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Sandia National Laboratories

# Rapid Systems Engineering of RF-Based IED Countermeasures

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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# Outline

- Background & Vision
- WSTAT methodology & uses
- Rapid Systems Engineering
- Progress to date
- Path Forward

# Background & Vision

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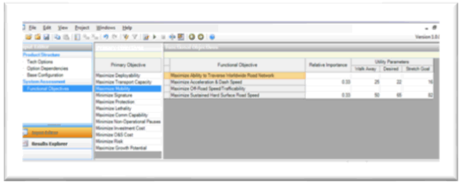
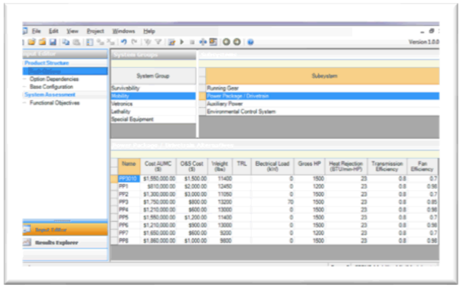
- JIDA (formerly JIEDDO) counter-IED effort: architecture and systems engineering to improve and accelerate development of advanced vehicle-borne IED countermeasures. Two thrusts:
  - Direct current injection
  - RF coupling
- WSTAT (Whole System Trades Analysis Tool)
  - Developed and applied for US Army programs to aid systems engineering
    - 10+ programs, incl. robots, watercraft, families of combat vehicles, contingency bases
  - Explained in more detail on next slides
- Vision: use WSTAT approaches to enable more rapid systems engineering of RF-based counter-IED capabilities
  - Dispense with the current necessity of a completely new systems engineering study each time a new threat or environment is encountered
  - Provide a persistent systems engineering capability which does up-front feasibility screening and technology selection
    - allows engineers to focus primarily on integration issues
  - Potentially expand to current injection systems later

# What is WSTAT and Why Is It Needed?

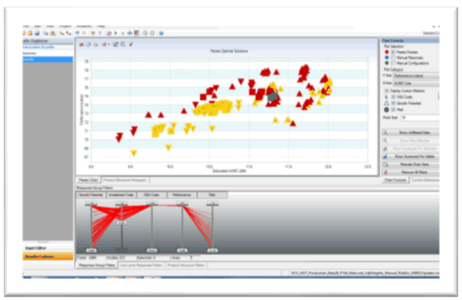
Input Stakeholder Objectives



Input design choices and relationships



View Holistic System Consequences in terms of stakeholder value



- **What**: A decision support tool that integrates otherwise separate subsystem models into a holistic system view mapping critical design choices to consequences relevant to stakeholders.

- **Why**: The military is in the business of designing and fielding very complex systems with many interrelated subsystems. Finding the sweet-spot among competing objectives (performance, affordability, risk, scalability and commonality) 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)

