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Balancing Survivability in Fleet Modernization Optimization

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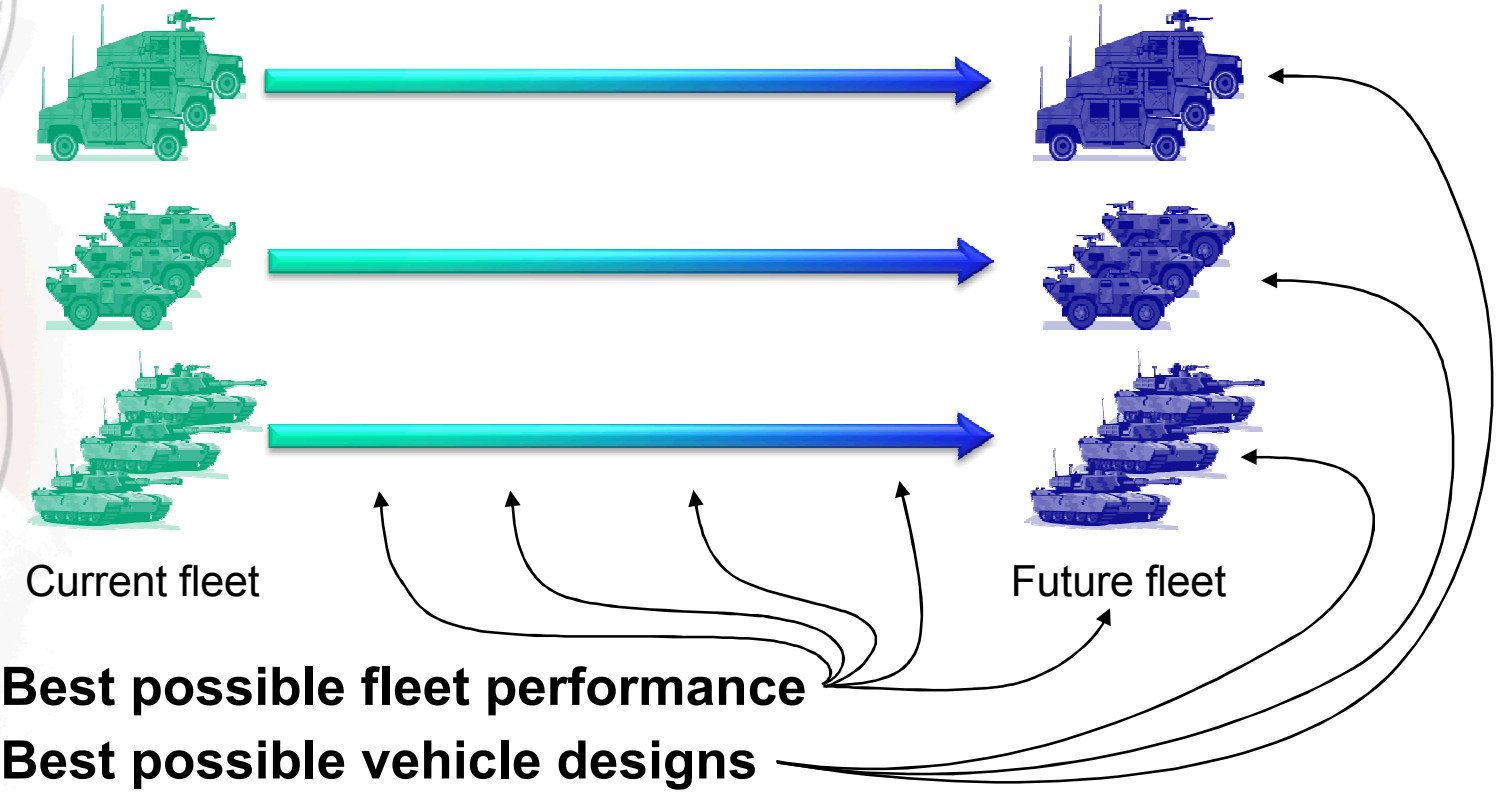
Outline

Work Sponsor: Program Executive Office Ground Combat Systems
Project Lead: Shatiel Edwards
Project Partners: Sandia National Labs, Booz Allen Hamilton,
Army Materiel Systems Analysis Activity (AMSAA),
Tank Automotive Research, Development and Engineering Center (TARDEC), and others

- **Give an overview of the analysis framework used to inform acquisitions and modernization decisions for the Army's ground combat fleet**
- **Examine the tools and capabilities of this framework**
- **Demonstrate the important role of survivability in this decision process**

