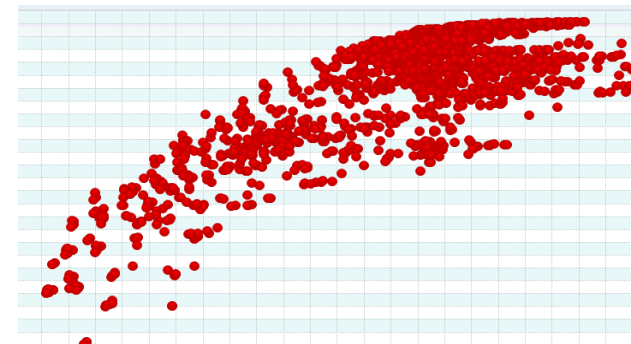


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Infrastructure Equipment Optimization for United States Military Contingency Base Designs

Alex Dessanti

INFORMS Annual Meeting

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Booz | Allen | Hamilton

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Overview

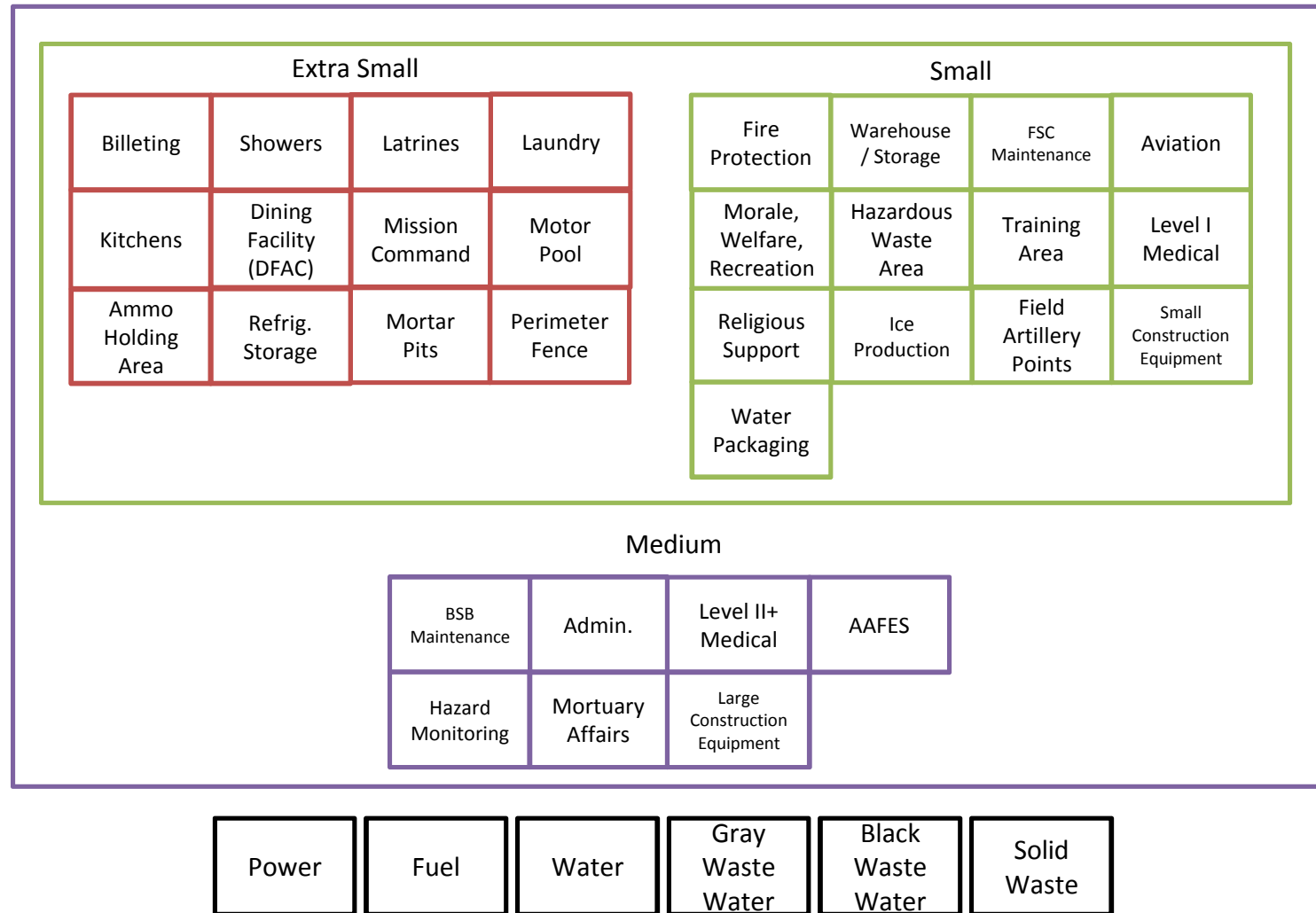
- What is a Contingency Base?
- CBI Analytic Problem Statement
- What is WSTAT?
- Methodology
- How does WSTAT work?
- WSTAT Applications
- CBI WSTAT Intended Uses
- CBI Application Challenges
- Accomplishments/Impact
- Questions