# Understanding the Problem

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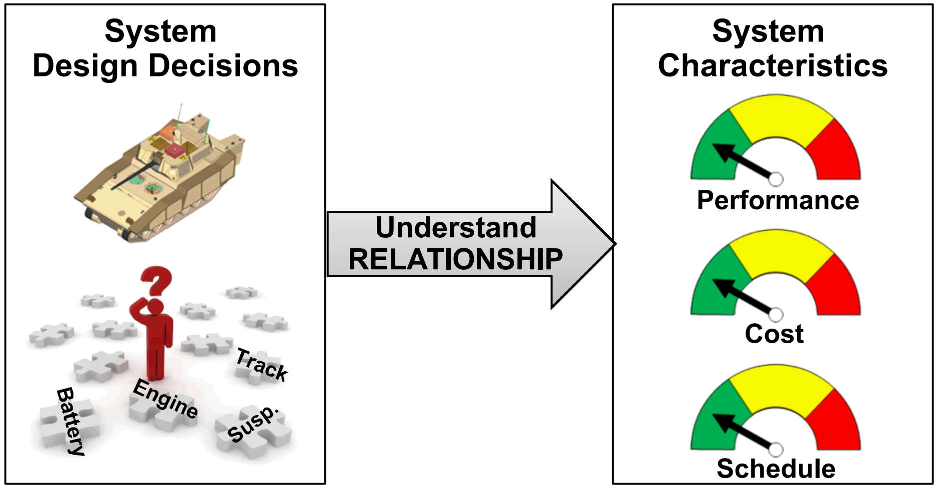
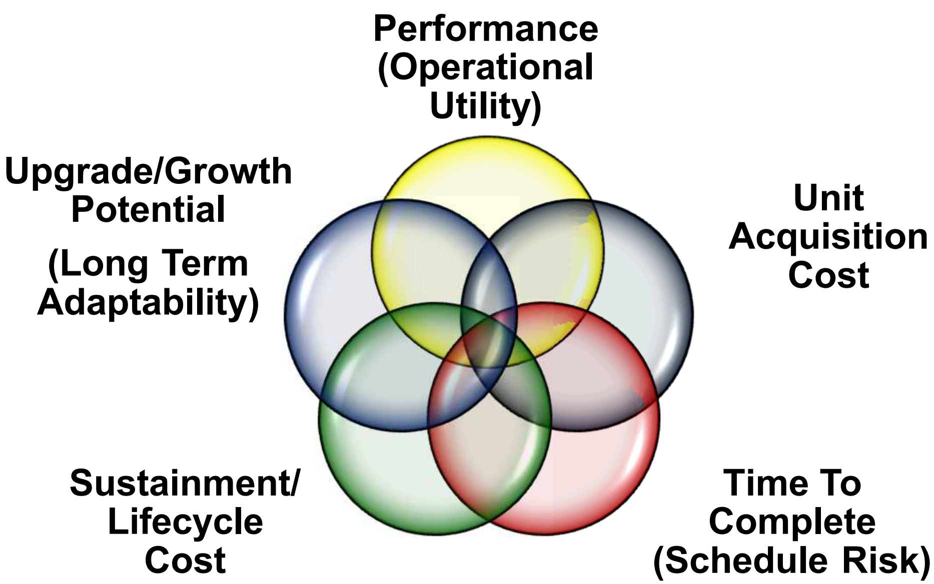
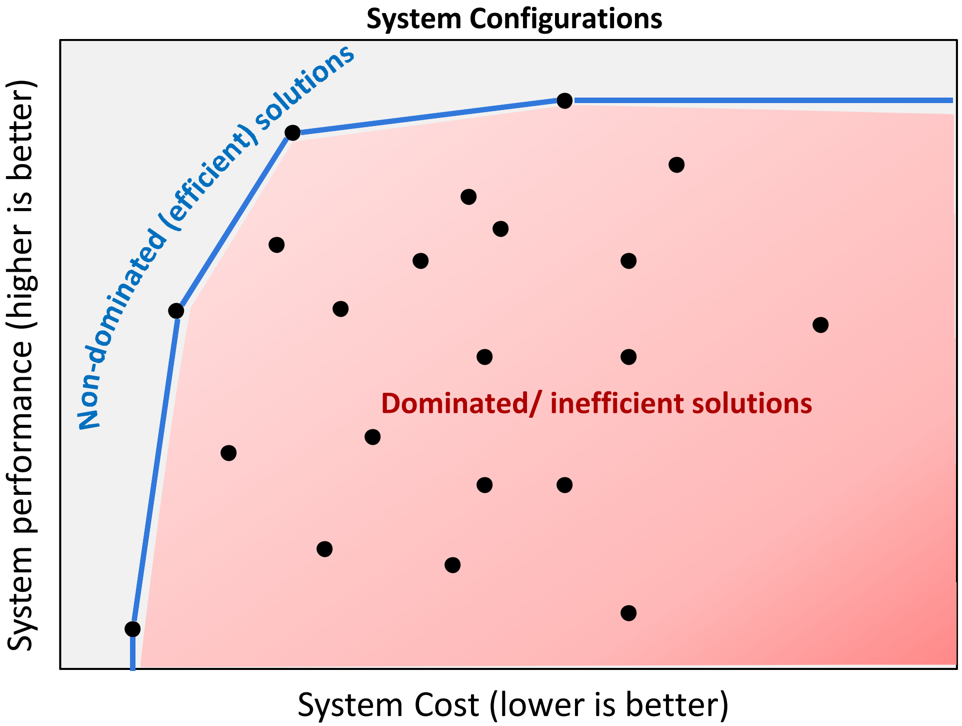



- System Decomposition
  - Understand the parts of the system that are tradable
- System Characteristics
  - Model relationship between system design decisions and system characteristics
- Challenges
  - Multiple dimensions of importance, measured in different units and with different levels of importance
  - Massive number of possible solutions ($10^{20}$ – $10^{150}$ typical)
  - Constraints
  - 2nd and 3rd order interactions
  - Dependencies between subsystems