Fleet Modernization Problem

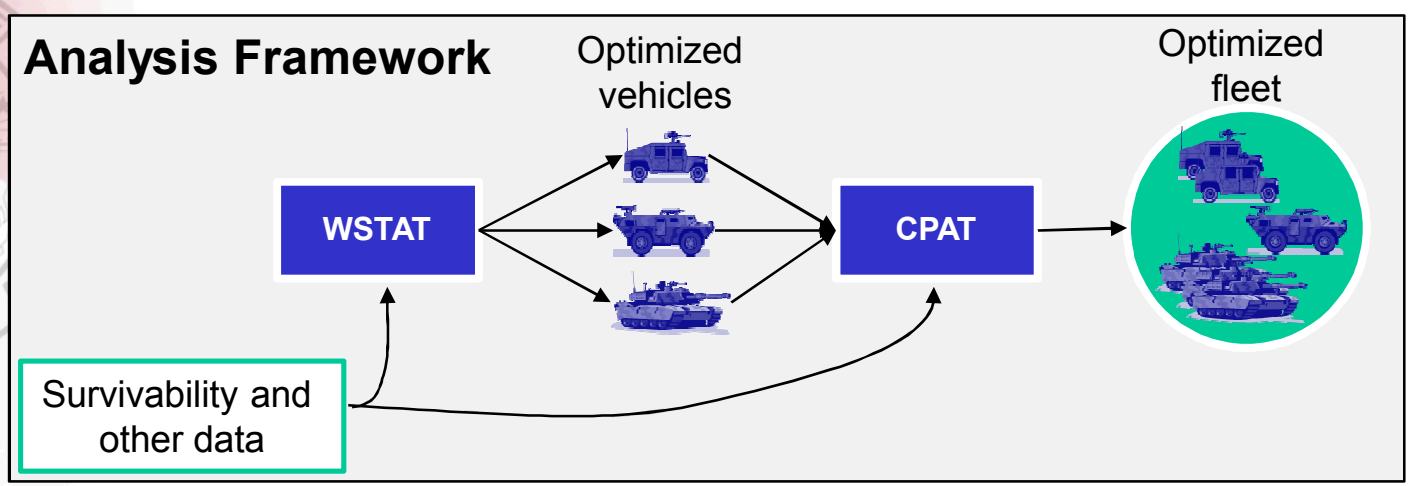
- **Basic Problem:**
  - **Modernize a fleet of disparate vehicles to achieve the best possible fleet**



  - **Best possible fleet performance**
  - **Best possible vehicle designs**

Two Stage Analysis

- **The need for both an optimized fleet and optimized vehicles within that fleet suggest a two-stage analysis framework**
  - **One stage will optimize the individual vehicles**
  - **The other will optimize the mix of vehicles within the fleet**



Role of Survivability

- **What role does survivability play in these two stages of fleet modernization?**
  - The performance metric of vehicles in the fleet is heavily influenced by the ability of the vehicles to survive different threats including:
    - Small arms
    - RPGs
    - Tank-fired rounds
    - Mortar shells
    - Mines and IEDs
    - CBRN
  - Survivability is a major driver of vehicle (and thus fleet) performance
- **However, survivability cannot be considered in a vacuum**

Survivability vs …

- **For any particular vehicle, survivability is crucial**
  - It's multifaceted, measures against many threat types
- **But it is also in competition with other factors including:**
  - Mobility
  - Lethality
  - Upgradability
  - Etc

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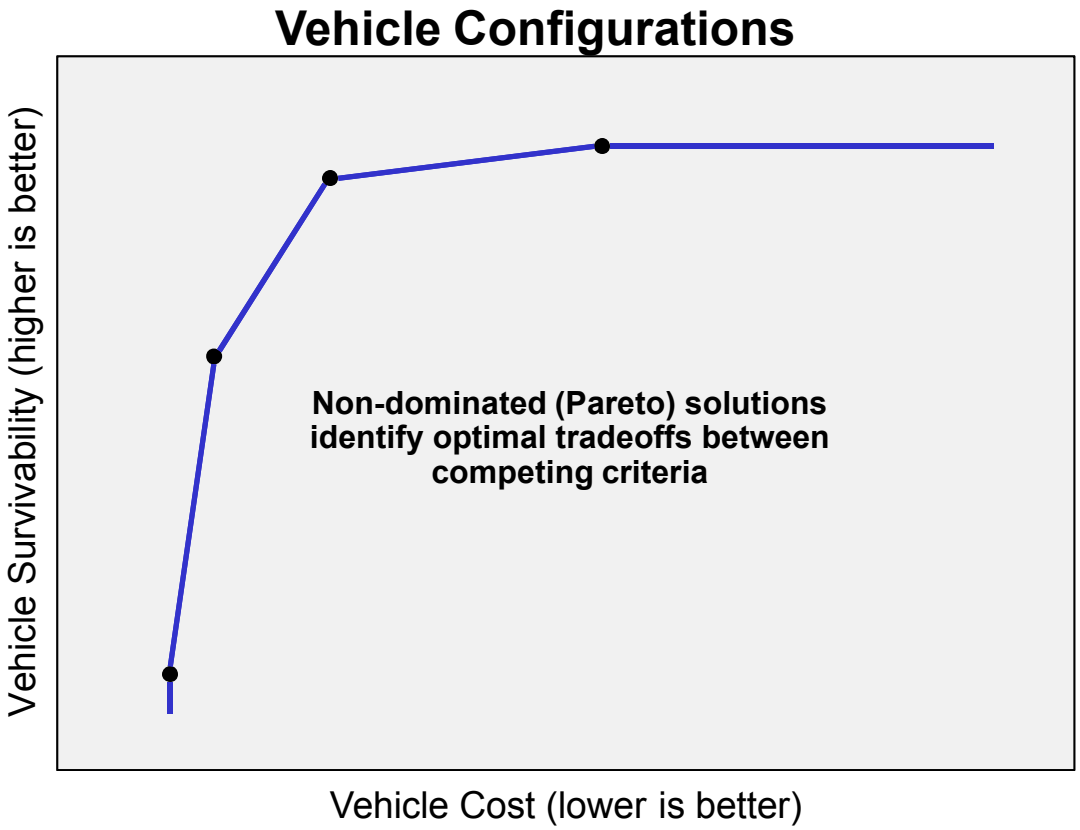
Optimally Balancing Survivability