What is a Contingency Base?

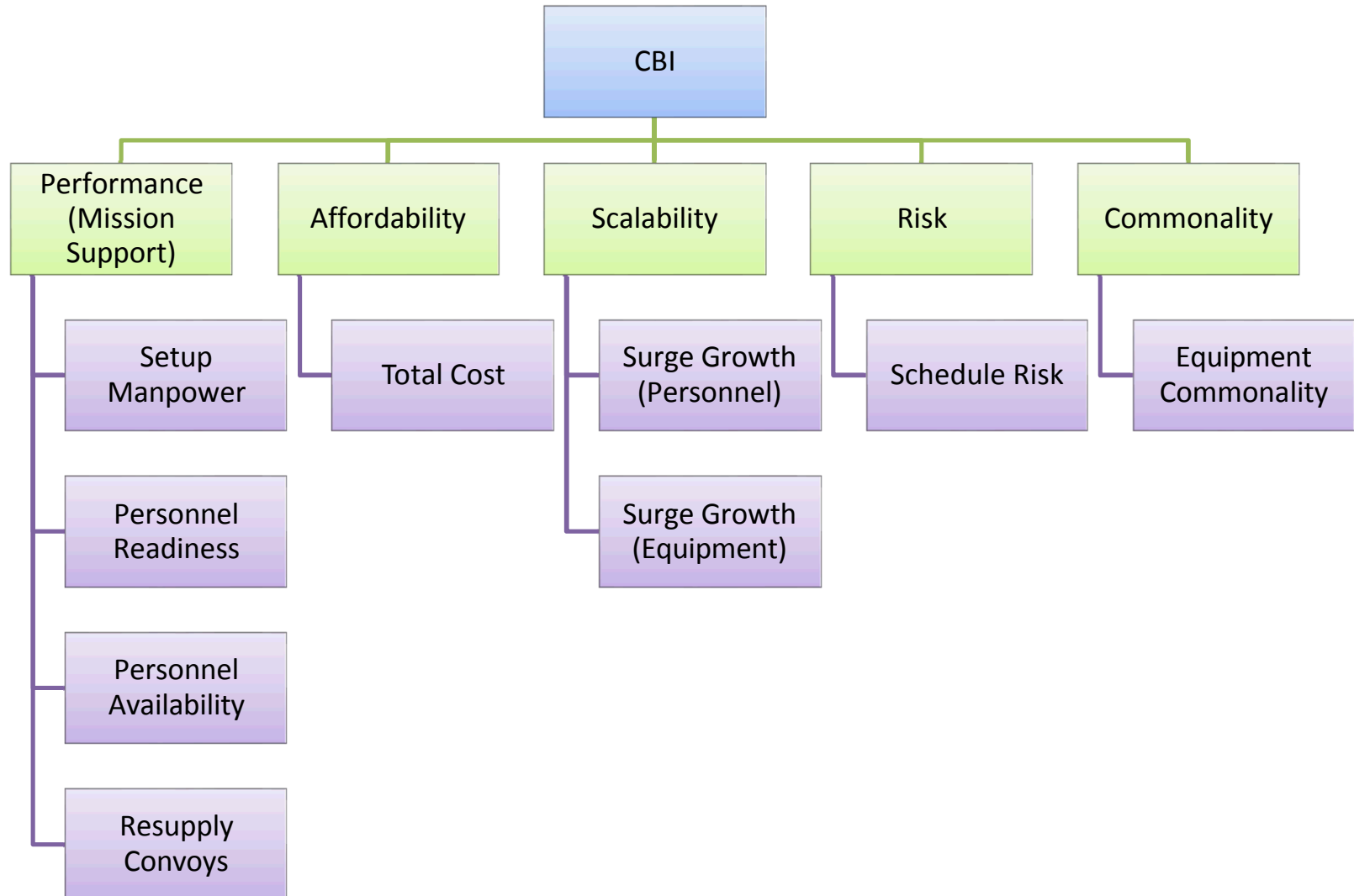
- Military base setup overseas for deployed forces to operate from
- Essentially a small town with various facilities (housing, dining, etc.) and infrastructure (power, water, etc.)
- Temporary in nature, not meant to be in use for more than 5 years
- Multiple camp sizes defined as population ranges
 - XS = 50 to 299 people
 - S = 300 to 1999 people
 - M = 2000 to 5999 people
- Currently assume an Army Infantry Brigade Combat Team is deployed in a cluster of bases
 - 12 XS
 - 5 S
 - 1 M
- For analysis purposes, assume all XS and S are identical to simplify problem
- Larger bases can provide support for select functions not on smaller bases (water bottling, ice production, etc.)