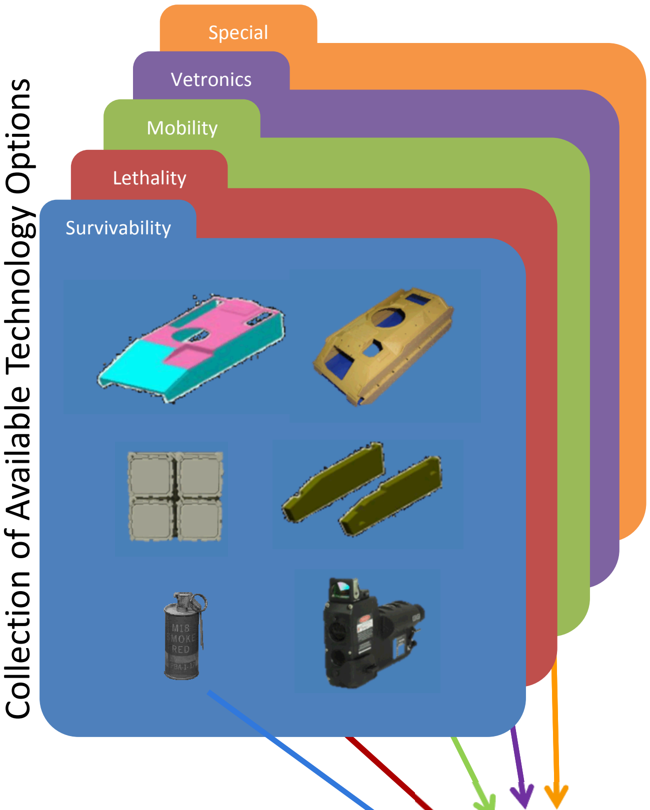
# How WSTAT Works

- WSTAT looks at the design of a system, aggressively examining many potential configurations in an effort to meet multiple competing requirements and objectives
- WSTAT uses a multi-objective genetic algorithm to find design "sweet spots" that balance multiple competing criteria
  - Consider 2 criteria, cost and performance
  - **Non-dominated (Pareto efficient) solutions** identify optimal tradeoffs between competing criteria
  - Same idea applies when balancing more criteria, except in higher dimensions

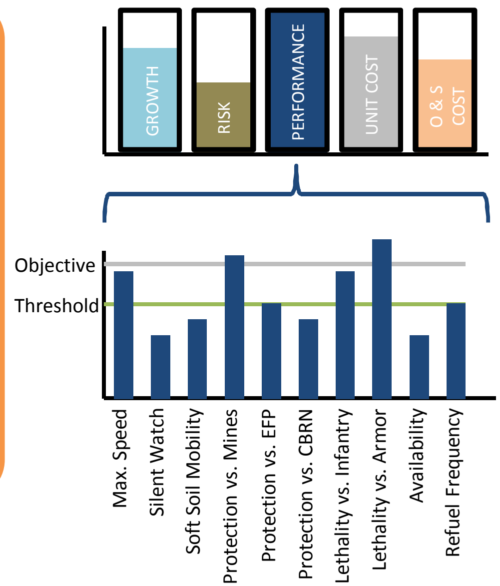


# How WSTAT Works

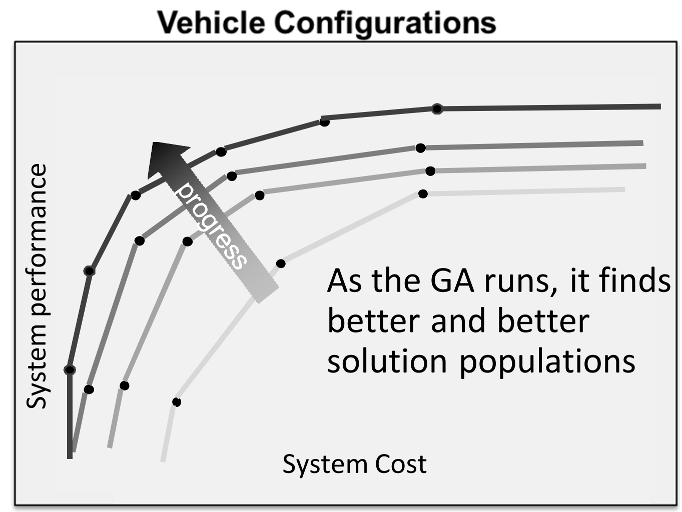
The WSTAT GA combines technology options into a system configuration, only keeping those configurations that best balance competing objectives




1) Technologies are selected to create configurations




2) Each configuration is scored in lower-level metrics that contribute to higher-level dimensions