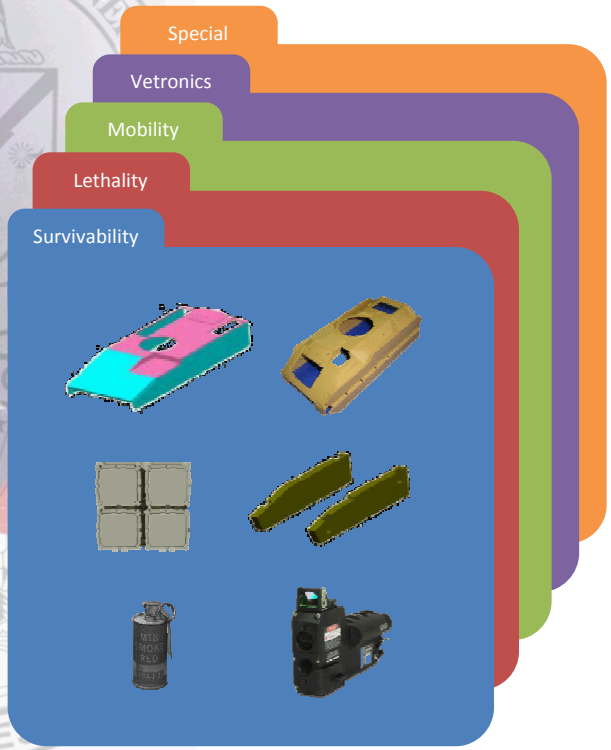
- **For a single vehicle, how do we rigorously balance survivability with these other competing factors?**
  - Multi-objective optimization mathematically weeds out “unbalanced” solutions
  - Consider only 2 criteria, cost and survivability
  - Same idea applies when balancing more criteria, except that higher-dimensional spaces are required



WSTAT Overview

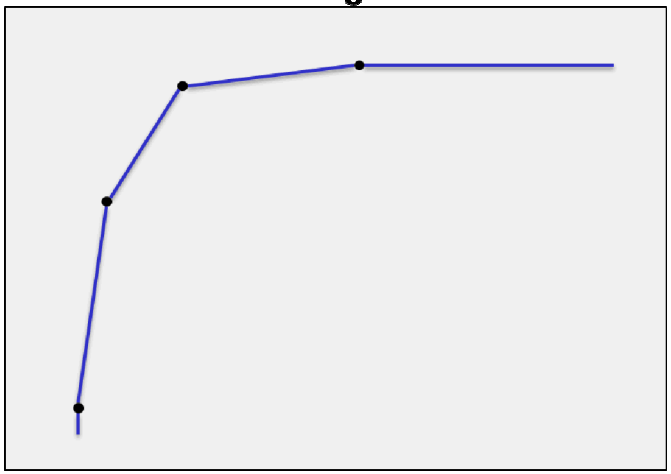
Whole Systems Trade Analysis Tool

Collection of Available Technology Options



Technologies are selected to create configurations

Vehicle Configurations



Configurations are scored in 5 value dimensions:

- Performance
- Procurement Cost
- O&S Cost
- Risk (immaturity of technologies)
- Growth (future modification potential)

Survivability options affect each of these 5

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WSTAT Tool

- WSTAT uses genetic algorithms to search for the configurations that optimally balance the 5 dimensions of performance, procurement cost, O&S cost, risk, and growth
- Typically finds thousands of these Pareto solutions
- This is the trade-space that decision makers can use to decide what configuration will actually be built
- How do you visualize a trade-space in 5-D with thousands of solutions?