Contingency Base Functions



Criteria for Evaluating Contingency Bases



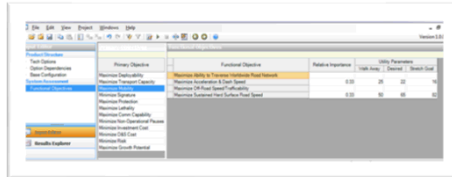
CBI Analytic Problem Statement

- When this effort began in 2013, the Army did not have an analytic capability to evaluate base camp designs
- Goal
 - Establish a method for determining the optimal set of base camp infrastructure equipment for any given scenario
- Objectives
 - Minimize cost, schedule risk, and logistic burdens
 - Maximize commonality and scalability

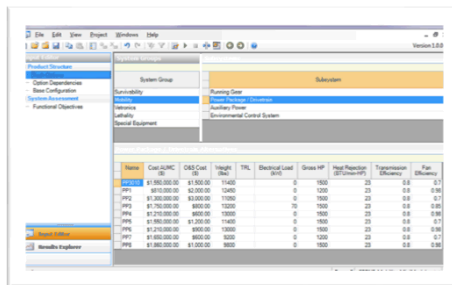
Existing Whole System Trades Analysis Tool (WSTAT)
approach was selected to address the need

What is WSTAT and Why Is It Needed?

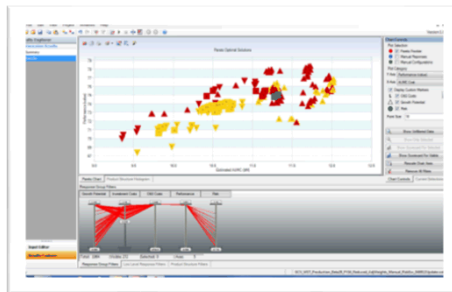
Input
Stakeholder
Objectives



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

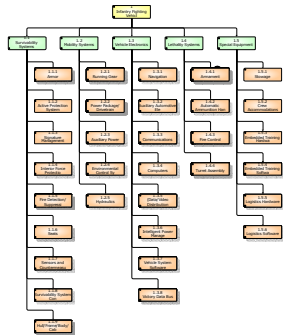
- Decision support tool developed at Sandia National Labs
- Integrates otherwise separate subsystem models into a holistic system view
- Maps critical design choices to consequences relevant to stakeholders

Why

- Contingency Bases are complex systems with many interrelated subsystems (can be greater than 10^{150} potential combinations of equipment)
- Finding the sweet-spot among competing objectives is a non-trivial task
- Multiple value dimensions
 - Performance (manpower, QoL, convoy demands)
 - Affordability (resource usage, procurement cost)
 - Risk (immaturity of technologies)
 - Scalability (equipment and personnel surge)
 - Commonality (common technologies)

WSTAT Methodology

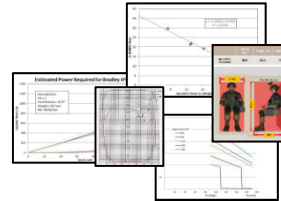
Establish Product Structure (LSA)



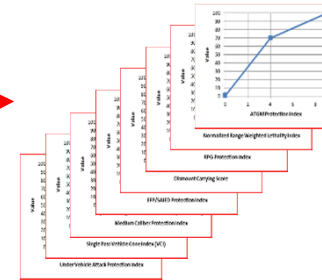
Identify Technology Options (Systems Database)