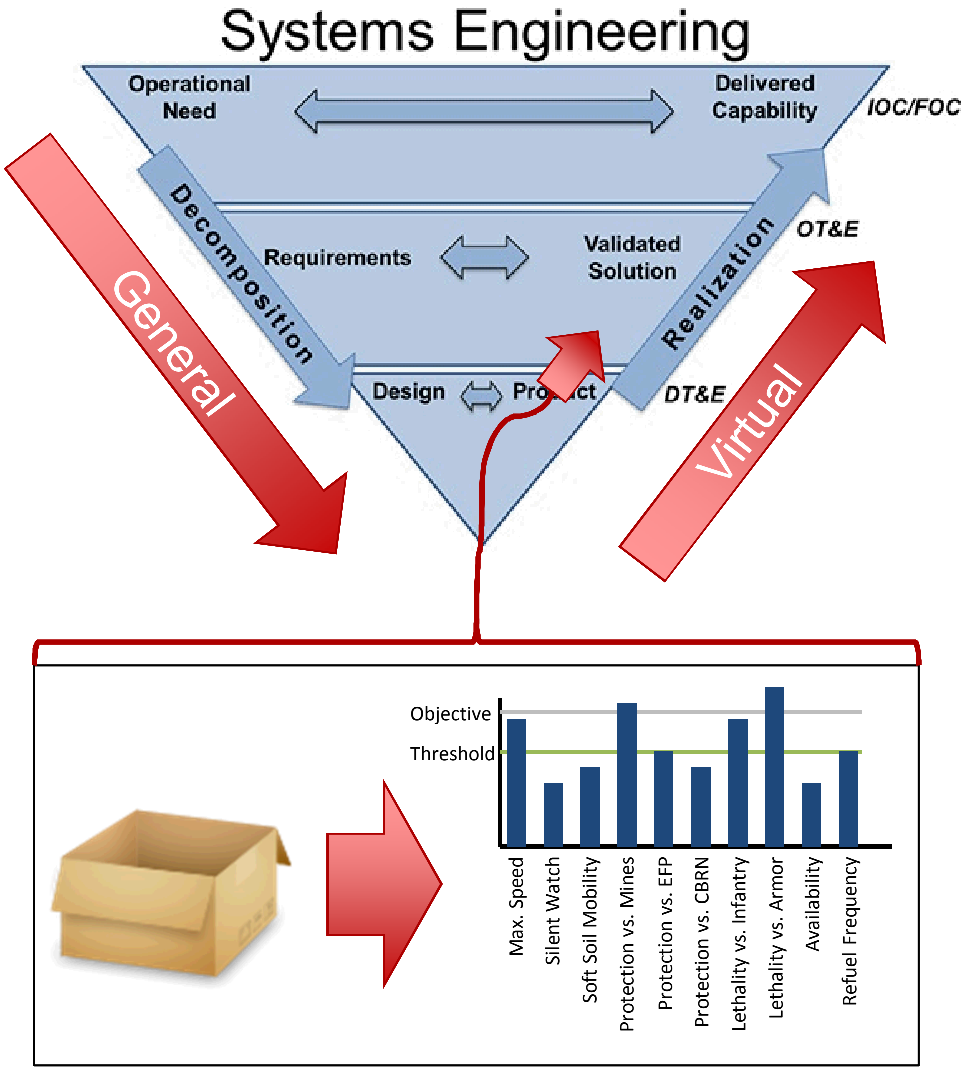

3) Configurations are bred and mutated within a Genetic Algorithm (GA), evolving the population towards optimality

**As evaluating all potential configurations is impossible, a genetic algorithm is used to identify a set of near-optimal solutions (typically several thousand)**

# WSTAT Uses

- Requirements analysis
- Tradeoff Analysis (between technologies, requirements, attributes)
- Assessing technology trends (e.g., in different price/weight ranges)
- Comparing Solutions
  - Pairwise/multiple solution comparison (radar, tornado, bar charts)
  - Priority weighting sensitivity analysis
  - With uncertainty
- Analyzing variations on a concept
  - Manually changing technology choices
  - Finding and analyzing Pareto points that outperform existing designs
- Parametric analysis (e.g., trends as non-tradeable weight grows)
- Family analysis
  - Analyze families of systems in one optimization, rather than optimizing single variants independently
  - Can incorporate cross-variant measures such as commonality

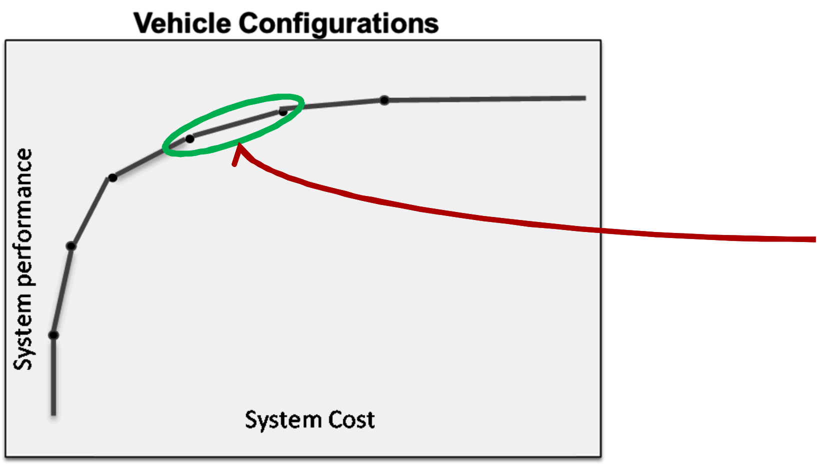
# Rapid Systems Engineering Vision




1. Define *range* of operational needs, requirements *trade space* (T-O), possible architectures, and possible component-level solutions

2. Develop functions that can assess fitness of any collection of components against full suite of requirements (assuming effective integration), *including cost, schedule etc.*

# Rapid Systems Engineering Vision




1. Define *range* of operational needs, requirements *trade space* (T-O), possible architectures, and possible component-level solutions

2. Develop functions that can assess fitness of any collection of components against full suite of requirements (assuming effective integration), *including cost, schedule etc.*