WSTAT Tool

Legend

Development Risk

- High Risk
- Moderate Risk
- Low Risk

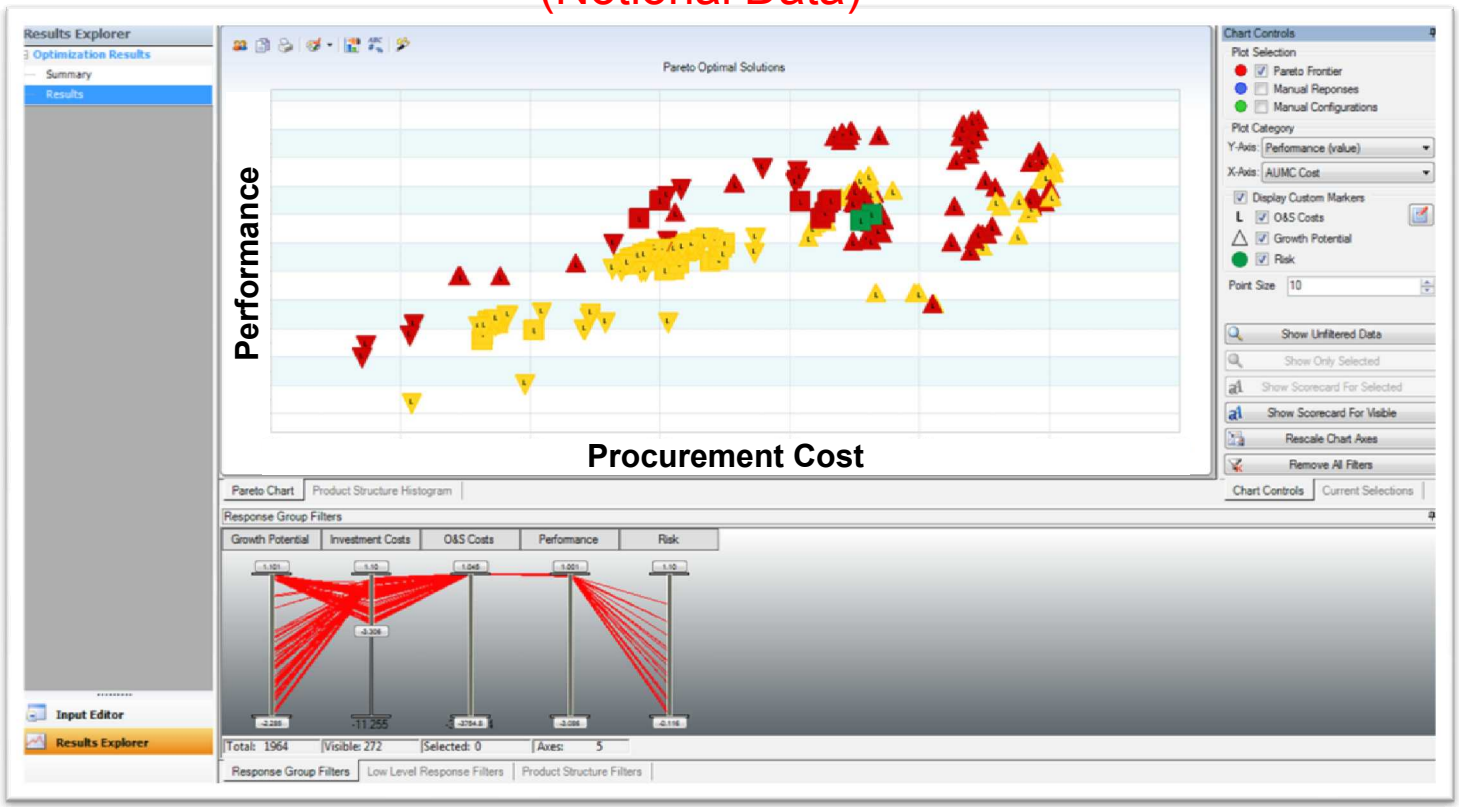
Growth Potential

- high growth potential
- moderate growth potential
- low growth potential

O&S Costs

- (H) High O&S Costs
- (M) Moderate O&S Costs
- (L) Low O&S Costs

(Notional Data)



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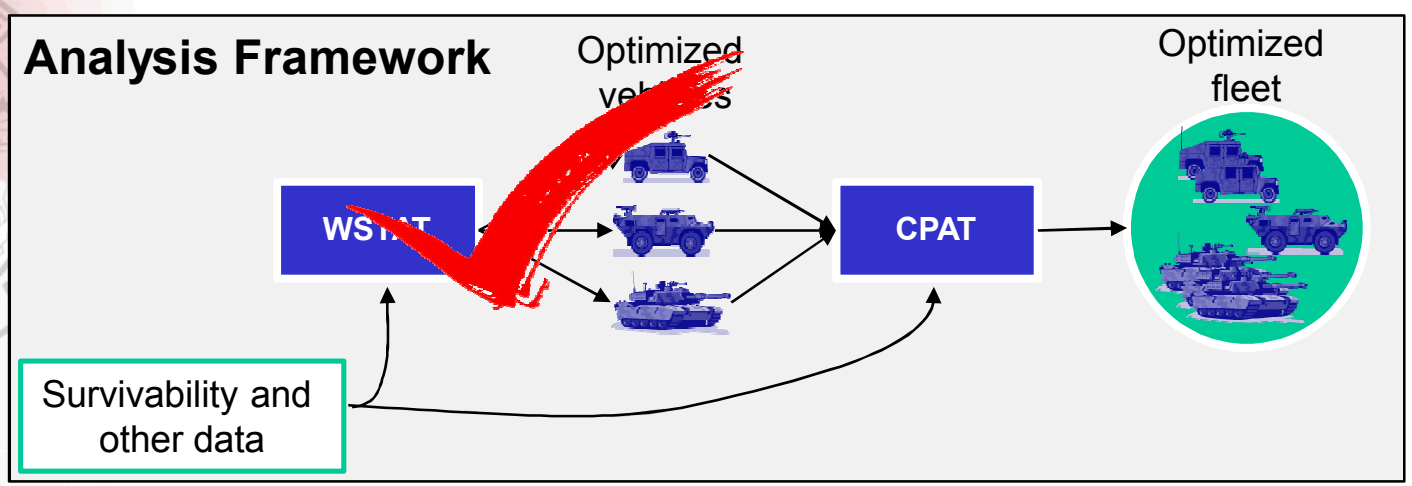
Two Stage Analysis

- **The need for both an optimized fleet and optimized vehicles within that fleet suggest a two-stage analysis framework**
  - **One stage will optimize the vehicles**
    - **Multiple Pareto optimal variants may be selected**
    - **This enriches the fleet modernization choices**
  - **The other will optimize the mix of vehicles within the fleet**