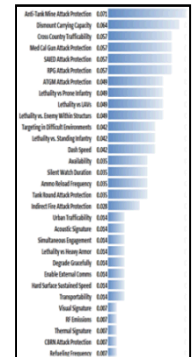
Define FO Calculations based on Tech Option Decisions



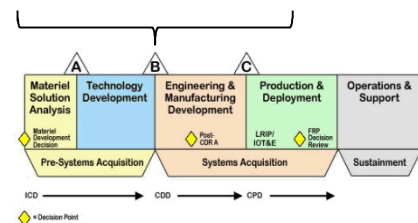
Craft Value Functions



Determine Priority Weightings



Understand Needs/Requirements



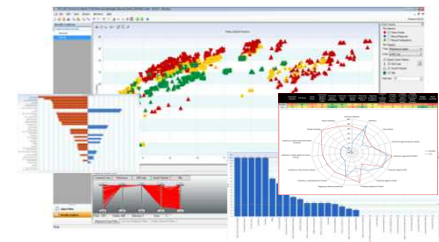
Develop Functional Objectives



Multi-Objective Optimization

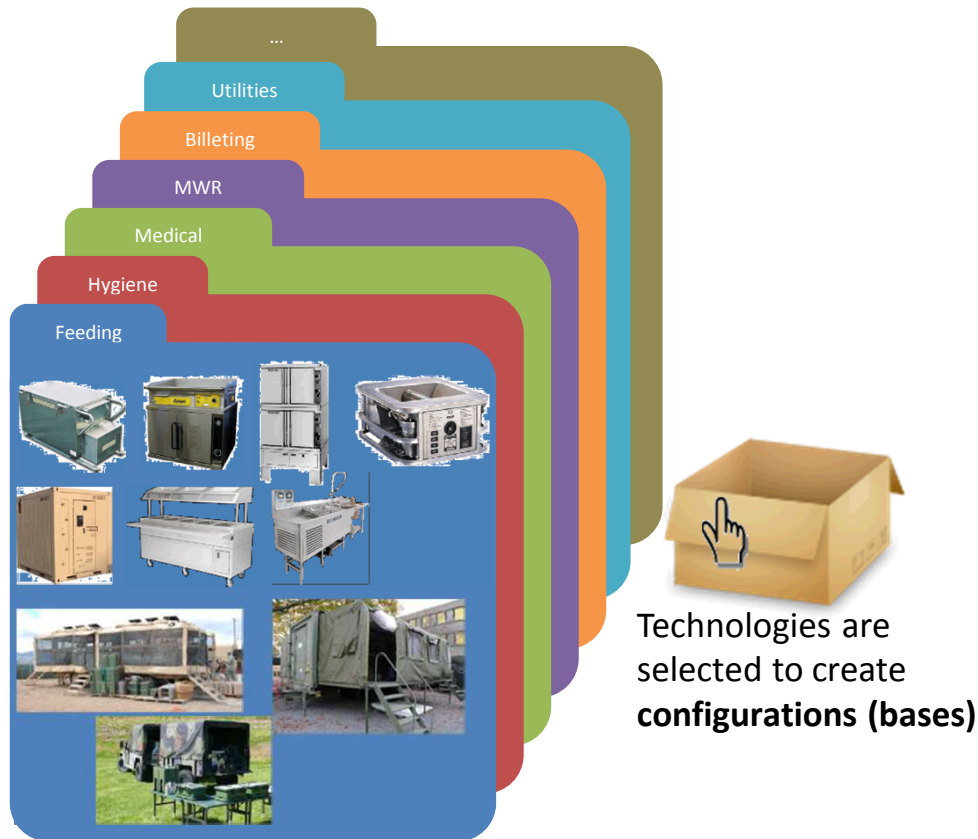


Generate Results & Conduct Analysis

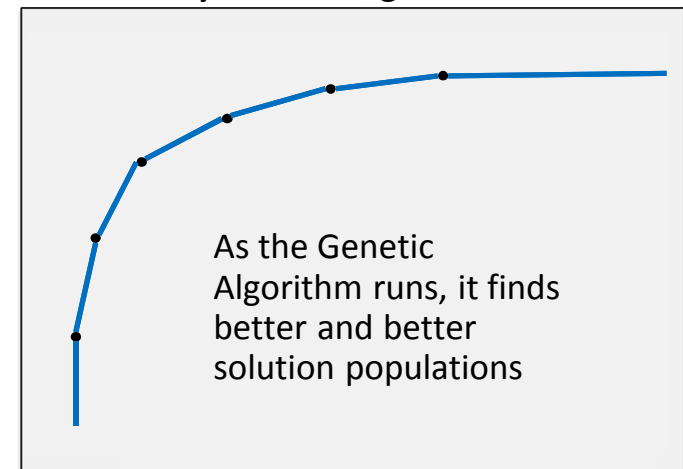


How WSTAT Works – Single Base

Collection of Available Technology Options



System Configurations



Configurations scored in **5 value dimensions**:

