BILATERAL ENTERPRISE ANALYSIS MODEL (BEAM)

Evaluating joint operational warfare strategies and force mixes

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(email to request BEAM software for free!)

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AGENDA

Overview

Demonstration

Applications and Sample Analyses

Structure and Data

Methodology

Status and Way Ahead

WHAT IS BEAM?

Defense enterprise-level (less resolution) simulation of theater campaigns with intelligent and adaptive adversary exploring:

- Military strategies at the operational level (theater campaign)
- Force structures (common mission format across all domains)
- Future systems
- Impacts of changing access to bases and infrastructure

Client-server architecture that runs on a laptop

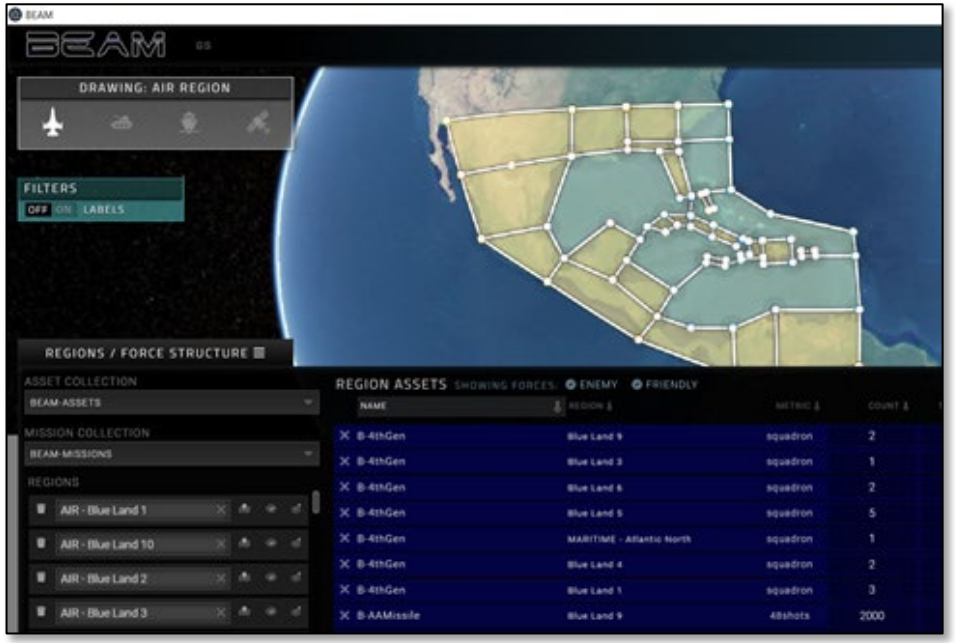
- Runs on standalone PC, currently in Windows environment
- Air Force certified for use on government networks

Goal is government tool with open architecture for defense analytic, wargaming, and planning communities

- US Government funded (USAF and USSF to date)
- NATO Next Gen M&S evaluating BEAM as host-nation capability
- Contractors benefit from government model to test innovations

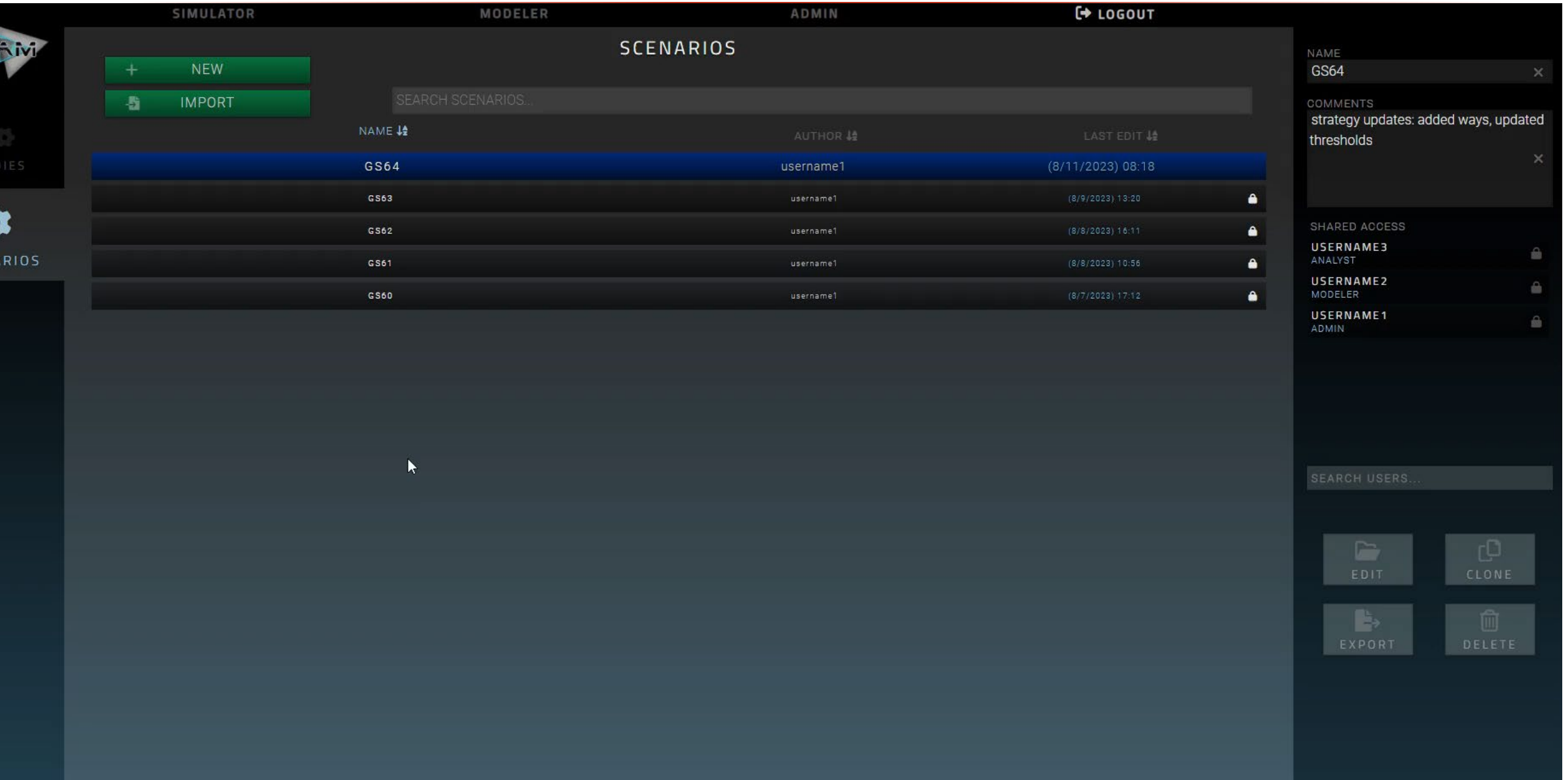
Improving capability with demonstrated use cases

- Adding features and better data
- Used and being used in US government studies



Provides new tool to investigate theater campaign issues and questions

DEMONSTRATION VIDEO



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BEAM APPLICATIONS

Exploring ***large trade-spaces*** of possible joint force-structure and strategy options

- Basing, Allies, Readiness & Positioning, Constellations, Munitions, Intel, Objectives, etc.
- Demonstrated in completed study

Assessing potential ***opponent adaptation*** in response to an enhancement

Determining mission areas where improvements significantly alter ***campaign success***

Exploring ***capability improvements*** that can alter scenario outcomes

- Example: % increases in damage or survivability
- Demonstrated in completed study

Enabling investigation of theater campaign ***military strategies***

- Military objectives specified in ends, ways, means, and risks by combat phase for each side
- A good strategy is as important as the right forces

Demonstrated ability to explore campaign success across large trade-spaces to include strategy, force structure, and capabilities

EXAMPLE MANY FACTORS STUDY

Goal: Modify a large scenario and perform a study

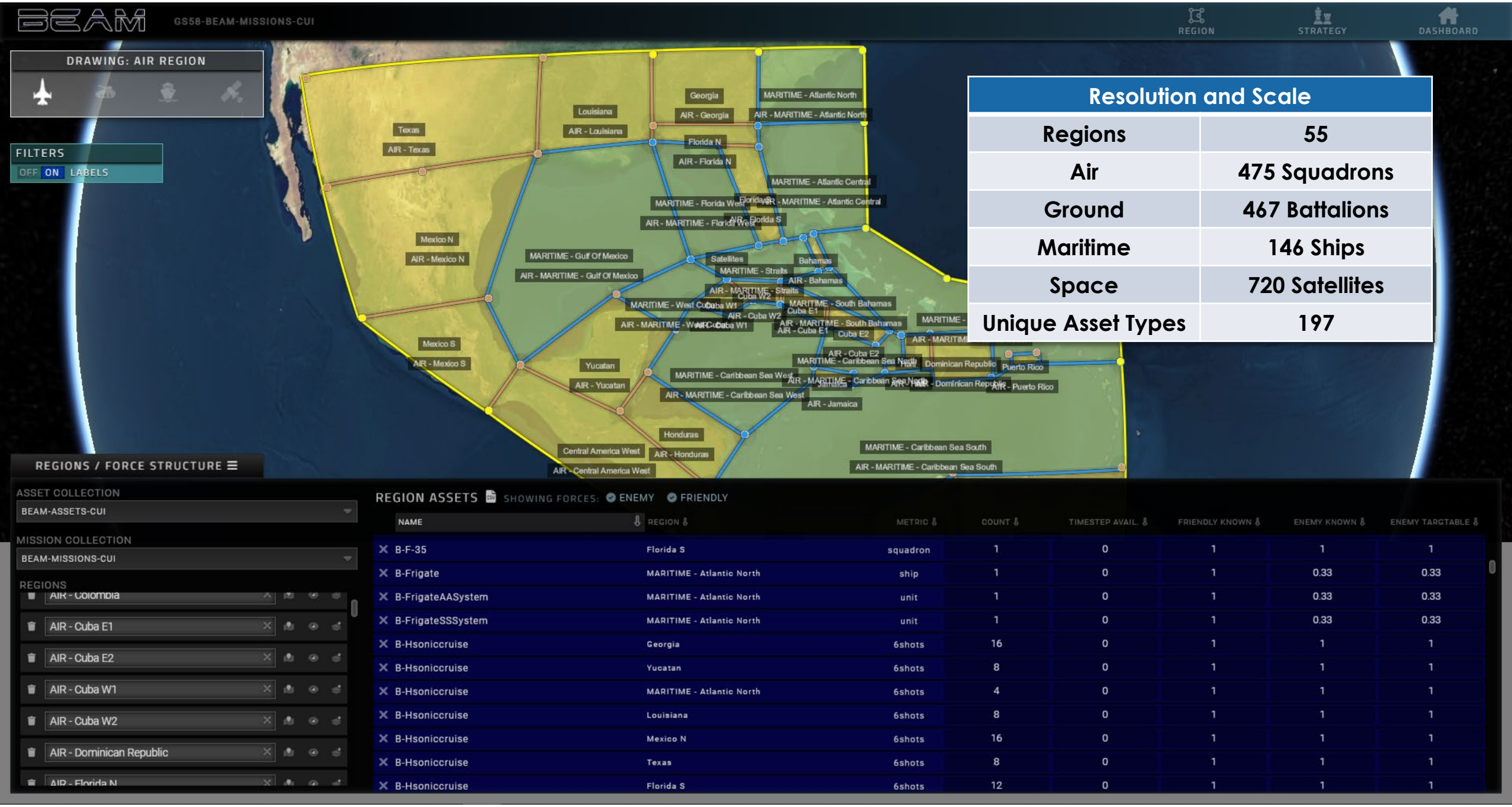
Manpower: 1 Analyst

Timeline: 1-week

Hardware: 16 GB Ram laptop

Classification: Unclassified

Illustrate BEAM Capability In Unclassified Environment



Resolution and Scale	
Regions	55
Air	475 Squadrons
Ground	467 Battalions
Maritime	146 Ships
Space	720 Satellites
Unique Asset Types	197

REGIONS / FORCE STRUCTURE

ASSET COLLECTION
BEAM-ASSETS-CUI

MISSION COLLECTION
BEAM-MISSIONS-CUI

REGIONS
- AIR - Colombia
- AIR - Cuba E1
- AIR - Cuba E2
- AIR - Cuba W1
- AIR - Cuba W2
- AIR - Dominican Republic
- AIR - Florida N