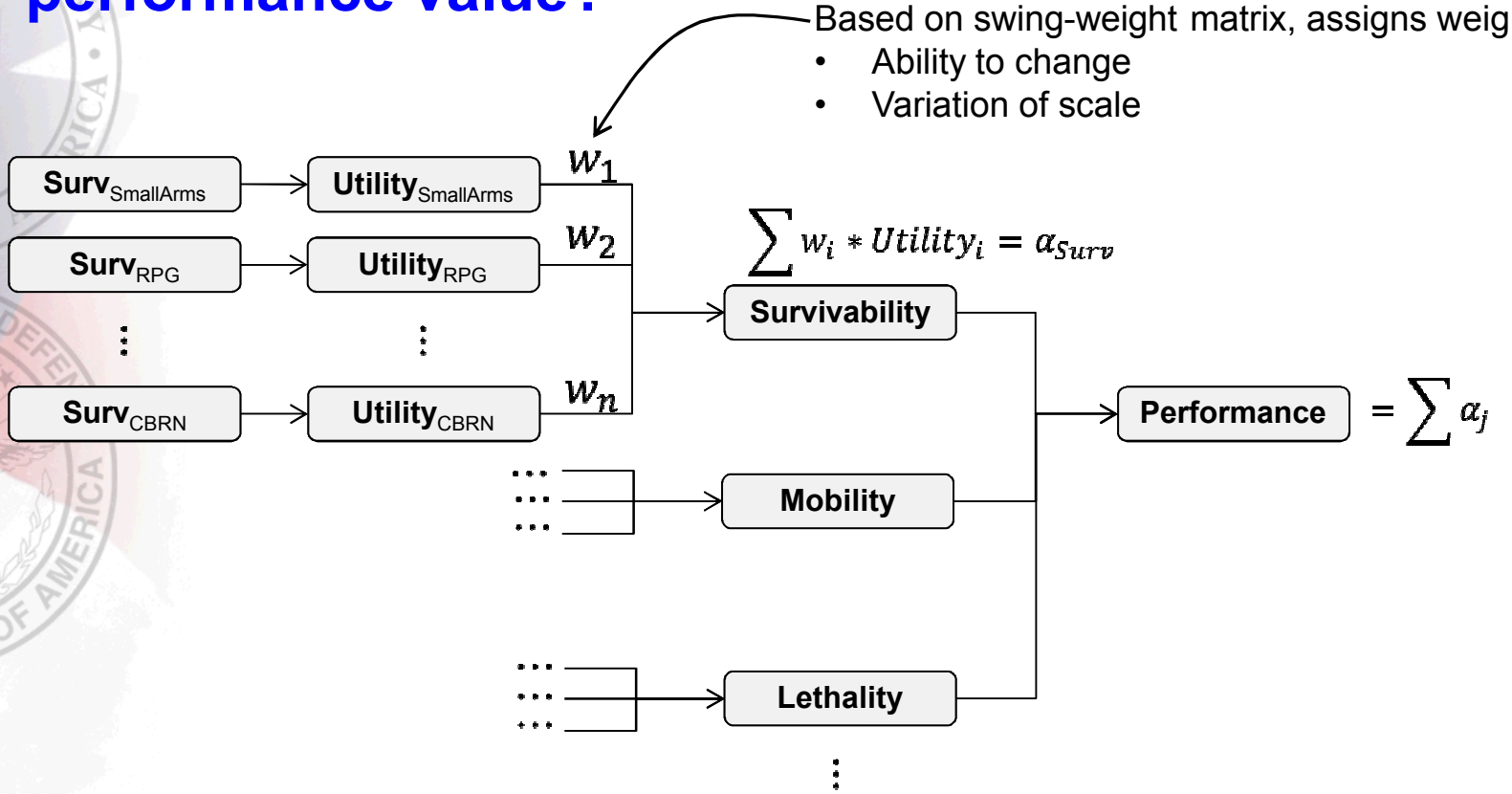
CPAT Introduction

Capability Portfolio Analysis Tool

- Now that the configuration of individual vehicles can be optimized, we next focus on optimizing the mixture of these vehicles within the fleet
- We use mixed-integer linear programming (MILP) under a single objective to perform this optimization
  - A mix of discrete and continuous decision variables (very challenging)
  - Maximize the sum of the performance of all vehicles in the fleet over the study horizon
- How does survivability factor into this single objective function?