- Performance (manpower, QoL, convoy demands)
- Affordability (resource usage, procurement cost)
- Risk (immaturity of technologies)
- Scalability (equipment & personnel surge)
- Commonality (common technologies)

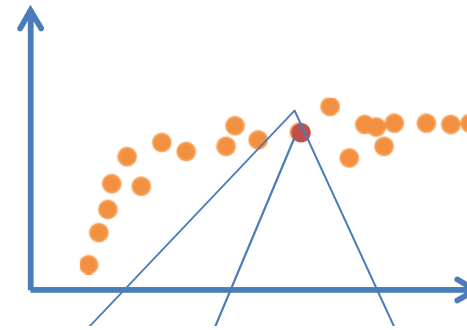
WSTAT combines compatible technology options into a **system configuration**, using a multi-objective genetic algorithm to efficiently explore millions of different configurations and identify those that best balance competing objectives

How WSTAT Works - Cluster

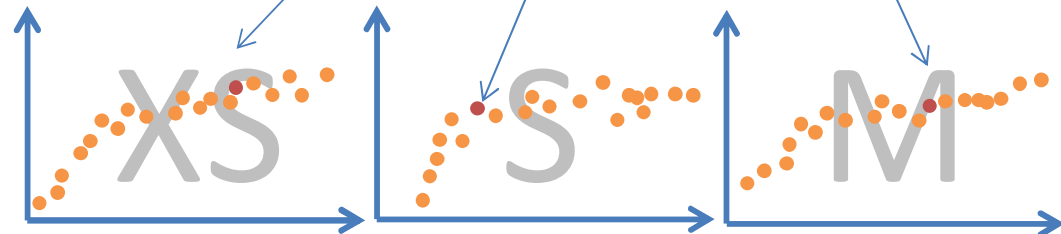
Collection of Available Technology Options



Similarly, configurations for various base sizes can be shown as a point in 5-dimensional value space representing a set of bases for a cluster configuration



Resulting optimal set can be filtered to view trends for each base size or the 3 base sizes are aggregated for the optimization

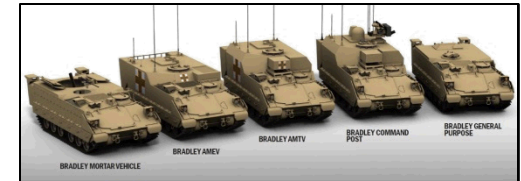


*With available system options, $\sim 10^{150}$ possible base camp cluster configurations

Cluster configuration solution set identifies best decisions at cluster level, making compromises across base sizes, and can be used to determine the effect of commonality on performance and affordability

WSTAT Applications

- WSTAT methodology has been successfully applied to design of a single platform...
 - Ground Combat Vehicle
 - Bradley Fighting Vehicle
 - Paladin Integrated Management
 - Future Fighting Vehicle
 - Main Battle Tank
 - Maneuver Support Vessel - Light
 - Squad Multi-Purpose Equipment Transport
- WSTAT also successfully applied to optimizing...
 - Family of platforms (Armored Multi-Purpose Vehicle, Robotic Systems)
 - Considers commonality across mission roles
 - **Cluster of contingency base camps**
 - Considers commonality within a single base and across multiple different size bases
- WSTAT can be applied to **any system** that can be **evaluated based on selection of its component parts** (technology options)
 - Usually many discrete choices for each part, yielding a combinatorial search space