REGION ASSETS SHOWING FORCES: ENEMY FRIENDLY

NAME	REGION	METRIC	COUNT	TIMESTEP AVAIL.	FRIENDLY KNOWN	ENEMY KNOWN	ENEMY TARGTABLE
B-F-35	Florida S	squadron	1	0	1	1	1
B-Frigate	MARITIME - Atlantic North	ship	1	0	1	0.33	0.33
B-FrigateAASystem	MARITIME - Atlantic North	unit	1	0	1	0.33	0.33
B-FrigateSSSystem	MARITIME - Atlantic North	unit	1	0	1	0.33	0.33
B-Hsoniccruise	Georgia	6shots	16	0	1	1	1
B-Hsoniccruise	Yucatan	6shots	8	0	1	1	1
B-Hsoniccruise	MARITIME - Atlantic North	6shots	4	0	1	1	1
B-Hsoniccruise	Louisiana	6shots	8	0	1	1	1
B-Hsoniccruise	Mexico N	6shots	16	0	1	1	1
B-Hsoniccruise	Texas	6shots	8	0	1	1	1
B-Hsoniccruise	Florida S	6shots	12	0	1	1	1

RANGE OF ISSUES INVESTIGATED

Large operational vector categories are broken down into components

Components are mapped to BEAM scenario-level specific changes:

- Targetability based on ISR
- Effectiveness
- Space constellations
- Rebasing forces
- Allied participation
- Munitions availability
- Runway repair

OPERATIONAL VECTOR	OV Component	BEAM Scenario Input	Range (Continuous)		Discrete/Categorical Levels
			Low	High	
CAPABILITIES	a. Speed of Response	**Delayed arrival** of key Force components (days)	7	0	n/a
	b. Demonstrating, planning, and prep activities	Initial **targetability** of Red Ships & TELs	0.5	1	n/a
	c. Effective delivery of combat power on objective	Multiplier on Blue **effectiveness** data (training)	1.0	1.1	n/a
	d. Readiness level	Proportion of assets **available for allocation**	0.8	0.95	n/a
INDICATIONS & WARNINGS	a. Collection and analysis activities	Multiplier on size of **Space asset constellations**	0.5	1.5	n/a
		Multiplier on size of **Overhead (air-breathing) assets**	0.5	1.5	n/a
		ISR PED delay (days)	0	1	n/a
	b. Relevant analysis activities	**Blue's perception** of Red's strategy			{opposite, equal weights, correct}
POSTURE	a. Advantageous distance of forces to threat (forward positioning)	CVW in Honduras			{No, Yes}
		Bomber Sqdrn to Texas			{No, Yes}
		Bomber Sqdrn to Mexico			{No, Yes}
		F35 Sqdrn to Florida			{No, Yes}
		Addl Subs forward			{0, 4, 8}
		Bomber Wing to Puerto Rico			{No, Yes}
		F35 Wing to Puerto Rico			{No, Yes}
		US Missile/Air in Yucatan			{No, Yes}
		USMC Air and MLRs to Florida			{No, Yes}
		C2 on Florida			{No, Yes}
	b. Degree of C2 centralization	**Inefficient allocation** (values > 1 are inefficient)	1.2	1.0	
	c. Force presence (loiter, persistence, permanent)	Multiplier on **Green munitions (ASCM, ATACMS)**	1.0	2.0	
		Multiplier on **Blue munitions (LRASM)**	1.0	2.0	
		Multiplier on Engineering assets for **runway repair**	1.0	3.0	
	d. Force/capability concentration (force density) **[Allies/Parnters]**	Mexican Host Nation Forces			{No, Yes}
		Honduras Host Nation Forces			{No, Yes}
		Puerto Rican Host Nation Forces			{No, Yes}
		Bahamas Host Nation Forces			{No, Yes}
		Jamaica Host Nation Forces			{No, Yes}

Big Ideas Translated To Concrete Actions

IDENTIFICATION OF CAMPAIGN DRIVERS

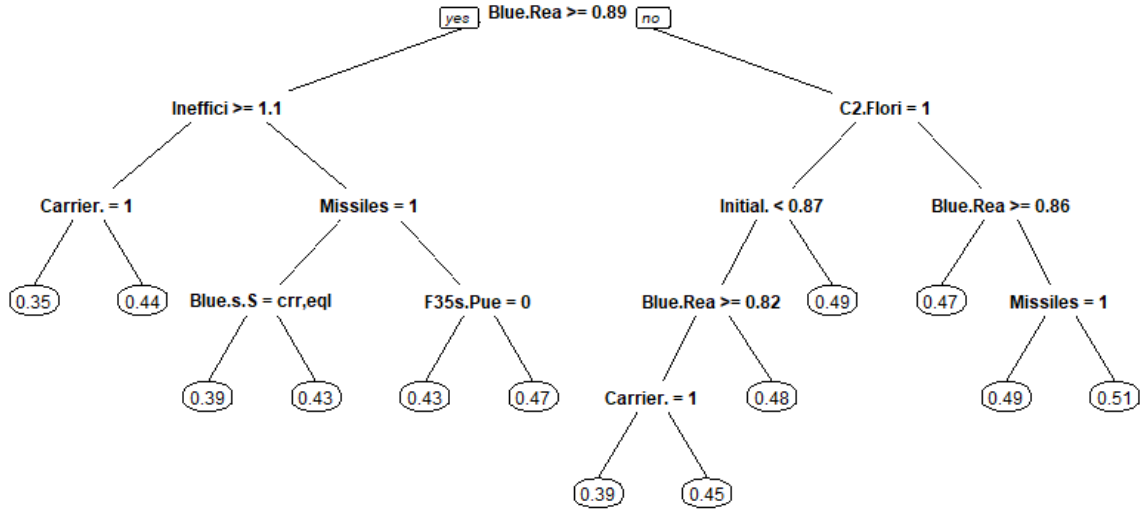
Single Factor Importance (Regression)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.236	0.072	17.226	0.000
Blue.Readiness	-0.659	0.056	-11.707	0.000
Carrier.Wing.Honduras	-0.041	0.005	-8.287	0.000
Missiles.Yucatan	-0.025	0.005	-5.104	0.000
C2.Florida	-0.038	0.005	-7.674	0.000
F35s.Florida	-0.017	0.005	-3.375	0.001
ISR.Delay	0.015	0.005	3.134	0.002
Bombers.Mexico	-0.014	0.005	-2.922	0.004
Inefficient.Allocations	-0.125	0.042	-2.969	0.004
F35s.Puerto.Rico	-0.013	0.005	-2.559	0.012
Blue.s.Strategy.Perceptionequal	-0.013	0.006	-2.083	0.039
Blue.s.Strategy.Perceptionopposite	-0.011	0.006	-1.897	0.060
Hoduras.Forces	-0.007	0.005	-1.514	0.133
Initial.Intel	0.025	0.017	1.495	0.137
MLR.Florida	-0.007	0.005	-1.482	0.141
Airborne.ISR	-0.011	0.008	-1.336	0.184
Forward.Subs	0.001	0.001	1.257	0.211
Bombers.Texas	-0.006	0.005	-1.165	0.246
Space.ISR	-0.008	0.008	-0.945	0.346
Bombers.Puerto.Rico	-0.004	0.005	-0.720	0.473
Mexican.Forces	-0.003	0.005	-0.543	0.588
Jamaica.Forces	-0.003	0.005	-0.505	0.614
Green.Munitions	0.004	0.008	0.469	0.640

Combined Factor Importance

	Estimate	Std. Error	t value	Pr(>|t|)
F35s.Puerto.Rico:Missiles.Yucatan	-0.040	0.013	-3.002	0.005
Blue.Readiness:F35s.Florida	0.308	0.145	2.132	0.039
Carrier.Wing.Honduras:F35s.Puerto.Rico	-0.028	0.014	-2.017	0.050
ISR.Delay:Bombers.Mexico	-0.027	0.014	-1.973	0.055

Partition Tree of Drivers



Top Single Drivers

1. Readiness
2. Carrier Wind in Honduras
3. Missiles in Yucatan
4. C2 in Florida
5. 5th Gen Fighters in Florida

Top Interaction Drivers

1. 5th Gen Fighters in PR, Missiles in Yucatan
2. Blue Readiness & 5th Gen Fighters in Florida
3. Carrier Wing in Honduras & 5th Gen Fighters in PR

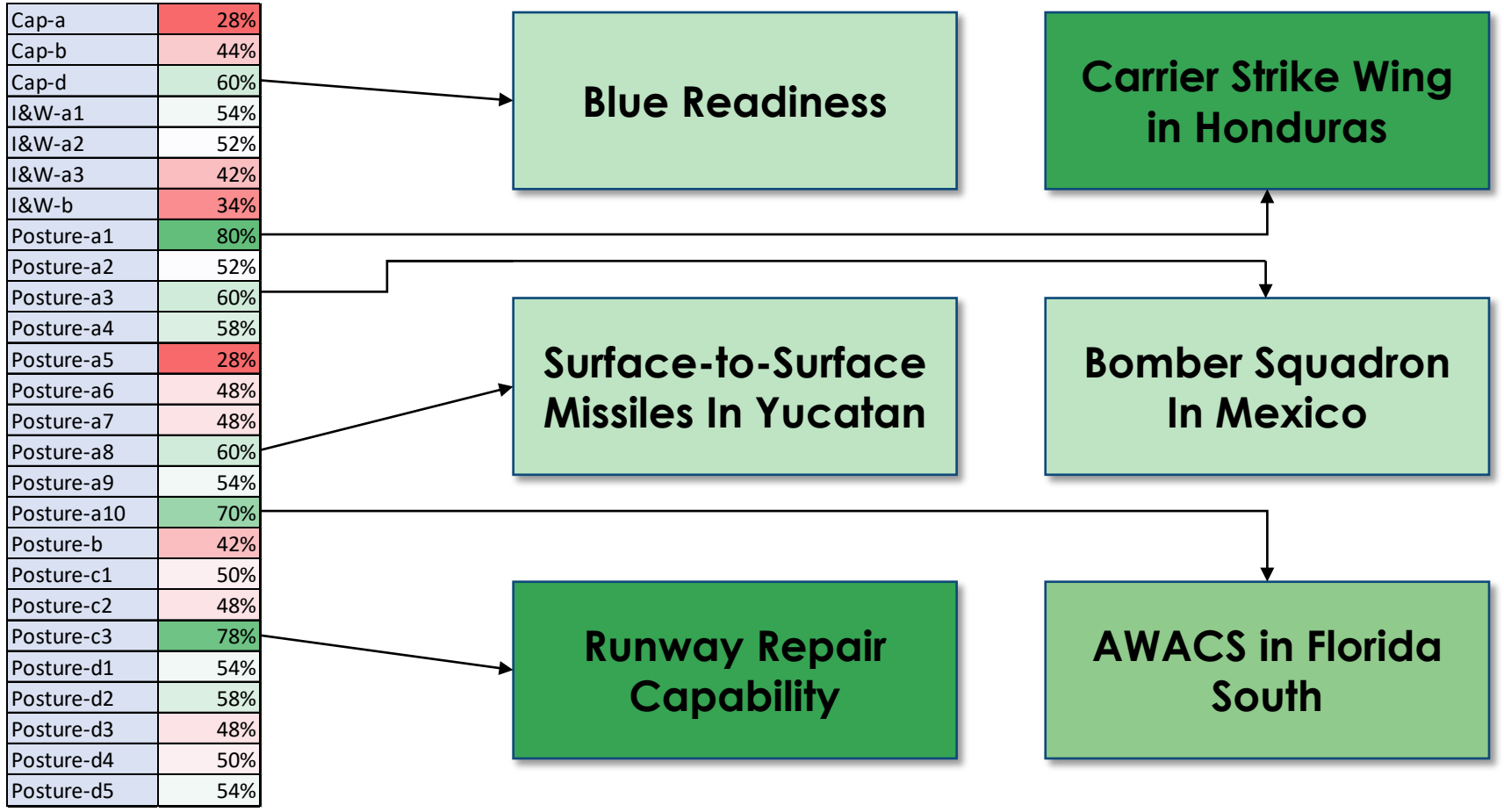
Multiple Methods For Analyzing Large Datasets

