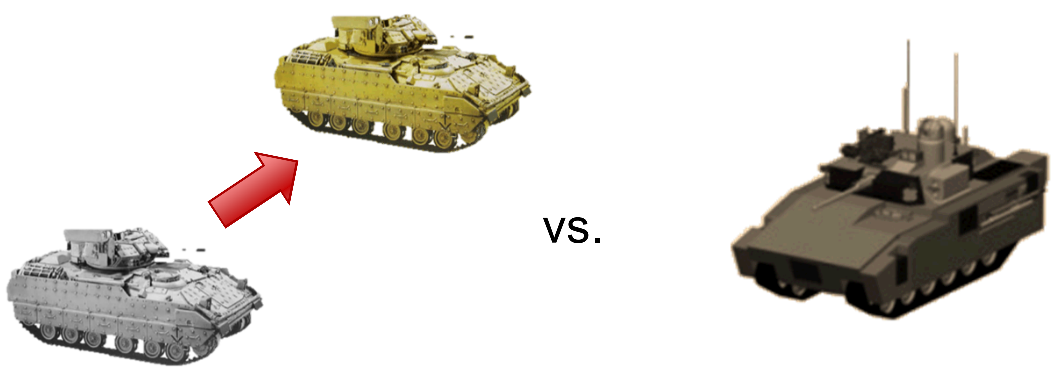


# What does success look like?

- Technical success for this research will be a functioning prototype tool that is able to optimize solutions and inform requirement targets
- In general, requirement sets identified by this prototype tool should:
  - Be self-consistent
  - Set goals that are neither too lax nor too restrictive given the available technology options
    - One can think of this as being similar to setting a course for a ski race
    - A good course should be challenging enough to differentiate between the competitors (system concepts) while not being so challenging that no competitor can complete it (unachievable requirements) nor so easy that all competitors perform essentially the same (requirements that are too lax)

# Example Applications

- New Program
  - Help new programs when first developing a set of requirements
  - Provides program with strong foundation to build from by ensuring initial requirements are feasible and consistent
- Upgrade/New Start Decisions
  - Can be used when assessing whether to build new platform or upgrade existing one
  - Provide insight into levels of performance attainable and tradeoffs that exist amongst requirements for each course of action



# Significance of Capability

- Enable understanding of interactions and conflicts between requirements during inception and suggest defensible, mutually compatible goals
  - Consistent initial requirements help avoid problems later
  - Requirements difficult to change once socialized
  - Meeting stated requirements becomes expected, seen as failure when proven unachievable and reason to cancel program
- Improve defense acquisition by injecting “feedback loop” into early requirements definition process
  - Ensures feasible and consistent initial requirements
  - Minimizes wasted funds
  - Eliminates time spent developing to infeasible requirements, reworking requirements, and restarting development to new requirements
  - Removes a reason for program cancellation, reducing risk of little to no tangible result from investment

# Status and Next Steps

- Now starting the final year of two year research project
- Brainstorming and preliminary testing of various approaches began October 2014
- Exploration of approaches and algorithm development is in progress and expected to last at least through December 2015
- A prototype analysis interface is in the early stages of development
- CY16 is envisioned to consist primarily of testing and finalization of a prototype tool

# QUESTIONS