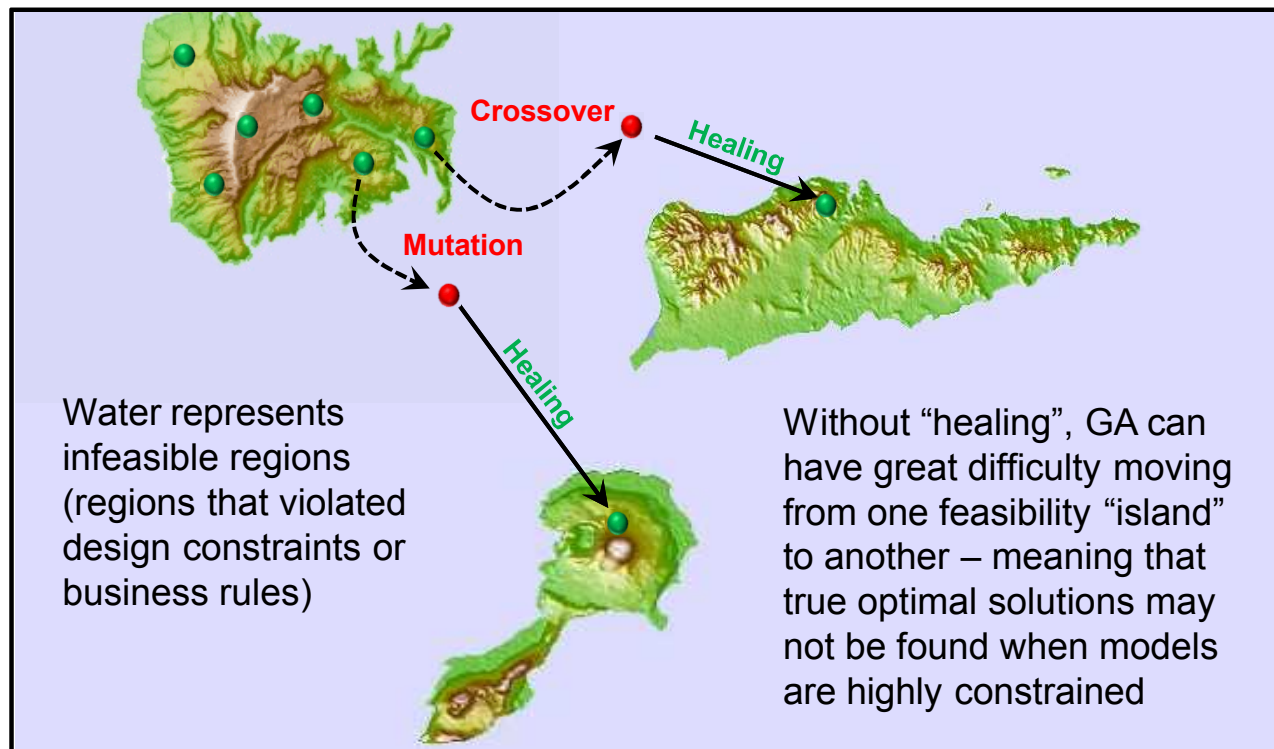


CBI WSTAT Intended Uses

- Support definition of Core and Expansion system sets
 - Core equipment sets defined for a specific population
 - Expansion equipment sets enable a modular approach to support additional personnel
- Support annual investment decisions by recommending optimized equipment sets
- Help identify systems to improve base camp efficiency while reducing cost
- Answer questions regarding technology insertion for base camps
- Integral part of the Contingency Base Interface to the Warfighter (CBIWar)
 - CBIWar will provide base camp commanders/planners with a hands-on design/layout capability
 - Optimal camp designs from WSTAT will serve as a starting point that can be tailored for a specific application

Challenges Addressed for CBI Application

- Large Problem Space
 - >300 Decision Variables with $>10^{150}$ possible combinations
 - Typical WSTAT is <50 Decision Variables with $<10^{30}$ possible combinations
- Many Technology Compatibility Constraints
 - For example, rigid structures require window mounted ECUs while tents require ducted ECUs
 - In conjunction with large problem size, drove change from 32-bit to 64-bit application
 - Also necessitated incorporation of a healing algorithm