CAMPAIGN CONTRIBUTION ANALYSIS

145 Total Cases

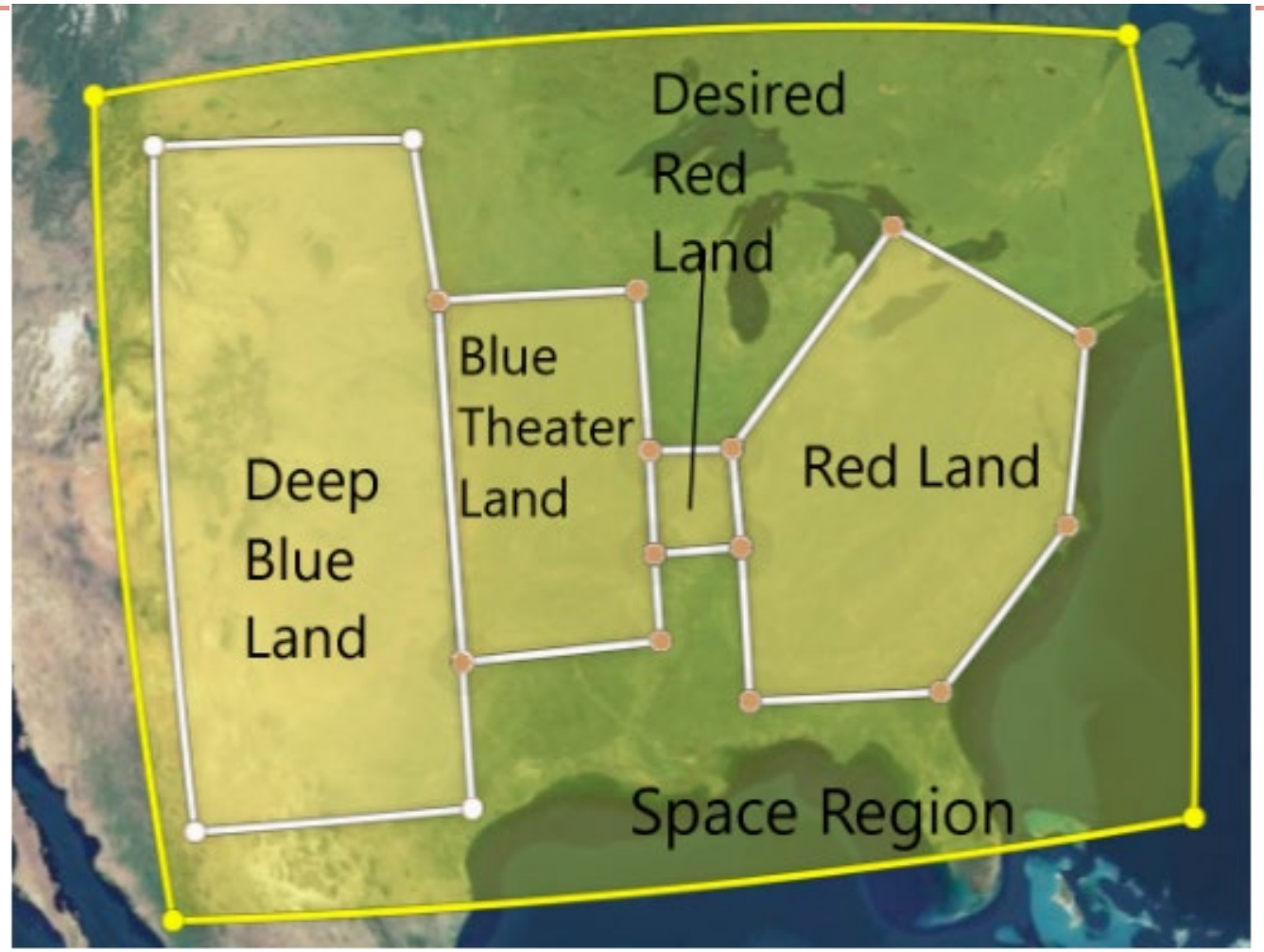
Analyze frequency of factors in top 50 cases based on NPS deterrence utility model

Cap-a	28%
Cap-b	44%
Cap-d	60%
I&W-a1	54%
I&W-a2	52%
I&W-a3	42%
I&W-b	34%
Posture-a1	80%
Posture-a2	52%
Posture-a3	60%
Posture-a4	58%
Posture-a5	28%
Posture-a6	48%
Posture-a7	48%
Posture-a8	60%
Posture-a9	54%
Posture-a10	70%
Posture-b	42%
Posture-c1	50%
Posture-c2	48%
Posture-c3	78%
Posture-d1	54%
Posture-d2	58%
Posture-d3	48%
Posture-d4	50%
Posture-d5	54%



Ability To Determine Campaign Drivers (Allies' and Adversary's)

A NOTIONAL STRATEGY EXAMPLE



Red intends to conquer Desired Red Land whereas Blue's goal is to defend it

THE DEMONSTRATION ASSETS

Asset	Metric	Blue Deep Land	Blue Theater Land	Desired Red Land	Red Land	Space
AirFuel	1000lbs	500	500	1000	2000	
Air-Surface Bomb	120shots	10	10	10		
Air-Air Missile	48shots		20	25	100	
Air-Surface/Surface-Surface Standoff	6shots		10			
Air-Surface Standoff	6shots	10				
Air Launched Cruise Missile	6shots				150	
Runway	runway	6	6	6	25	
4th Gen Fighter	squadron			3	6	
5th Gen Fighter	squadron		2		6	
Bomber	squadron	2			4	
C2 Airborne	squadron	1				
EW Airborne	squadron	1			1	
IMINT UAV	squadron	10			10	
Tanker	squadron	5	2	2	20	
C4ISR Airborne	squadron				1	
Ground Ammunition	1000lbs	1000	1000	1000	2000	
Ground Fuel	1000lbs	1000	1000	1000	2000	
Land Area	100sqkm	100	50	50	150	
Major Supply Route	300km	100	50	50	150	
Intermediate Range Ballistic Missile (IRBM)	6shots		10		75	
Surface-Air Missile Short	6shots			100	100	
Ground Launched Cruise Missile	6shots				75	
Large TEL	6-TEL battery		4		5	
SAM TEL (Short)	6-TEL battery			3	5	
Small TEL	6-TEL battery				5	
Armor	battallion			3	7	
Artillery	battallion		3	2	5	
Attack Aviation	battallion			1	3	
Light Infantry	battallion	2		2	4	
Mechanized Infantry	battallion	1		2	6	
Engineering	squadron			1		
Comm Satellite Access	15 minute accesses	100	100	100	200	
Missile Warning Access	15 minute accesses	100	100	100	200	
Missile Warning C2 Center	unit	1			1	
Comm Satellite C2 Center	unit	1			1	
Missile Warning Satellite	10 sat constellation					1R 1B
Comm Satellite	10 sat constellation					1R 1B

Every asset is a potential target for their adversary

Asset quantities are expressed in units (squadrons, brigades) assigned to a specific region

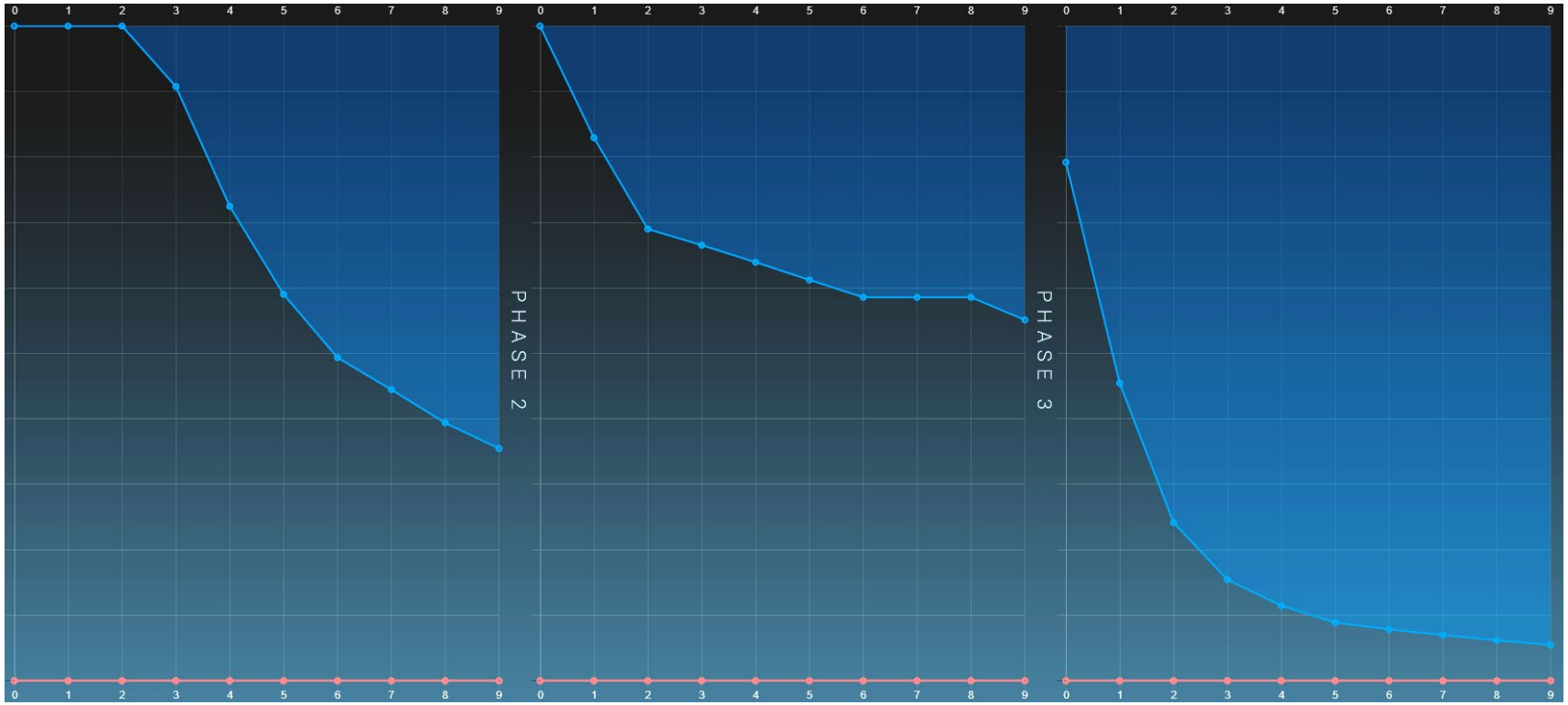
Forces are held constant in this study of military strategy (theater objectives)

DEMONSTRATION BASELINE STRATEGY
(ENDS ONLY FOCUS WITH CONFLICT TIME RESTRICTED)

- Red Main Objective: Conquer Blue-controlled Desired Red Land by taking Major Supply Routes (MSRs) and Land Area
- Red Achievement restricted to predefined timeline of **22 days**:
  - Phase 1 (Attack IADS in Desired Red Land) – 2 Days
  - Phase 2 (Attack TAC Air and IADS in Desired Red Land) – 3 Days
  - Phase 3 (Bombard blue troops/air assets in Desired Red Land) – 5 Days
  - Phase 4 (Take Land and Major Supply Routes in Desired Red Land) – 12 Days
- Red strategy is to maximize achievement of all ends (military objectives)
- Investigate Red strategy of IADS and TAC Air thresholds in Phase 1 & 2 (i.e., what level of degradation of enemy assets leads to best Red achievement percent?)
- **Baseline Blue strategy is strictly defensive**

Red strategy is evaluated based solely on Red Achievement percent

SAMPLE BEAM OUTPUT



BEAM results show conditional probability of achieving the Ends (objectives) in each combat phase for each time-step (simulated day)

BEAM produces extensive data including missions, assets impacted, and ends achieved

RED STRATEGY EXPLORATION

	Red Achievement Percent							
	Overall	Phase 1	Phase 2	Phase 3	Phase 4	Phase 1 IADS Threshold	Phase2 IADS Threshold	Phase 2 Tac Air Threshold
Baseline	34%	76%	64%	100%	70%	1	0.5	1.5
COA 1	76%	92%	86%	100%	96%	1.5	1	1.5
COA 2	61%	76%	100%	100%	80%	1	0.5	2.5
COA 3	53%	92%	100%	100%	57%	1.5	1	2.5

Relaxed IADS thresholds lead to higher Red Achievement rates, but benefit decreases as thresholds are further relaxed

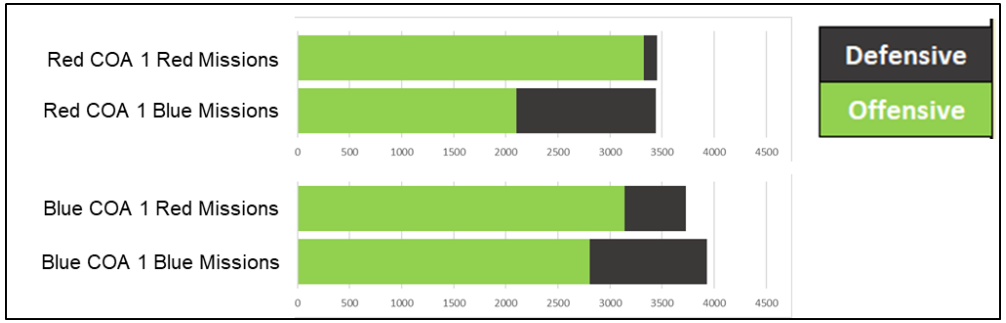
Relaxed TAC Air thresholds not as impactful as IADS

Military objective Ends tend to have a "sweet spot"
-- Too little results in insufficient impact
-- Too much wastes time and resources (losses)

BEAM enables quickly and easily analyze ends balancing impact, losses, and duration!