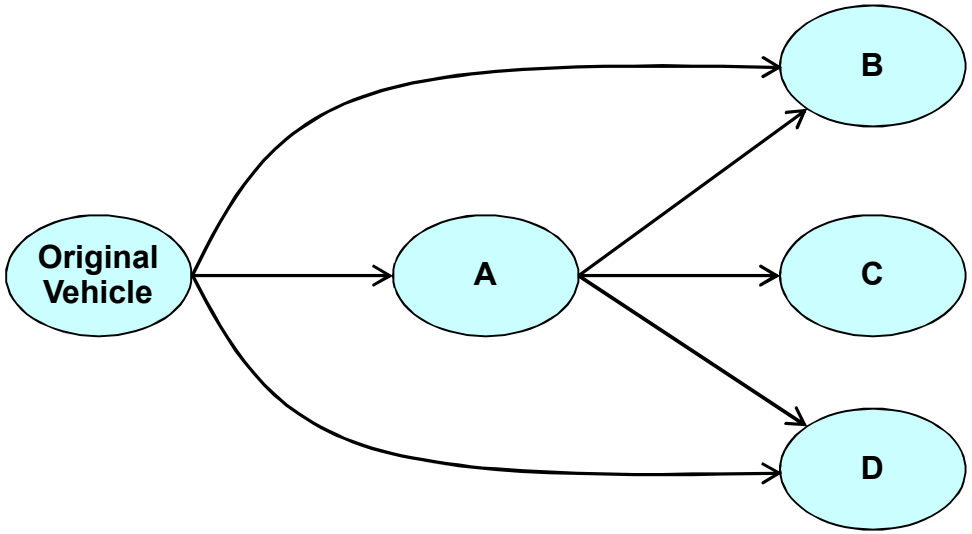
Fleet: Balancing Survivability

- **How are the various attributes of survivability rolled up (with other metrics) into a single performance value?**



Modernization via Transitions

- **Vehicles are modernized via the notion of transitions**
  - **These transitions define which vehicles can be "turned into" which other vehicles**

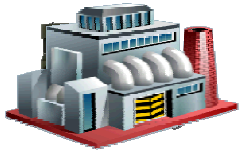


  - **Each transition has an associated cost, delay, capacity, and type**

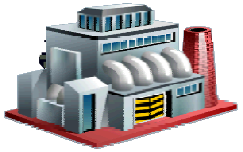
Modernization via Transitions

- **Transitions can happen in a number of ways, each representing a different means of acquisition**

Upgrade:



Purchase:



Storage

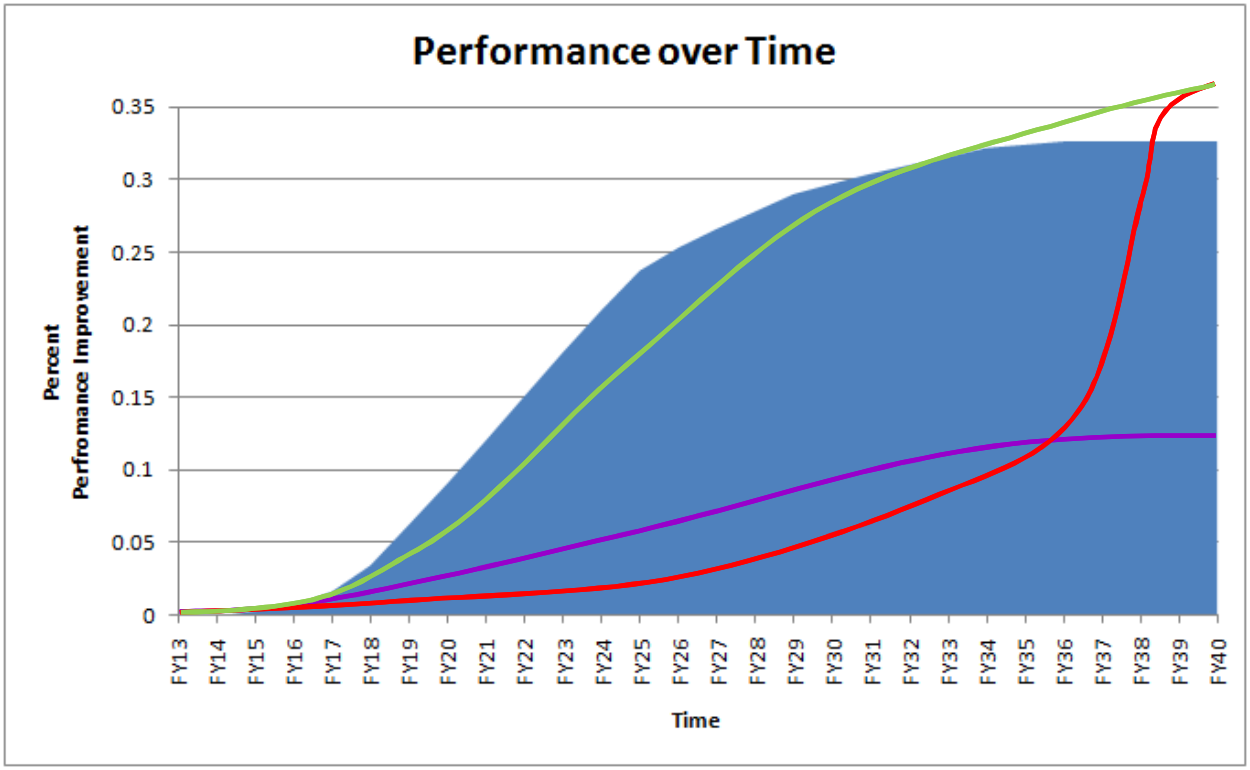
Storage Swap:

- **This provides a very rich set of modernization possibilities**

Modernization Optimization

- **What do we actually want to optimize?**
  - **We maximize the area under the performance curve. This gives the "overall" best performance through time.**
  - **There are other possible objectives that have been considered, but are not currently used**

- Given 100% modernization, minimize procurement cost
- Maximize the performance of the final fleet
- Given maximum performance of final fleet, maximize overall fleet performance