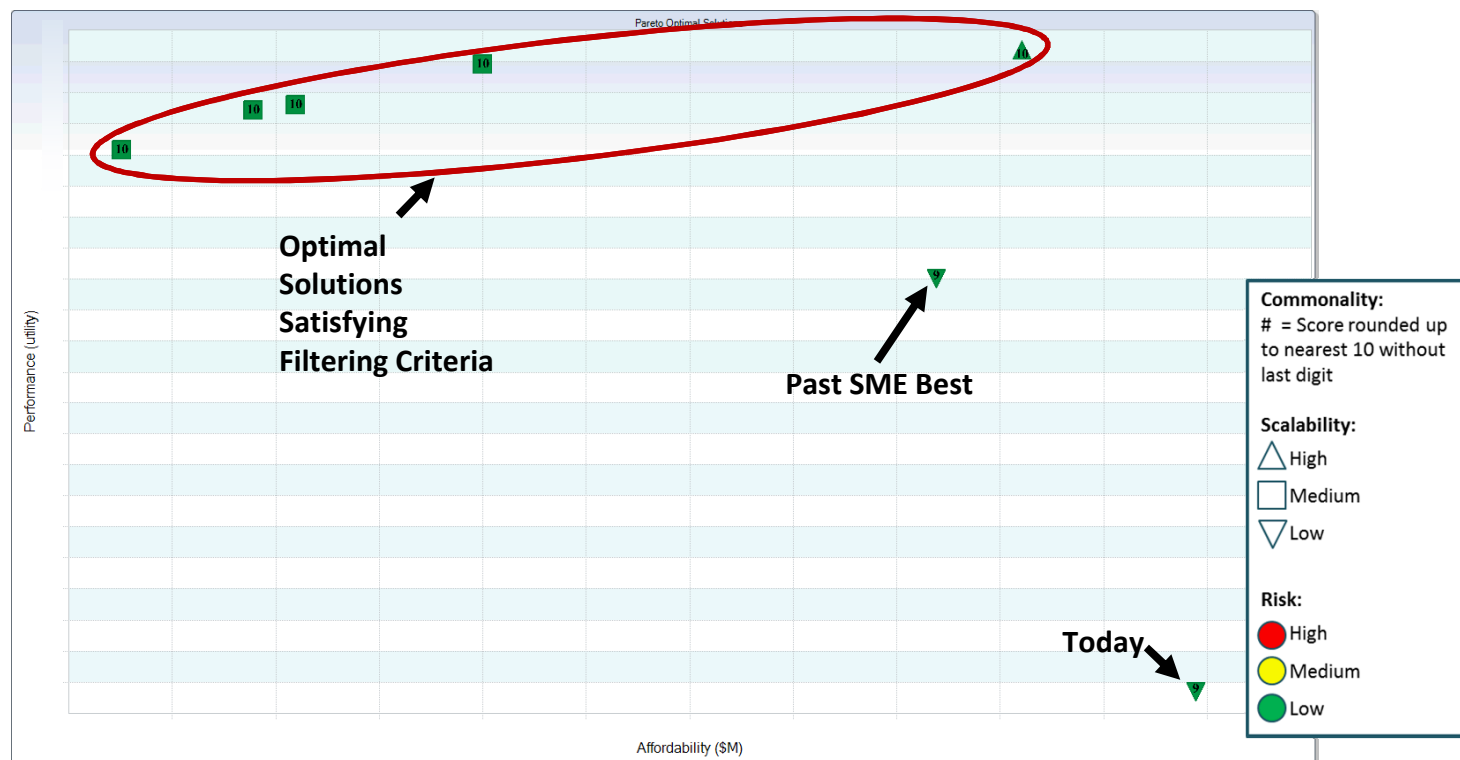
Optimization Goal:
find the highest “peak”

Challenges Addressed for CBI Application

- Large User Community and Little Standardization Until Recently
 - Common saying “if you’ve seen one contingency base, you’ve seen one contingency base”
 - Because of this, most people have a different frame of reference for how things should be
 - Many differing opinions make it challenging to get firm modeling rules
- Concept of Quantities
 - Planning Factors specify space requirements for various functions (billeting, dining, etc.)
 - Example: structure options are different sizes, so different quantities needed to meet space requirements
 - Not enough to just say one configuration utilizes structure A and another utilizes structure B
 - Quantity impacts tradeoffs
 - Required architectural changes to incorporate concept
 - Significantly more calculations to implement/verify than a typical WSTAT
- Architecture Flexibility
 - Need to optimize a single base in isolation or a cluster of bases working together
 - Requires modeling rules to work in either mode
 - Input and output structures need to stay adaptable to either mode
- Result Visualization
 - Very different domain than past WSTATs (base vs. platform), necessitating new result views
 - Accommodate quantities, resource consumption, common product structure elements