BLUE COUNTER STRATEGY

	Blue Strategy (vs. Red COA 1)	Red Achievement Percent				
		Overall	Phase 1	Phase 2	Phase 3	Phase 4
Red COA 1	Defensive Posture	76%	92%	86%	100%	96%
COA 1	Attack IADS	6%	44%	16%	88%	98%
COA 2	Attack Tac Air	6%	44%	15%	95%	99%
COA 3	Attack IADS and Tac Air	6%	44%	15%	95%	100%

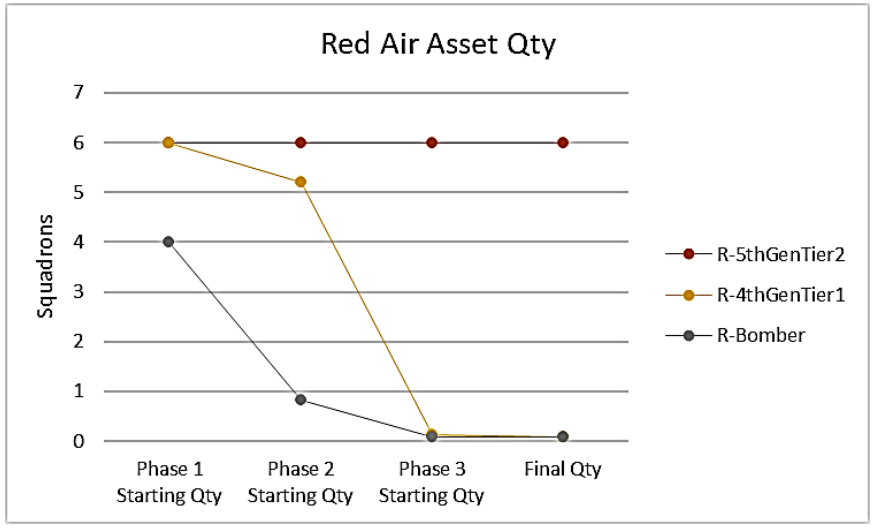


- Blue adds offensive missions (~2100 to ~2700)
- Red responds with defensive missions (~100 to ~500) at the expense of offensive missions (~3400 to ~3200)
- Blue missions did not damage much because Red countered their strikes
- Red's reallocation slows their advance and overall achievement in 22 days

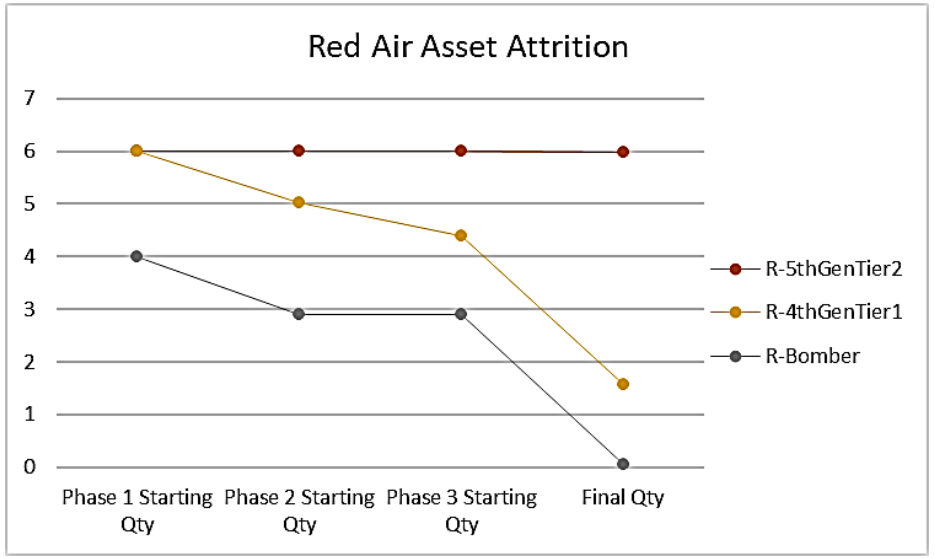
The major impact of Blue's offensive attacks is Red having to adapt by reallocating from offensive to defensive missions to counter these attacks

RED BALANCES ACHIEVEMENT, DURATION & LOSSES

IADS Threshold	Achievement	Completion Time	Red Casualties	Blue Casualties
0.75	100%	28.9	5914	8135
1	100%	27.1	5592	8362
1.25	100%	26.9	5743	8326
1.5	100%	26.6	5398	8333
1.75	100%	26.1	5604	8284
2	100%	26.5	5511	8526



	IADS Threshold	Achievement	Completion Time	Red Casualties	Blue Casualties
COA 1	N/A	0%	N/A	N/A	N/A
COA 2	1.5	100%	26.6	5398	8333
COA 3	0.75	100%	26.2	5676	8331
	1	100%	27	5620	8146
	1.25	100%	27.6	5805	8247
	1.5	100%	30.9	6625	8089
	1.75	100%	25.7	5293	8477
	2	100%	25.5	5372	8491



- COA 1: No IADS attack—0% achievement
- COA 2: IADS to 1.5 units—100% achievement, 26.6 days, 5398 causalities
- COA 3: Reduce bomber and fighter risk in Phase 1 & 2, IADS to 1.75 —100% achievement, faster 25.7 days, fewer 5293 causalities

Ends thresholds (extent) affect achievement, completion time, and casualties

BLUE RESPONSES

- Blue evaluates two options
  - Blue COA 1: Attack Red runways
    - Decreases Red achievement by 5%
    - Increases Red duration by 3.4 days (13%)
    - Increases Red casualties by 1%
    - Reduces Blue casualties by 5%
  - Blue COA 2: Increase Blue air defense in Desired Red Land
    - Significantly more causalities for both sides
- Red has a more robust scenario limiting Blue's ability to affect
  - Longer duration than previous scenario of only 22 days
  - Red reducing risk of their fighter and bomber losses

	IADS Threshold	Achievement	Completion Time	Red Casualties	Blue Casualties
Red COA 3	1.75	100%	25.7	5293	8477
Blue COA 1	1.75	95%	29.17	5345	8034
Blue COA 2	1.75	100%	26.94	6052	8299

Our warfighters need tools (like BEAM) to balance achievement, losses, and duration

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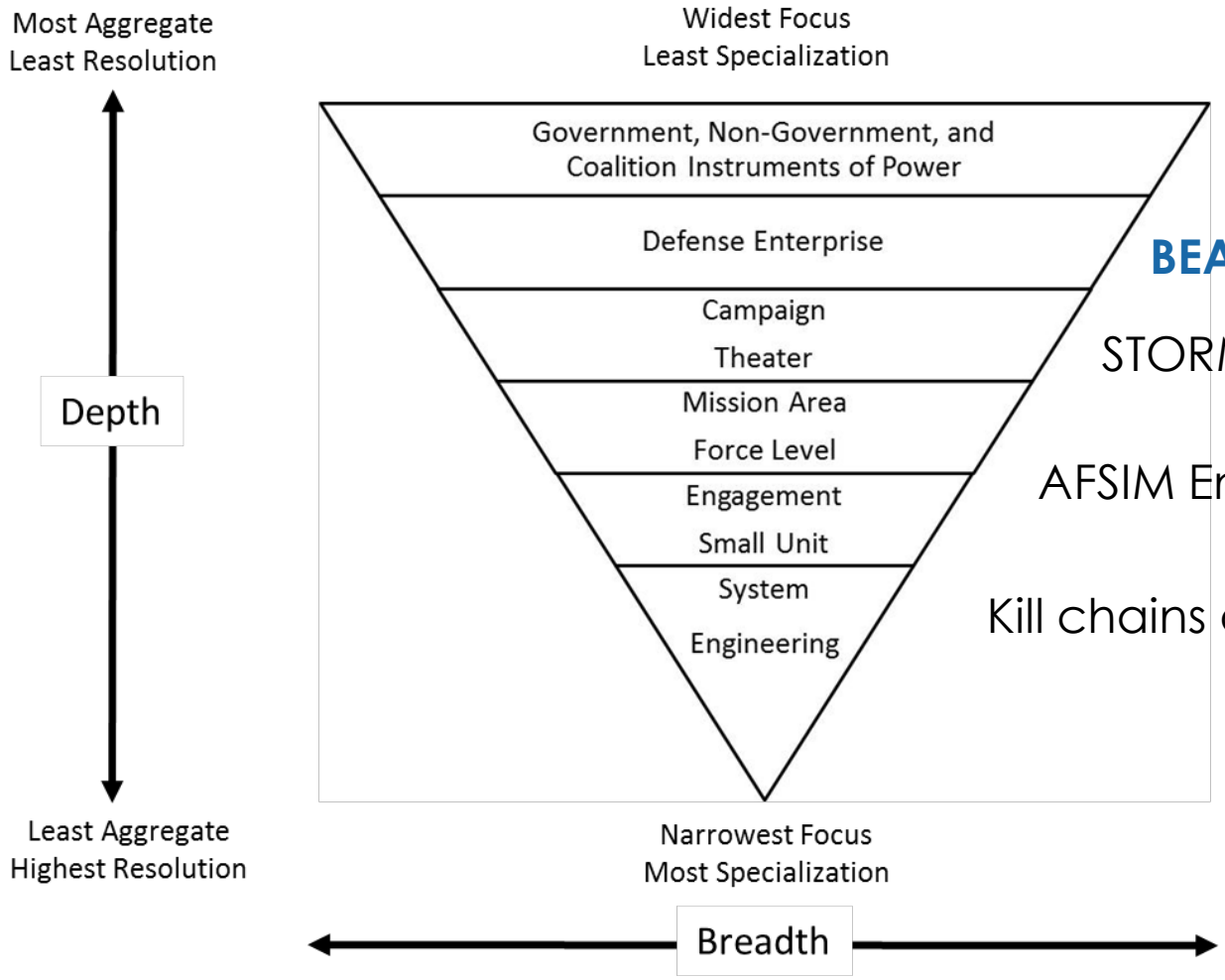
HIERARCHY OF COMBAT MODELS



BEAM assesses changes in strategies, forces, & bases

STORM and JICM evaluate force structures

AFSIM Environment for building performance models

Kill chains and mission threads

Gallagher, Mark A., David J. Caswell, Brian Hanlon, and Justin M. Hill. "Rethinking the Hierarchy of Analytic Models and Simulations for Conflicts." *Military Operations Research* 19, no. 4 (2014): 15-24.

BEAM has more breadth and less resolution than campaign models

BEAM RESOLUTION RULES

- Common format for missions
  - Assets are any thing that affects missions (units, munitions, runways, satellites, transportation, EW, etc.)
  - Missions are sets of offensive and defensive assets affect targets
  - Assets allocated proportional to quantity needed for each type of mission
- Every asset for one side is a potential target for their adversary
  - Enables alternative attack vectors
  - All employed assets encounter probability of being destroyed, failing, or being consumed
- Military strategy objectives (ends, ways, means, & risks) by combat phase drive asset-to-mission allocations including movement for both sides
- No latitude or longitude; hence geographic regions
  - Vary in size to reduce computations on insignificant areas
- Evaluate uncertainty without Monte Carlo techniques
  - Statistical distributions of every asset per region
  - Simulation threads, which are daily design of experiments (DOE) to sample current space
  - Computationally fast with one pass through data produces outcome distributions

Enables consistent resolutions across domains and multi-domain representation

RESOLUTION/DEFINITIONS

Regions

- Map is strategically divided to represent areas meaningful to the campaign
  - Land, Sea, Air & Space
  - No Lat/Longs
- Assets are assigned to regions and can move between regions

Assets

- Anything that enables/modifies a mission outcome and represents an important constraint on a mission
- Assets include resources (runways, fuel, munitions, available ISR, communication satellite etc.)
- BEAM maintains statistical distributions of assets by regions

Missions

- Combination of offensive & defensive packages and a target
  - Packages of assets to achieve an objective
  - Packages cross domains & regions
- 900K+ unique missions, and growing
- Missions are principal organizing entities
  - Common format of missions

Military Strategy

- *Objectives* that need to be accomplished to complete *each phase* of the campaign
  - Ends, Ways, Means, & Risks
- Actual and Perceived set for each phase for both Blue and Red enables deception
- Drives allocation of assets to missions

MILITARY STRATEGY

Theater campaign objectives specify desired achievements

- By phase, by region, to a specified threshold with an importance weight
  - Ends specify the objective (target asset) along with threshold (extent)
  - Ways specify the type of attack for a particular ends, such as use long range fires
  - Means specify specific asset (unit or system) to employ for that ends
  - Risks penalizes or limits the use of an asset during that phase
- Offensive assets must be part of a mission contributing to an objective to be allocated

Strategy drives assets to mission allocations and basis for assessment

- For each side, BEAM selects missions with their assets to best achieve their strategy
- All primary objectives must be met to proceed to the next combat phase
- Secondary objectives influence mission selection; but not phase progression

Military strategy evaluation is possible because missions are the primary modeling entities

MILITARY STRATEGY EXAMPLES

BEAM Campaign Objectives

Ends: Achieve Air Superiority in enemy region (all assets targeting adversary air)

- Ways: Enemy runways below 0.7 threshold
  - Means: Friendly fighters target enemy runways
    - Risks: Avoid use of F-35s for runway attack

Ends: Gain control of Major Supply Routes (MSR) in combat region

Ends: Gain maritime superiority of enemy sea region

BEAM MULTI-DOMAIN FRAMEWORK

Missions consist of assets across domains to impact adversary assets (targets)

MARITIME FRAMEWORK

Assets

- Carrier, LCS, cruiser, frigate, missile submarine, munitions, etc.
- Surface control is a unique asset used indicate freedom of movement

Regions

- Includes surface & subsurface combat
- Likely to have air and space regions layered above it
- Can be used to represent strategic importance of different areas of the domain

Missions

- Air defense, surface to surface strikes, sub strikes, etc

Strategies

- Destruction of Anti-Ship Cruise Missiles (ASCMs) before advancement of carrier, control of the maritime region, etc

Dependencies on other Domains

- Tanker support from land-based aircraft, space-based support, etc

GROUND FRAMEWORK

Assets

- Armor, light infantry, mechanized infantry, artillery, fuel, munitions, etc
- Main Supply Routes (MSRs) is a unique asset used indicate freedom of movement

Regions

- Likely to have air and space regions layered above it
- Can be used to represent strategic importance of different areas of the domain

Missions

- Unit vs unit, capturing MSRs, defending beachhead, SAMs, etc

Strategies

- Capture MSRs and advance, establish total dominance in a region, etc

Dependencies on other Domains

- CAS (Close Air Support), space-based support, etc

AIR FRAMEWORK

Assets

- Fighters, tankers, enabling aircraft, runways, fuel, munitions, etc.