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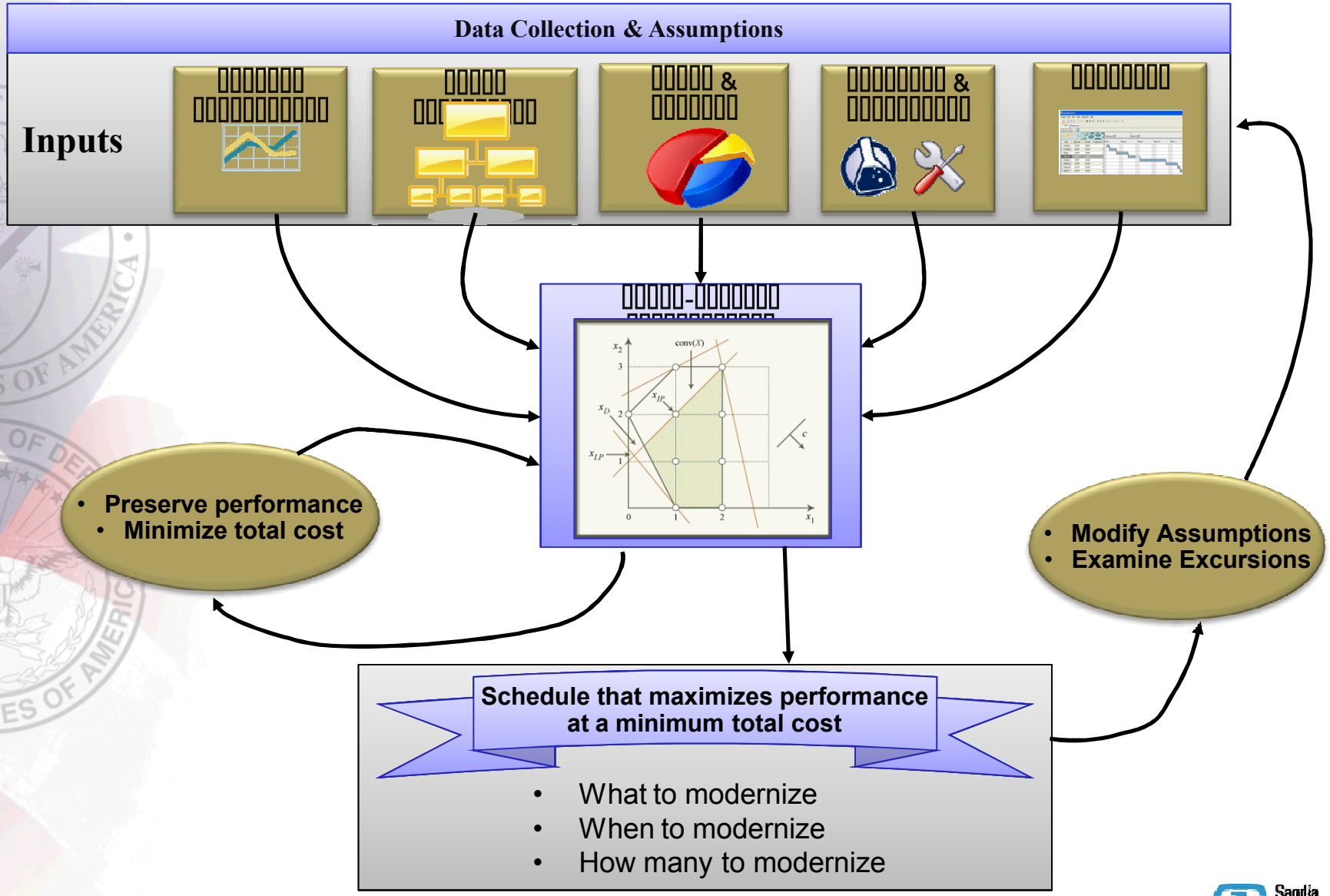
Fleet Management Optimization Process



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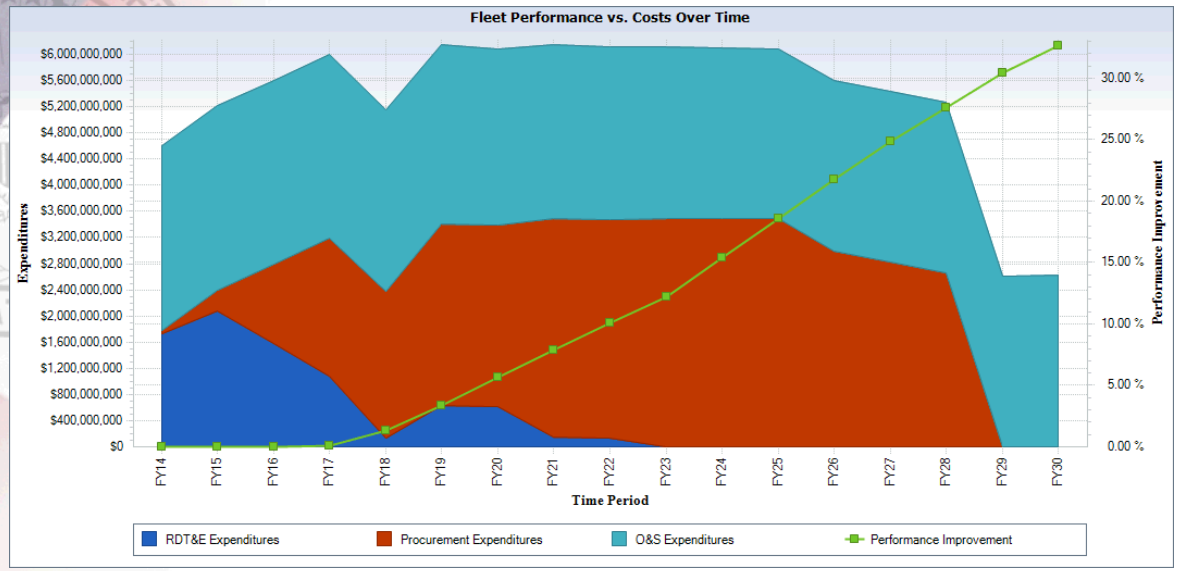
Modernization Schedule Example