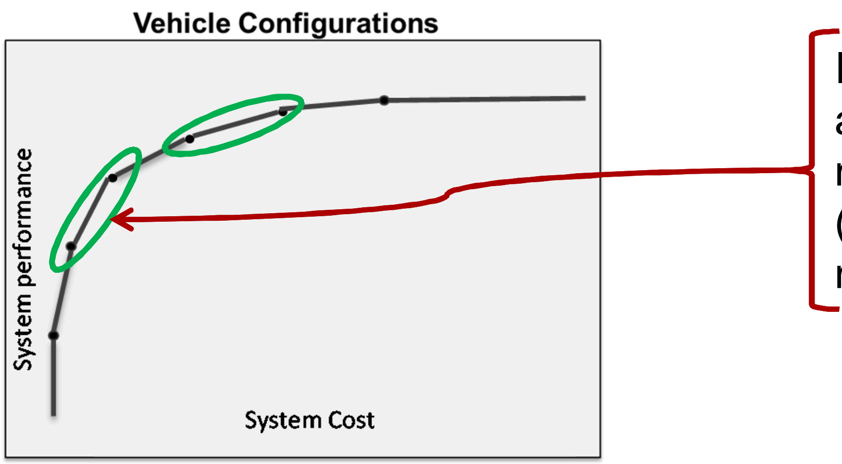
3. In software, generate candidate solutions that efficiently trade off within acceptable requirements trade space

4. Downselect to point solution (or family/platform) via interactive analytics

# Rapid Systems Engineering Vision

This process has screened the trade space, focusing technology selection choices and allowing engineering efforts to be focused on integration, test and evaluation.

Once the capability is developed, it is completely reusable for different operational needs (e.g, threats, environments).




If something about the operational need and/or requirements changes, it usually just requires a new downselect analysis (possibly after rerunning the software with revised inputs)