Regions

- Distance between regions critical for building mission subpackages
- Likely to have ground or maritime regions below and space regions above
- Can be used to represent strategic importance of different areas of the domain

Missions

- Air superiority, direct strikes, standoff strikes, ISR, etc.

Strategies

- Destroy enemy long-range missile launchers, defend a critical region, etc

Dependencies on other Domains

- Runway defense, carrier launched aircraft, space-based support, etc

SPACE FRAMEWORK

Assets

- PNT constellation, IMINT constellation, ground stations, ASAT, etc

Regions

- Generally single region covering all maritime, ground and air regions

Missions

- ISR, SATCOM support to maritime conflict, space-based ASAT strike, etc

Strategies

- Jam PNT, ISR collection, destroy COMSAT capability, etc

Dependencies on other Domains

- Defense of space assets in other domains

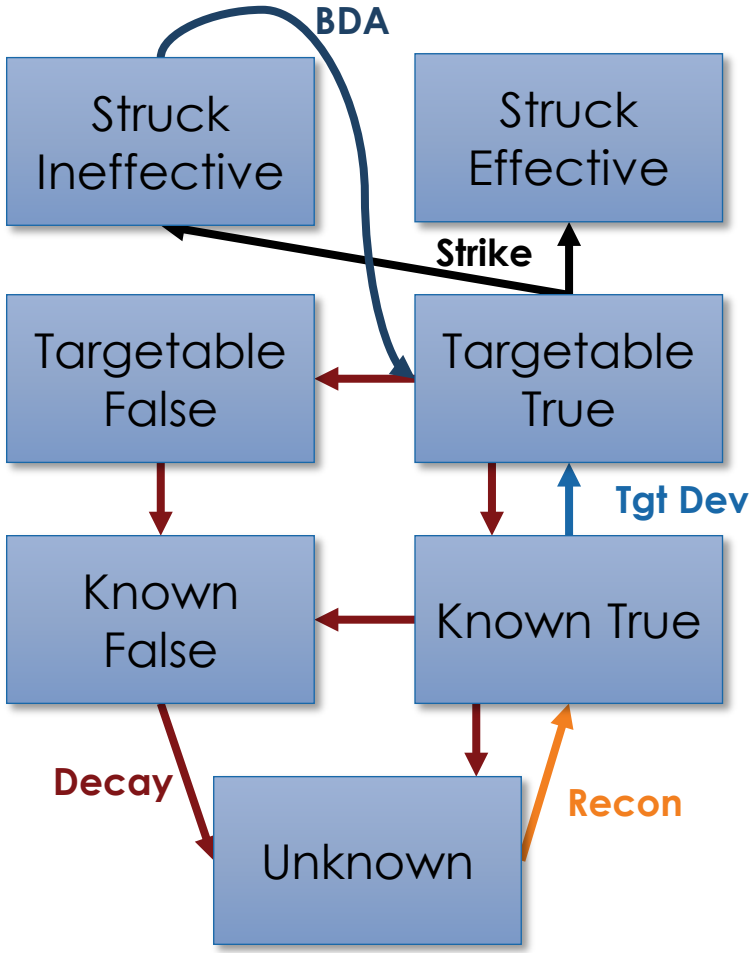
ISR REPRESENTATION

Two primary purposes for ISR

- Situational awareness for target development
  - Active (part of allocation) & passive (non-traditional ISR from fighters) missions
  - Decay (rate is dependent on the asset)
  - Processing delay 1-day, 2-day, etc.
- Direct support to missions
  - Incorporated as a mission subpackage
  - Real time support, not strategic target development

Computation for a particular ISR property

- Computed for every pair of detector & enemy asset for each mission
  - Capability and range of detector
  - Vulnerability of enemy asset to this type of ISR
  - Size of region being searched
- Capture decay of ISR over time



LOGISTICS FRAMEWORK

Assets

- Fuel, Munitions, Movers, Repair, Useable vs in-Region etc

Regions

- Movement across regions and possibly within

Missions

- Repair, resupply, forward-deploy

Strategies

- Strike logistics lines, appropriately support fighting units

Dependencies on other Domains

- Other domains depend directly on logistics

Dependency on logistics is integrated

Movement, resupply, and repair data is being expanded

ASSETS AND THEIR PROPERTIES

Assets

- Everything that supports or contributes to a mission
  - Units, weapon systems, munitions, fuel, bases, runways, communication satellites, …
- Assets modify mission outcomes
- Limited availability of assets constrains number of possible missions

Every asset is a potential adversary target

- BEAM users talk about each side's assets realized those are the other side's targets
- Missions have probabilistic losses to all involved assets
  - Offensive, defensive, and targets
  - Combat losses along with consumption

Unit size

- Synchronized with mission data and current force numbers

Cost

- Estimated cost per unit

Groups

- Categorization for strategy creation

ISR Properties

- Type –IMINT, SIGINT, etc
  - Capability – likelihood to detect (1, 0.7, etc)
  - Vulnerability – likelihood to avoid detection (1,0.6, etc)
  - Range – (1000km)

Mission effectiveness are based on results from higher-resolution models

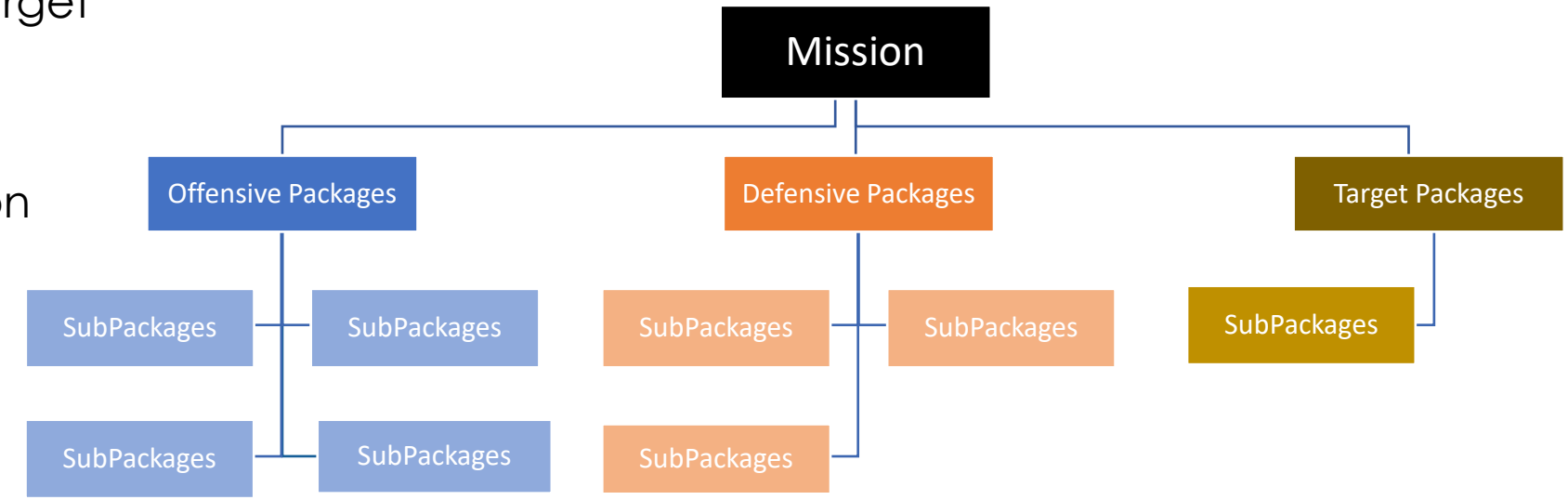
MISSIONS
PACKAGES AND SUBPACKAGES

Packages:

- Offensive, defensive, & target

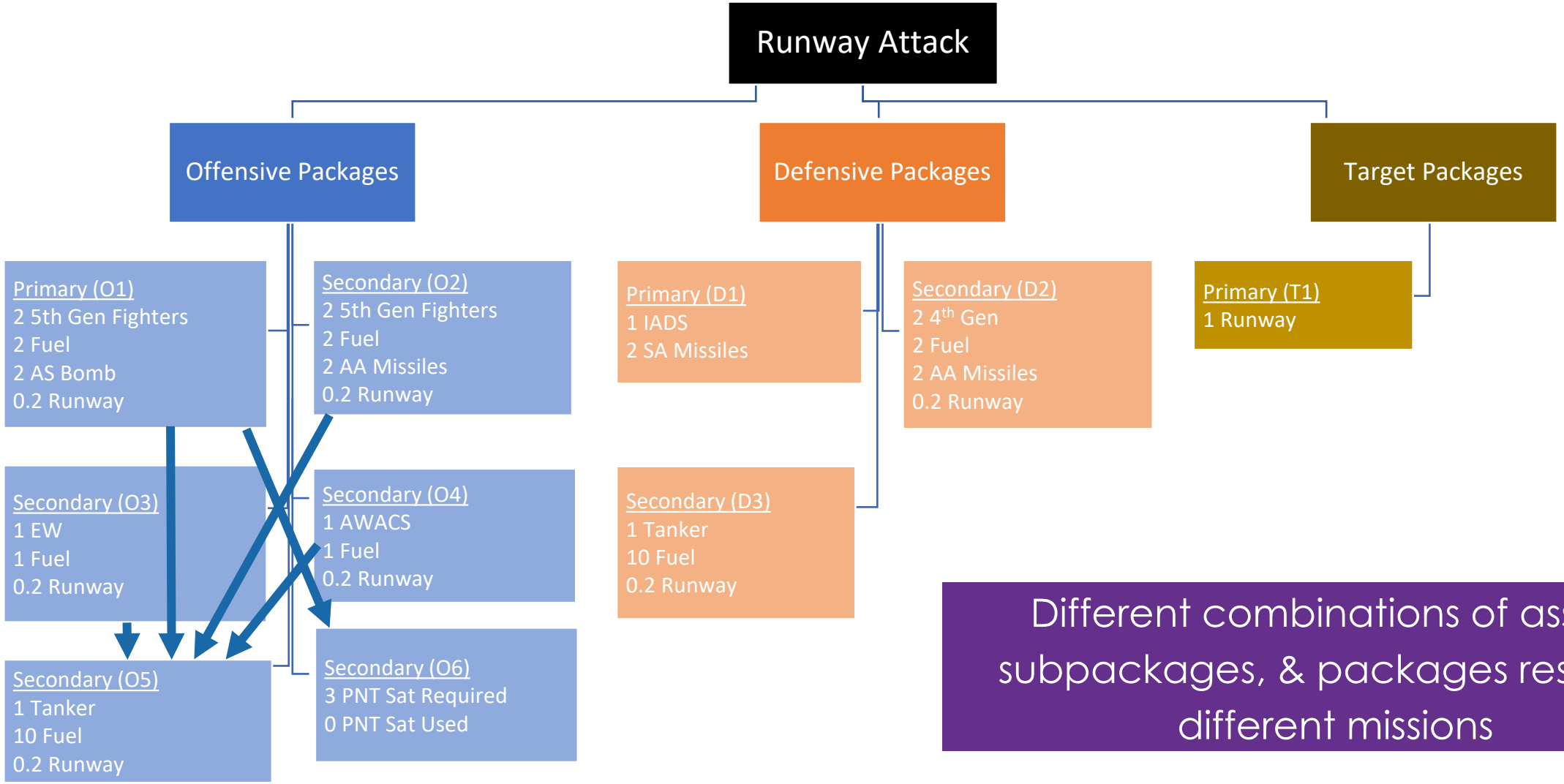
Subpackages

- Smallest allocatable unit
- All assets from same region
- Dependencies can exist between subpackages
- Information included:
  - Primary/Secondary
  - Assets & quantities
  - Dependencies on other subpackages (fighters need tankers)
  - Range (must reach target or just path of primary subpackage)