(Notional Data)

$90.938B			FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30
$13.961B	Mission1	Vehicle4	1680	1680	1680	1680	1540	1330	1120	910	700	490	280	140	70				
		Vehicle5					140	350	560	700	840	910	1050	1120	1120	1120	1120	1120	1120
		Vehicle7								70	140	280	350	420	490	560	560	560	560
$4.641B	Mission2	Vehicle20	600	600	600	550	500	450	400	350	300	250	200	150	100	50			
		Vehicle21				50	100	150	200	250	300	350	400	450	500	550	600	600	600
$2.814B	Mission3	Vehicle23	360	360	360	360	345	315	285	255	225	210	180	150	120	90	60	30	
		Vehicle32					15	45	75	105	135	150	150	150	150	150	150	150	150
		Vehicle33											30	60	90	120	150	180	210
$5.223B	Mission4	Vehicle24	1080	1080	1080	1080	990	900	810	720	630	585	495	405	315	225	135	45	
		Vehicle32					90	180	270	360	450	495	495	495	495	495	495	495	495
		Vehicle33											90	180	270	360	450	540	585
$6.106B	Mission5	Vehicle25	1200	1200	1200	1200	1100	1050	950	850	750	700	600	500	400	300	200	100	
		Vehicle32					100	150	250	350	450	500	500	500	500	500	500	500	500
		Vehicle33											100	200	300	400	500	600	700
$3.250B	Mission6	Vehicle26	480	480	480	480	480	440	400	360	320	280	240	200	160	120	80	40	
		Vehicle32						40	80	120	160	200	200	200	200	200	200	200	200
		Vehicle33											40	80	120	160	200	240	280



- Population schedule shows the entire fleet modernization plan
  - What's in fleet
  - What's upgraded
  - When
  - How many

- Quick comparison of performance vs costs through time
  - Costs broken down by **R&D**, **Procurement**, and **O&S**

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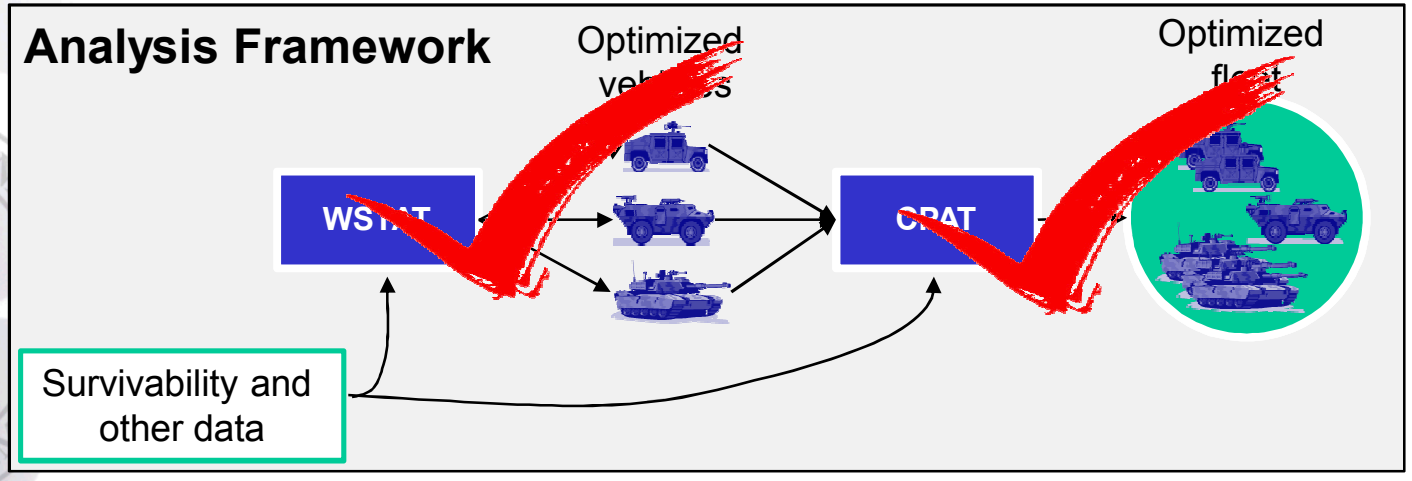
Summary



- **Combination of WSTAT and CPAT provides framework to optimally modernize vehicles and fleets thereof**
- **Methodology hinges on multicriteria and mixed-integer optimization**
- **Survivability is a major driver of the optimization in both stages, but must be considered in balance with other attributes**
  - **This framework could trivially be modified to find the "most survivable" fleet, but such a fleet would sacrifice other capabilities**