# Counter-IED Objectives

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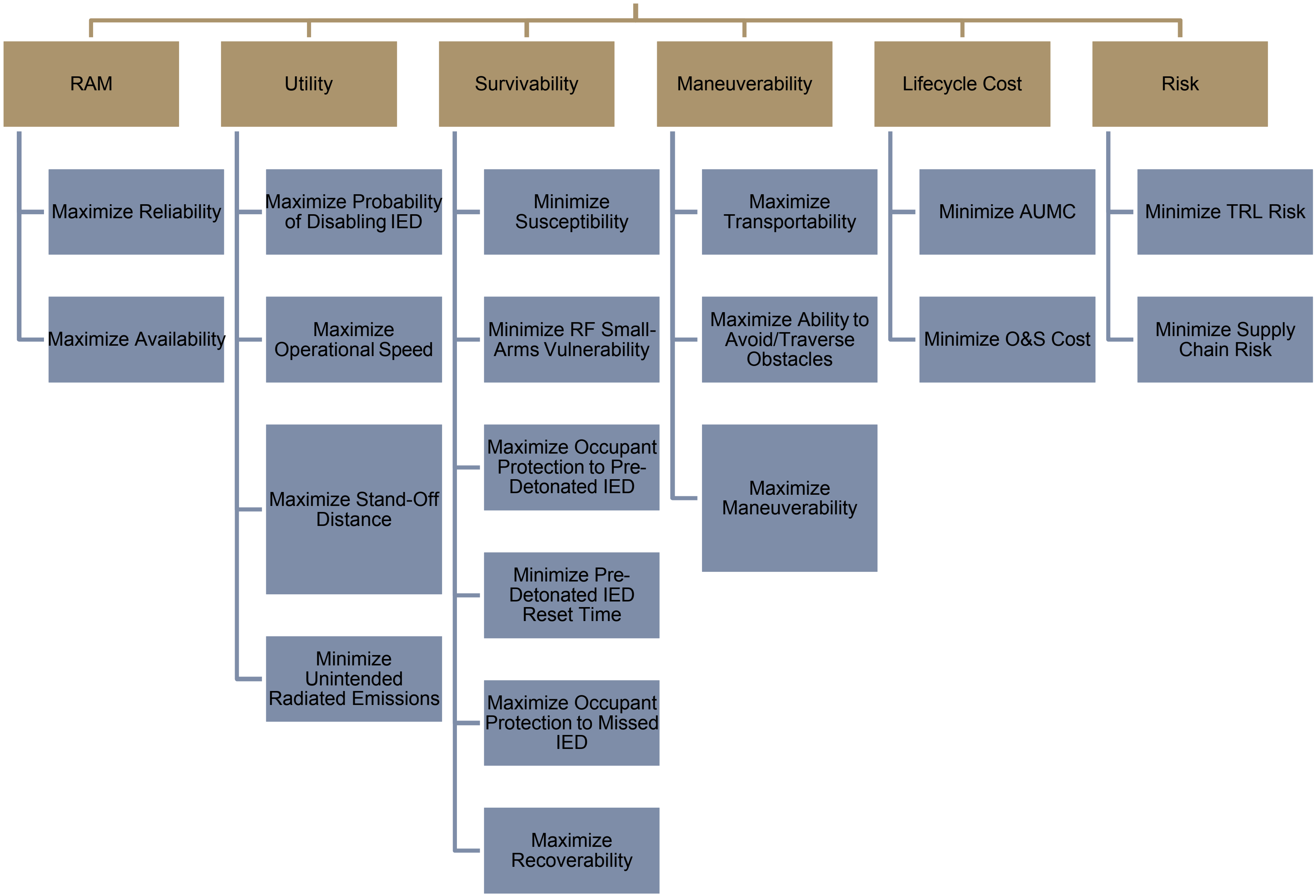