Missions are the primary modeling entity in BEAM

EXAMPLE MISSION



Different combinations of assets, subpackages, & packages results in different missions

MISSION IMPACTS

Each subpackage added to a package impacts assets in the mission

- Adding offensive subpackages with enablers improves mission performance
  - Offensive assets more survivable
  - Targets and defensive assets more vulnerable
- Adding defensive subpackages decreases offensive mission performance
  - Offensive assets more vulnerable
  - Targets and defensive assets more survivable
- Different combinations of similar subpackages are different missions
  - Full scale scenario has 550k+ unique missions

Asset-to-Mission algorithm

- Best achievement of military strategy (as specified by ends in that combat phase)
- Accounts for prediction of adversary's missions (enables adaptation)
- Constrained by asset availability for mission packages and subpackages

Asset availability for missions drives asset-to-mission allocation to achieve strategy

SUBPACKAGE CONTRIBUTIONS TO MISSIONS
NOTIONAL OUTCOME COEFFICIENTS

Direct Attack 5th Gen Fighters impact on health of defensive 4th Gen units
- None

Escort AA 5th Gen Fighters impact on health of Offensive 5th Gen Fighter units
- Allocating 1 subpackage results in preventing destruction of 1 offensive 5th Gen Fighter unit

Subpackages	Offensive 5th Gen Fighters	Defensive 4th Gen Fighters	Target Runway
Direct attack 5th Gen Fighters	0	0	-0.5
Escort AA 5th Gen Fighters	1	-2	-0.2
EW Support	0.5	-0.5	-0.1
AWACS Support	1.5	-1.5	-0.3
Tanker Support	0	0	0
IADS	-1	0.5	0.2
4th Gen DCA	-0.5	1	0.4
Tanker Support	0	0	0

IADS effect on health of Offensive 5th Gen Fighter units
- Allocating 1 subpackage results in destruction of 1 offensive 5th Gen Fighter unit

4th Gen DCA defends target better than IADS

Tankers impose a constraint for allocation, but do not directly impact survivability

Adding asset to mission (such as satellite support) adds row (impacts) and column (losses)

SUBPACKAGE CONTRIBUTIONS TO MISSIONS
CALCULATING OUTCOMES (NOTIONAL VALUES)

Subpackage	Offensive 5th Gen Fighters	Defensive 4th Gen Fighters	Target Runway	Number Allocated
Direct attack 5th Gen Fighters	0	0	-0.5	3
Escort AA 5th Gen Fighters	1	-2	-0.2	1
EW Support	0.5	-0.5	-0.1	2
AWACS Support	1.5	-1.5	0.3	0
Tanker Support	0	0	[illegible]	3
IADS	-1	0.5	0.2	2
4th Gen DCA	-0.5	1	0.4	2
Tanker Support	0	0	0	2
Outcome	**-1.0**	**0**	**-0.7**	

No AWACS (O4) Allocated

Change in asset health limited to decreasing in this mission

Sum of Column Products = 0*3 + 1*1 + 0.5*2 + 1.5*0 + 0*3 + -1*2 + -0.5*2 + 0*2

Goal program selects asset-to-mission allocations to best achieve military strategy

DATA GENERATION PROCESS

Determine mission effectiveness for new or modified assets

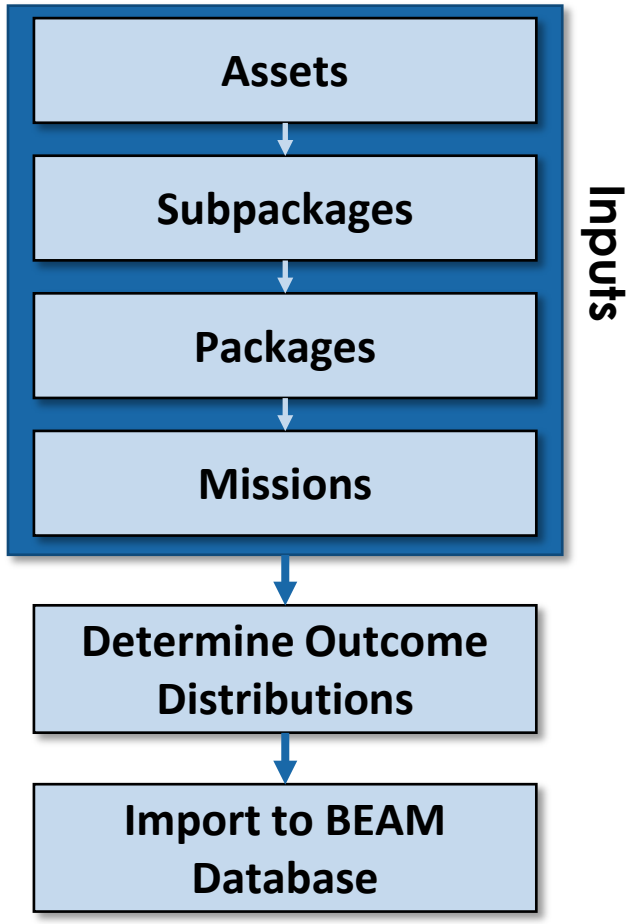
Define mission inputs

- Assets
- Assets combine to build basic subpackages
- Subpackages combine to build mission packages
- Offensive, defensive, & target packages combine to define missions (which are the primary modeling entity in BEAM)

Define asset outcome distributions for every asset in a mission

- Probabilistic losses to offensive, defensive, and targeted assets
- Currently leverage the Joint Wargaming Analysis Model (JWAM) to produce unclassified outcome distributions
  - JWAM is a Center for Army Analysis (CAA) tool that provides rulesets for adjudicating missions across multiple domains
- Can use results from various mission-level models as data source

Import mission effectiveness data into BEAM database



Data generation occurs external to BEAM only for new or updated asset

AGENDA

Overview

Demonstration

Applications and Sample Analyses

Structure and Data

Methodology

Status & Way Ahead

BEAM METHODOLOGY

BEAM employs a new approach to simulation

- One pass through simulated time produces statistical distributions of outcomes
- Each time period initiates a new Design Of Experiment (DOE) for new **simulation threads**
  - Design points sample asset distributions to account for scenario uncertainty
  - Start simulated thread at each design point with known asset quantities
  - Uncertainty assessed across threads with no Monte Carlo pseudorandom draws and **no replications**

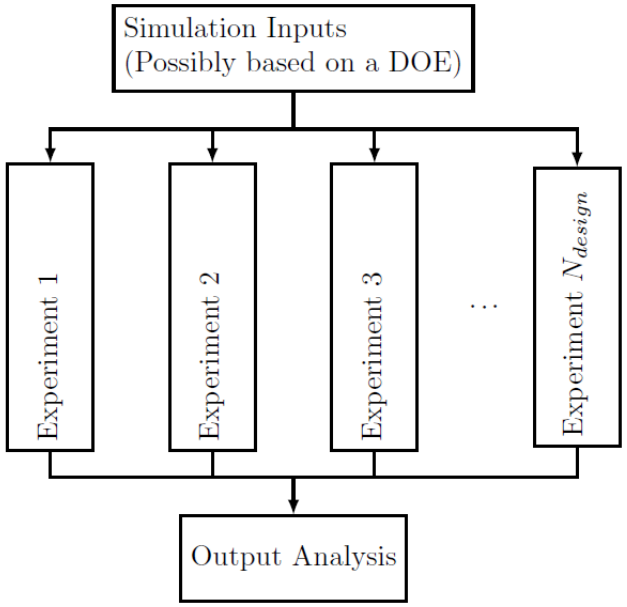
BEAM application of simulation threads

- BEAM maintains statistical distribution of each asset by region for both sides
- Start of each simulated day, BEAM applies DOE with new threads at each design point
  - Blue varies bins from low to high. Similar Red bins. New thread at each Blue bin and Red bin combinations
  - Each thread has known quantities of each assets with an associate thread probability
  - Thread's goal program allocation of assets-to-missions
    - Prioritized achievement through military strategy ends in the objective function
    - Effectiveness accounts for predicted adversary missions
  - Each thread's combat adjudication has probabilistic outcomes (losses to attacking, defending, and targeted assets)
- End of each simulated day, BEAM consolidates distributions across threads (Markov assumption)

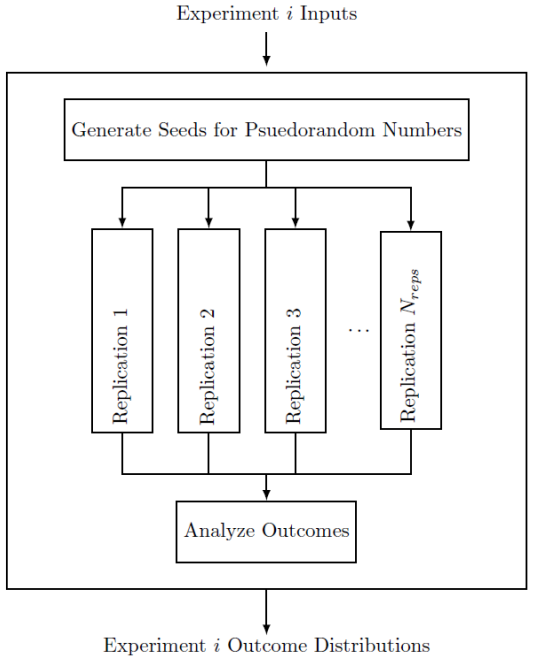
SIMULATION REPLICATIONS VERSUS THREADS

How Experiment Uncertainty Is Evaluated

Both approaches use DOE to test different experiments (inputs)

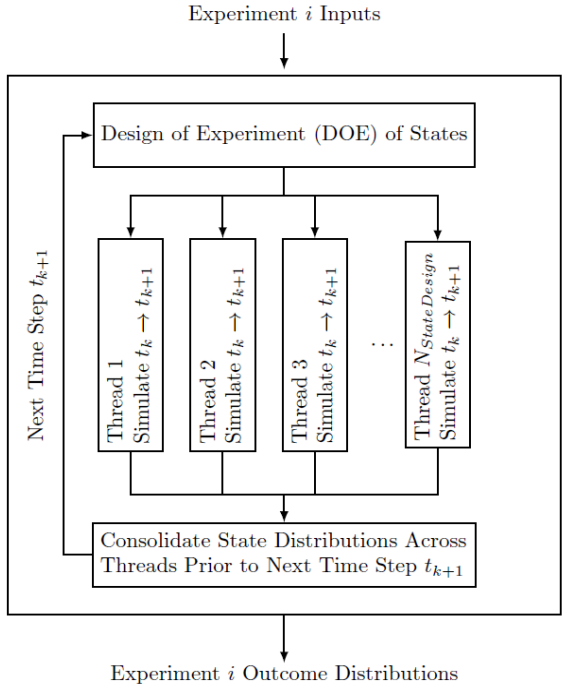


Replications use different pseudorandom seeds to test experiment uncertainty over entire conflict duration



BEAM Approach

Threads use applies a new DOE to span the uncertainty for every single time step



BEAM's simulation threads evaluate uncertainty with one pass through simulated time and no Monte Carlo draws