Accomplishments/Impact

- PdD CBI vision is to be lead agency for base camp analysis across DoD and WSTAT is a key analytic capability to support that vision (CBI WSTAT capability first operational in 2015)
- WSTAT is a high visibility capability, briefed to senior Army and OSD leadership
- CBI WSTAT Analysis Team selected as winners of 2015 Army Modeling & Simulation Award
 - Theme was “best applications of Army models and simulations in an era of fiscal austerity and rapid innovation”
- Early optimization results have identified potential cost savings while increasing performance, scalability, and commonality



QUESTIONS

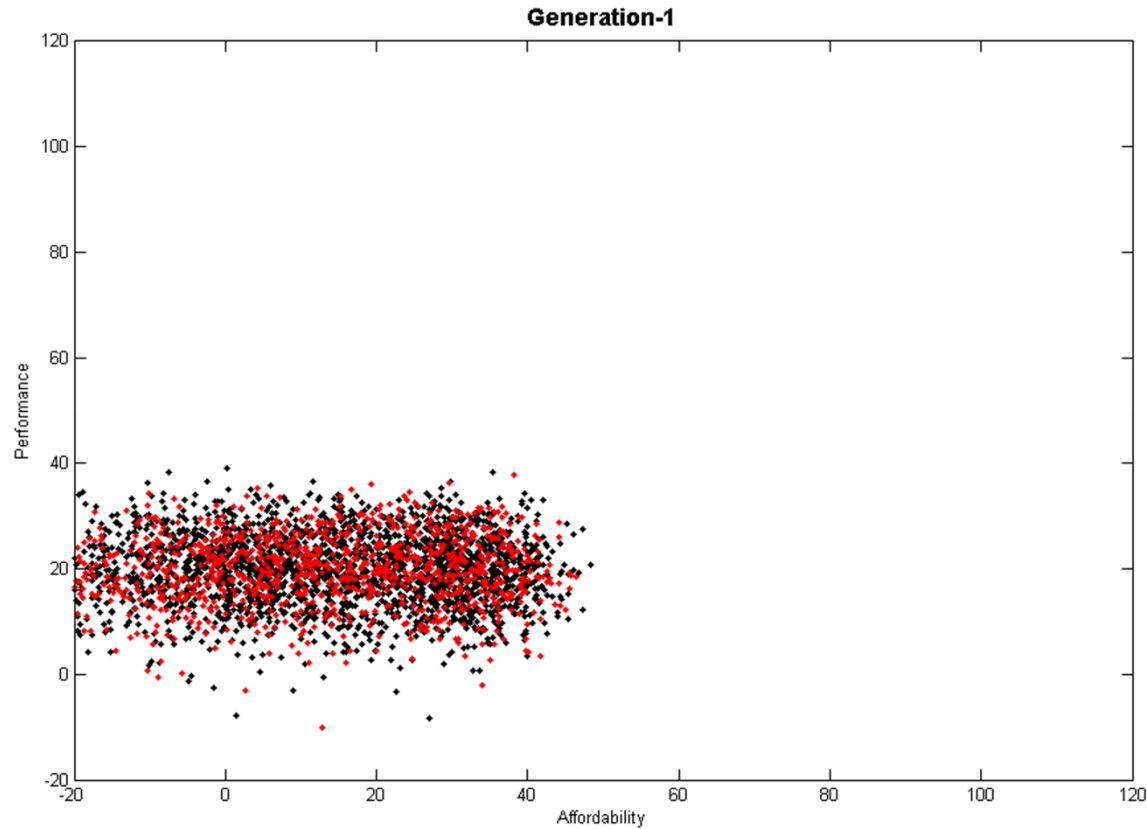
BACKUP

Commonality

- WSTAT has the ability to assess commonality across a family of systems
- What do we mean by commonality?
 - When considering multiple base camps in a family, commonality simply refers to using the same parts
 - For example, using the same structure, ECU, or generator for multiple purposes on a base and across a cluster of bases
- Why is commonality useful?
 - Fewer spare parts are needed (both in types and in number)
 - Repairs, training, and operations are more consistent
 - Economies of scale
- Tension between commonality and specialization
 - Seeking the absolute best performance for a base, often leads to solutions that are highly specific to that base's needs
 - Commonality is at odds with this tendency and WSTAT allows the decision maker to explore these tradeoffs

Evolution Example

5D Cluster Model
2D Cluster Test



Population converges within ~200 generations (half a day) and achieves similar results to 2D test