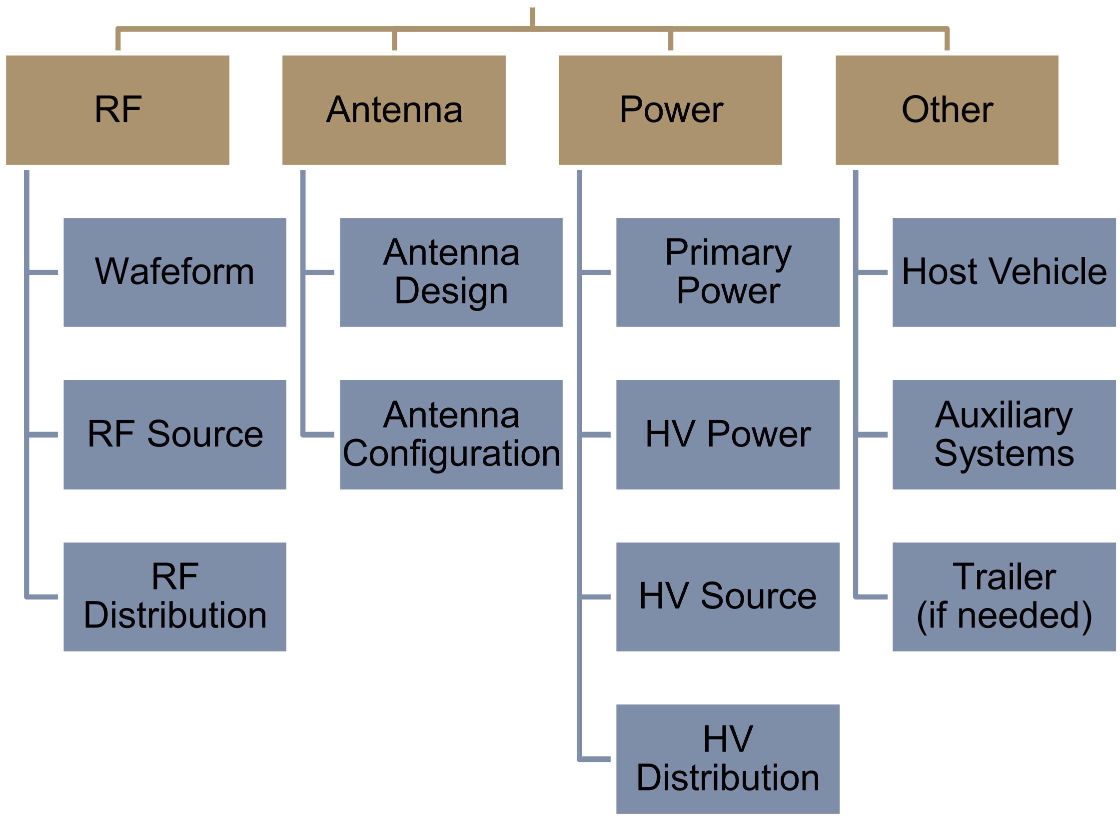
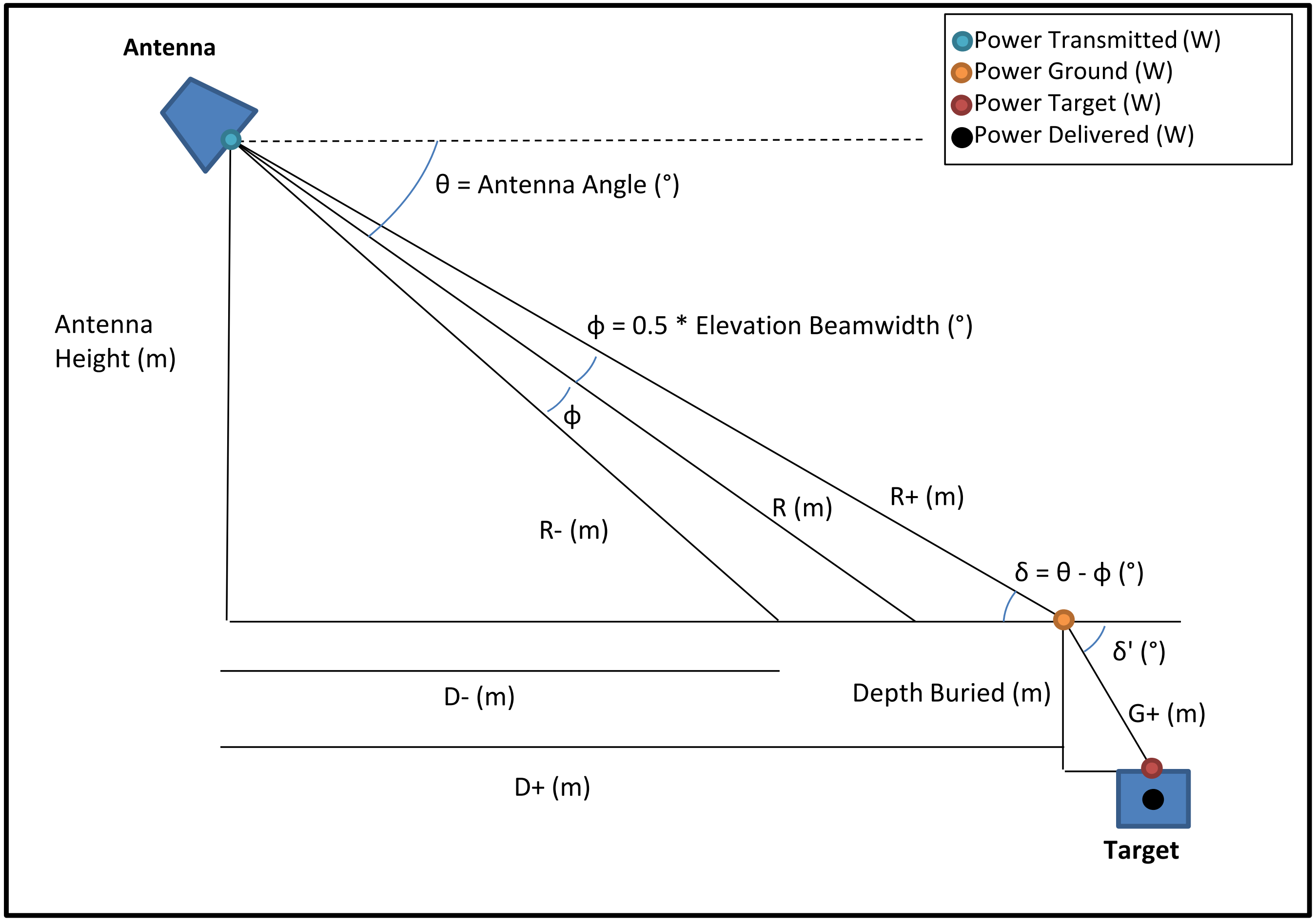