SIMULATION THREADS DEMONSTRATIONS

CONVERGE TO THEORETICAL VALUES WITH MORE THREADS

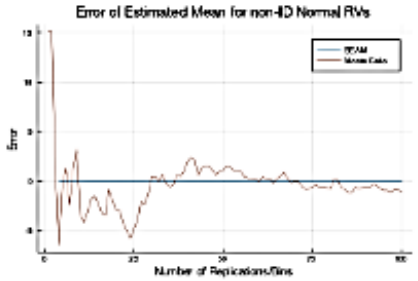


Figure 3: Non-iid Normal Mean Error

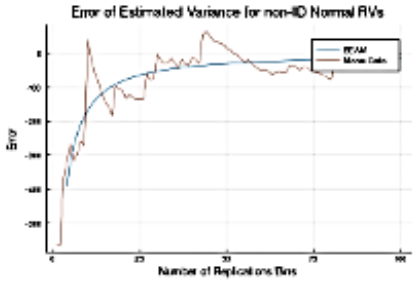


Figure 4: Non-iid Normal Variance Error

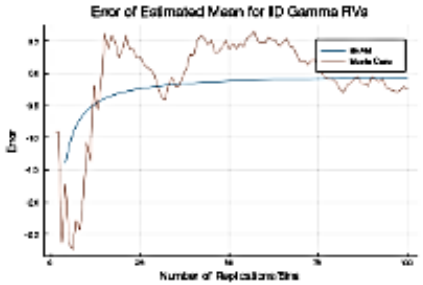


Figure 5: iid Gamma Mean Error

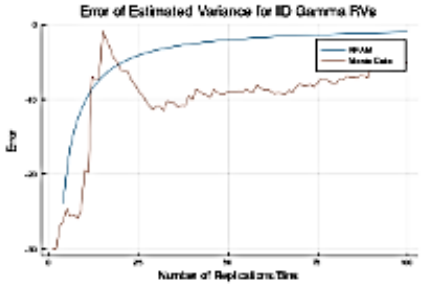
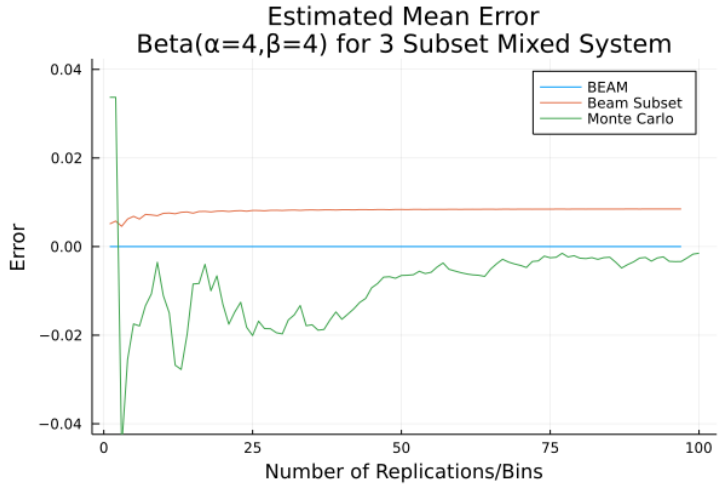
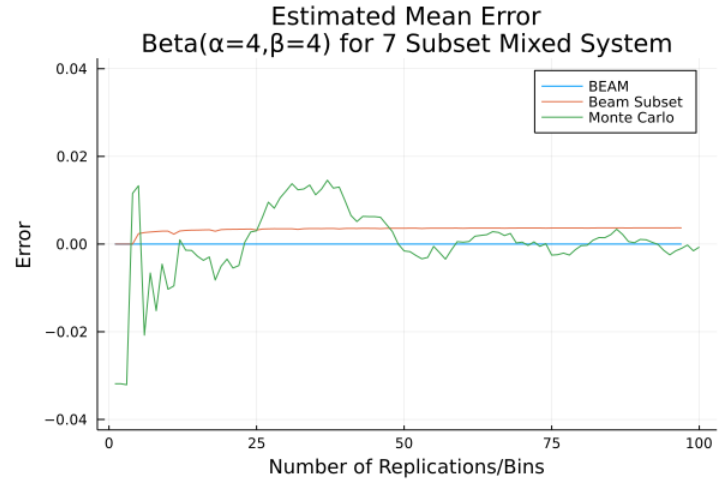


Figure 6: iid Gamma Variance Error





Simulation threads predicts the mean and variance better than Monte Carlo approaches

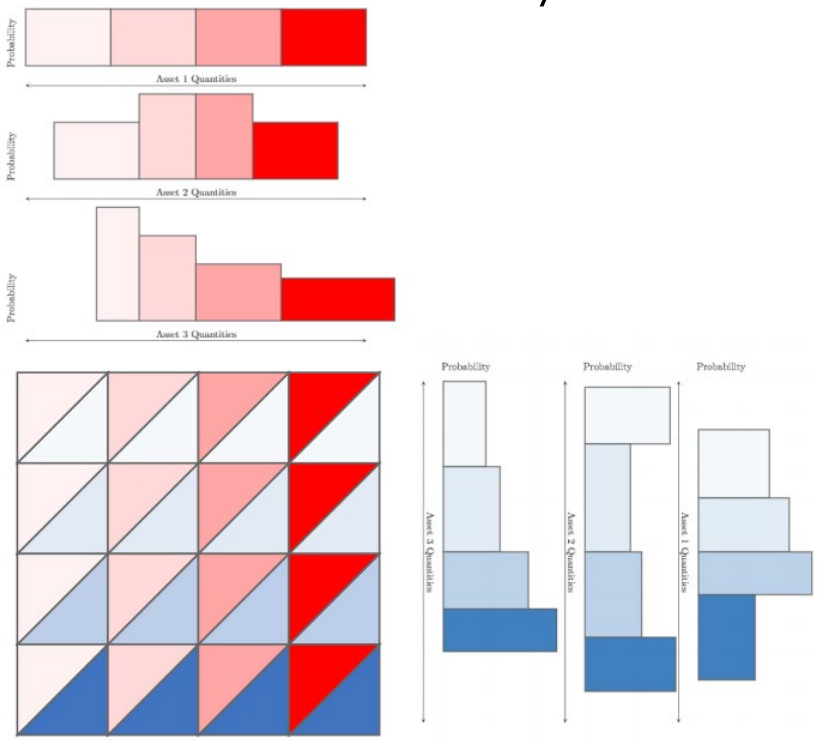
WHY SIMULATION THREADS MAY OUTPERFORM MONTE CARLO TECHNIQUES

- Simulation threads may avoid ineffective sampling in two ways
  - A Normal (Gaussian) random variable will have many samples (replications) near the mean. In contrast, simulation threads computes one thread near the mean weighted with higher probability.
  - Additionally, Monte Carlo outliers can skew results; Simulation threads restrict samples to the centroid of the lowest and highest bins.
- Simulation threads have limited applications
  - Need set recurrences (fixed time intervals) to evaluate states
  - State space must not expand (such as tracking all possible trajectories)

BEAM THREAD CONSTRUCTION

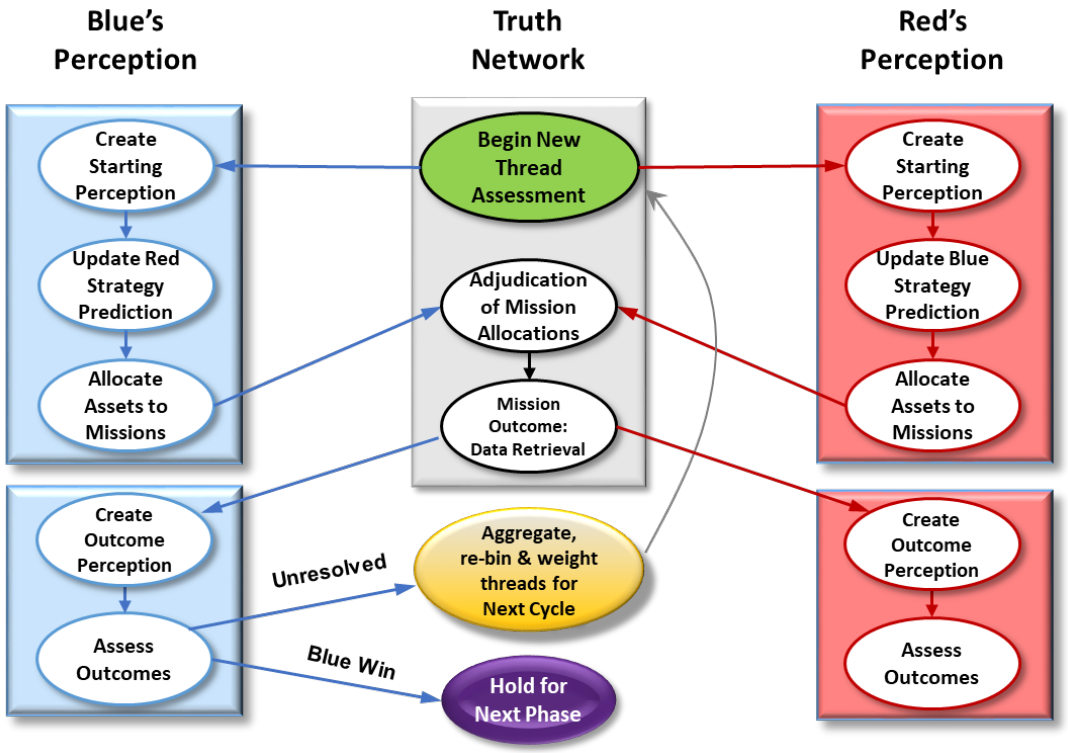
- **Each type of mission changes assets probabilities**
  - All involved offensive, defense, and targeted assets are affected
  - Models a probabilistic range of outcomes, not just a single probability of damage
  - For each asset, region, simulated day, and thread, combine all outcomes involving that asset to new asset distribution
  - Asset distributions combined across threads
  - New cases of different asset levels created
  - New threads started in all combinations of cases each simulated day

- Example of 16 simulation threads from 4 cases (bins) for each side in each simulated day



BEAM uses the cases/bins to create threads representing combinations across assets

THREAD MODEL FLOW / KEY ALGORITHMS



Both Red and Blue select best strategies based on their respective perceptions

Simulation threads sample asset distributions

Perception – generate perception that is influenced by time, Intelligence, Surveillance and Reconnaissance (ISR), troops in contact, etc.

Infer Strategy – create a basic enemy strategy that guides expected enemy asset allocations

Allocation – allocate assets to missions for each time step to best achieve strategy given inferred adversary's missions (fictitious play conducted within one side's perception)

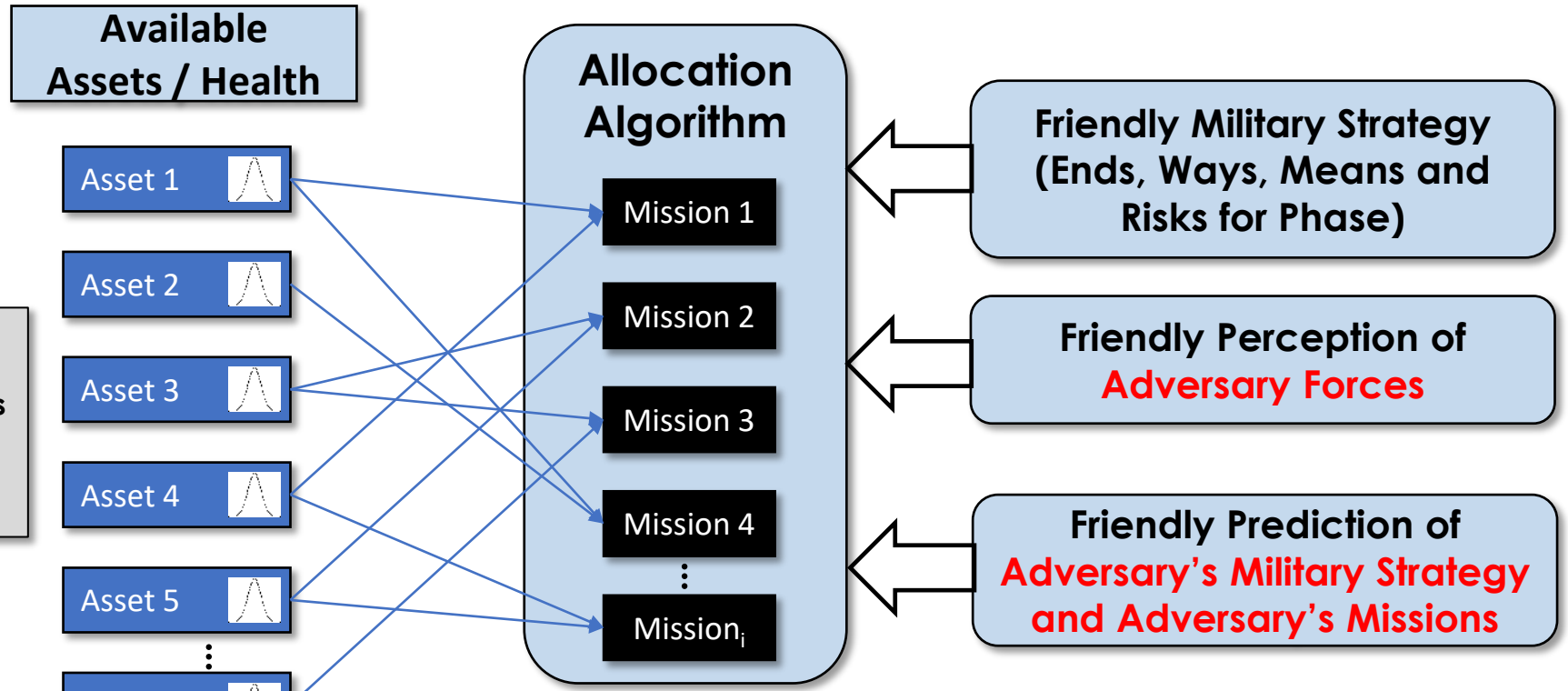
Adjudication – determine combat outcomes with uncertainties based on each side's planned missions