# Product Structure (so far)

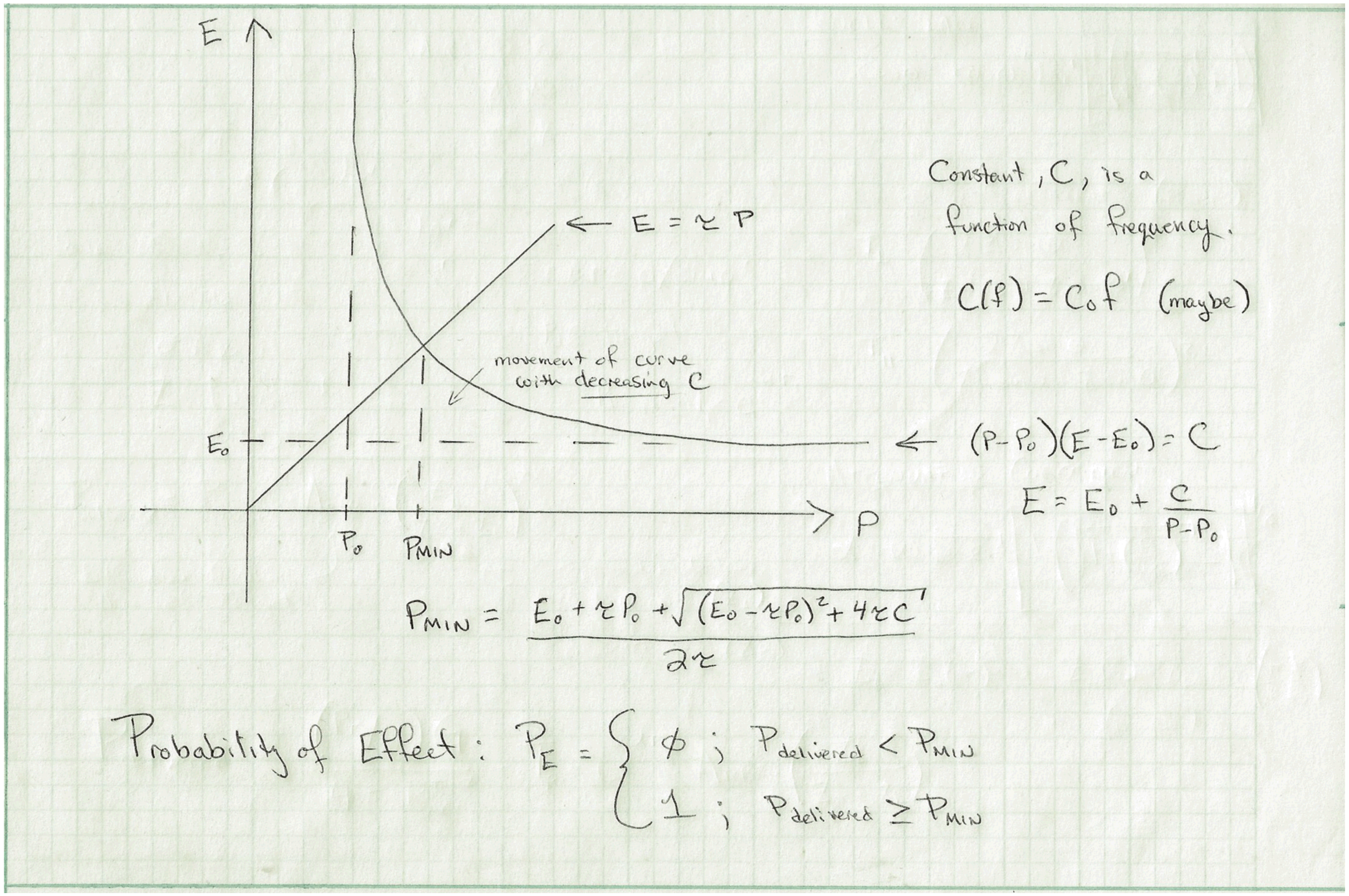


# Propagation Physics




Can calculate power/energy on target based on losses, pulse width etc.

# Min Power-Energy to Defeat




Can calculate whether power/energy on target sufficient to create effect

# Objectives – Example Definitions

**Standoff Distance**

- Maximize the distance between an IED and the system at which there is a 95% chance of defusing or pre-detonating an IED, assuming a minimum viable operational speed. Return zero if system does not meet at least 95% chance at any standoff distance.

**Recoverability**

- Maximize the number of towing methods/ platforms with which the system can be recovered upon incurring a system abort (SA) failure or an IED blast

# Objectives – Example Calculations

## Standoff Distance

- Use P-E curve and pulse width to determine minimum power to couple into mechanism
- Back-calculate required power at ground
- Back-calculate R+ given power from antenna
- Back-calculate Standoff distance given R+ and antenna angle

## Recoverability

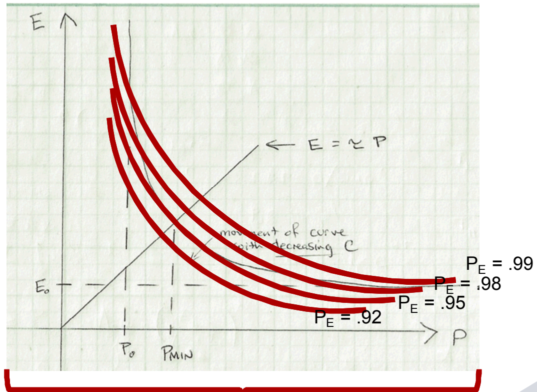
- For each towing/recovery method, compare system attributes to method attributes as follows:
  - tow score: if towing capacity > system weight, 1; else, 0.
  - recover score: if has winch, load capacity > system weight and bed width > system width, 1; else, 0.
- Total score is weighted sum of method scores
  - Weight of tow vs. recover depends on relative likelihood
  - Higher weight is given to methods likely to be closer to the system at time of failure (e.g., like vehicles in the same convoy)

# Unique aspects of this problem

- This capability is intended to support system development timeframes in months
  - WSTAT was originally designed for major acquisition programs with a development timescale of years
- It is also intended to enable quickly and easily “dialing in” a specific environment/threat (or class thereof) – even if new and unanticipated – and design a tailored solution
  - rather than optimizing on static, precalculated average performance against *anticipated* threats and environments as is typically done in WSTAT today

# Project Phases & Tasks






Multi-target, Multi-environment

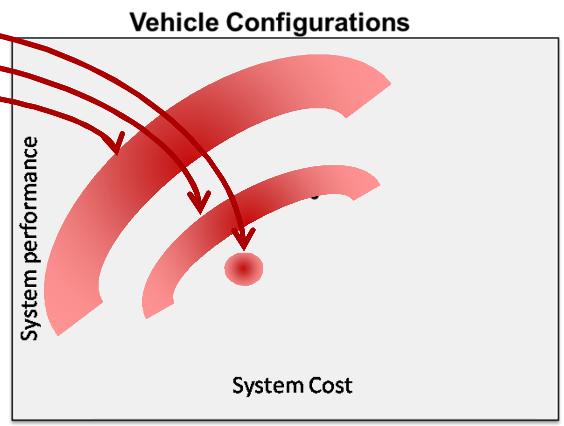
- Allows easy context-switching
- Allows tradeoff analysis between specificity and generality

Refine Objectives

- Especially Probability of Defeating IED

Analyses

- Evaluate existing design
- Suggest modifications
- Suggest new designs




Initial Phase

- Architecture/ decomposition ✓
- RF physics and objectives ✓
- Pre-antenna physics
- Mobility objectives (informed by Army PEO CS&CSS)