Assessment – determine if phase goals have been met

Asset Aggregation – re-bin asset health based on the outcome state vector and weight of each unresolved thread

Thread Weight and Generation – calculate new thread weights and combine with re-binned assets to generate threads for next time step

ALLOCATING ASSETS TO MISSIONS



1. Available assets, their health/availability, and their contributions to missions through subpackages are known

2. Allocation Algorithm assigns assets to missions based on their contributions to best meet strategy objectives given assets constraints

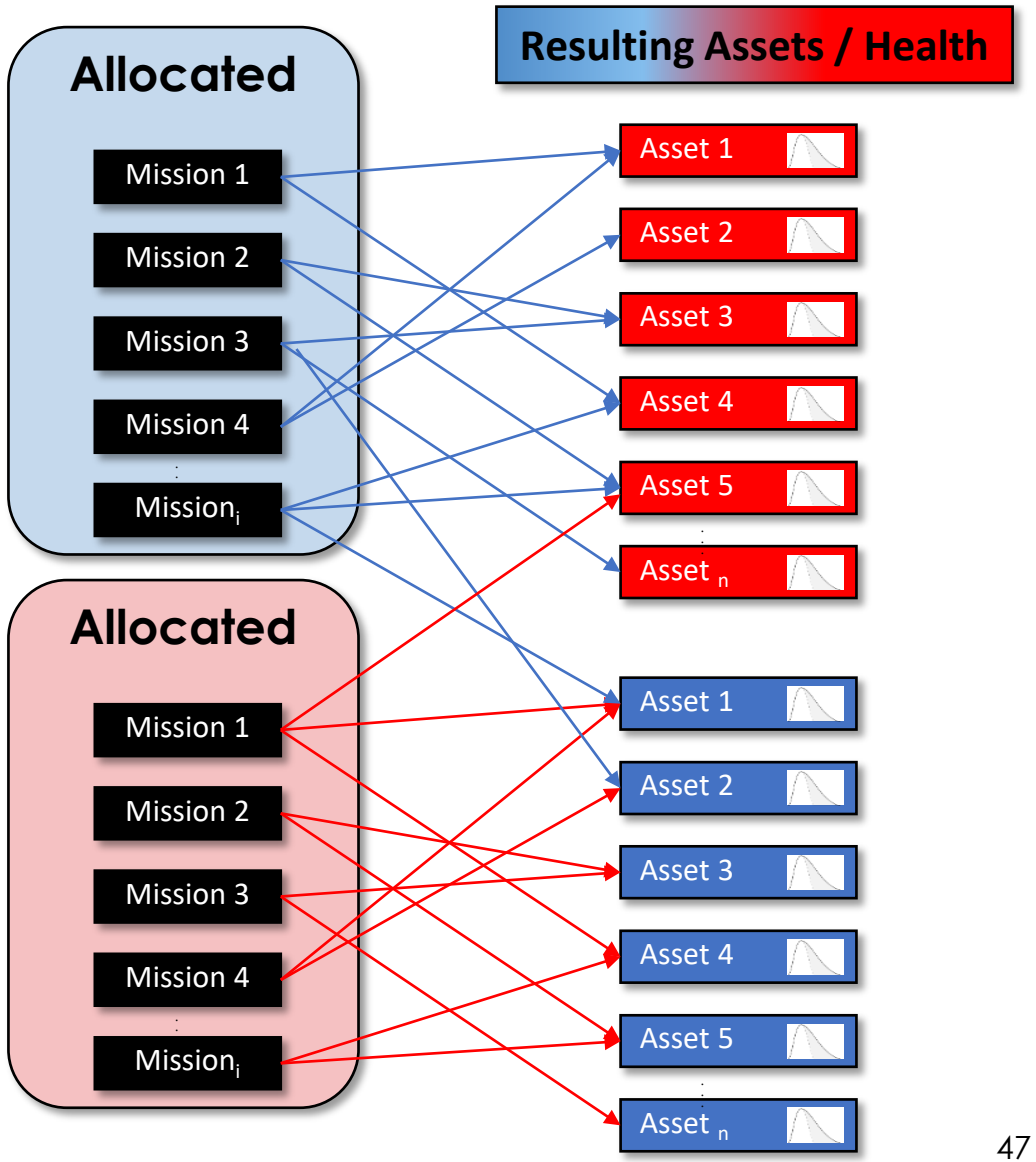
Allocation algorithm links strategies to assets. Fictitious play (within each side's perspective) enables each side to adapt against their adversary

ADJUDICATION MISSIONS TO COMBAT RESULTS

Adjudication algorithm

- Evaluates the allocated missions from both sides
- Assess adversary assets (targets) destroyed
- Includes friendly consumptions and losses
- **Determines outcomes with uncertainties**
  - Probabilities of different loss quantities
- Results in updated statistical distributions of assets by region

Adjudication affects friendly and adversary assets



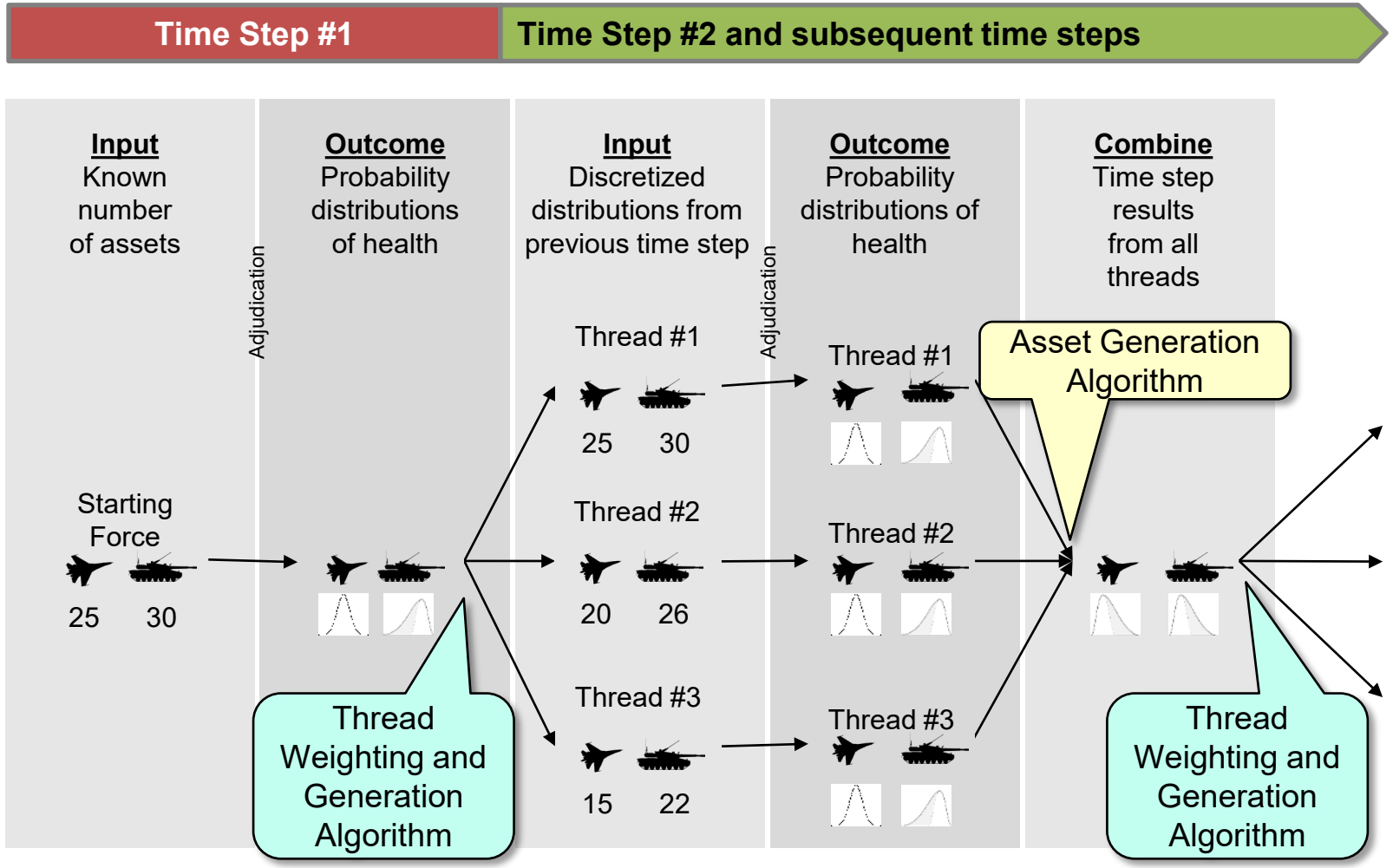
PRESERVING VARIABILITY (SIMULATION THREADS)

Purpose

- Provide variation with only a single model run

Methodology

- Generate variable-width equally-weighted bins to represent distributions
- Combination of Blue and Red bins create multiple "threads" for each time step (day)
- Carry asset health distributions through the simulation
- Aggregate assets distributions from unresolved threads
- Re-bin assets and weight threads for next time step



Simulation threads sample asset-by-region distributions to evaluate uncertainty

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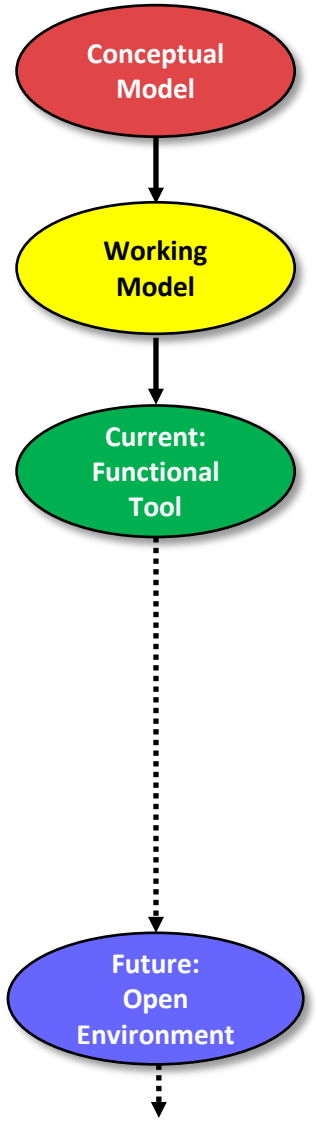
HISTORY & CURRENT STATUS

History

- CY13: Concept exploration began
- CY19: LinQuest started; modified methodology & started coding
- CY20: Working prototype / user interface
- CY21: Algorithm / data enhancements inspired by classified use case
- CY22: Stable functional tool

Status (as of Sep 2023)

- BEAM Version 4.29 (second release) being distributed
  - Includes joint scenario
  - Unclassified & CUI mission performance datasets
  - Classified scenario may be requested separately
  - Beta wargaming capability to stop simulation and change strategy
  - Initial data management module capabilities
- AF/A3T cleared BEAM for network use on 13 June 2023
- BEAM capability demonstrated in a major DoD study
- Military services evaluating force designs with BEAM



WARGAMING BETA CAPABILITY
(OPERATIONAL/THEATER CAMPAIGN)

Provides "user in the loop" inputs at decision points

- Game organizers select decision points for wargame
  - May be in terms of the warfighting phases in the campaign
  - Alternatively, may be a specified number of simulated days
- Wargamers may modify military strategy or add/move forces
  - Choices may modify either the actual or perceived strategies for either or both sides
  - Choices may be prior to Day 0 (such as positioning forces, ISR, jamming)
- Given move inputs, BEAM evaluates outcomes
  - BEAM allocates their assets to missions to best achieve their strategy
  - BEAM adjudicates the combat results between the combatants
  - Gamers may test potential plays and see results in minutes

Modification allows for campaign wargamers to use BEAM to test or make strategy and/or force plays

Current beta capability as it has not employed yet!

BEAM may provide an analytic engine for theater campaign wargames

DEVELOPMENT PLAN

Foundational Tasks

- Project Management – manage and integrate efforts, communicate with government
- Sustainment of software and support to current users – fix issues, make minor improvements, and responsive support to our growing number of users
- Funded studies help spread these costs and results in more effort going towards other tasks

Planned 2024 Enhancements

- Second theater scenario – build and test another scenario
- Logistics/Repair – algorithm change, SME time, data collection, and testing
- Classified Effectiveness Data – explore data sources and connections to other models;

Initiated 2024 BEAM Studies (as Sep 2023)

- One military service is conducting force design study
- The same service is analyzing far-term futures
- Another service is developing wargame scenario with BEAM

Funding Supporters (AFRL SDPE, SPOC/S9A, AF A5/7)

Support users while building towards an open environment capability

PLANNED FUTURE DEVELOPMENT

Additional desired enhancements

- Cyber missions – need source for effects
- Search for Best Strategy (given forces) or Best Forces (given strategy)
- Training Course – develop and publish guidebooks and videos for new and current users
- Improve User Interface / algorithm enhancements
- Production Software – revise prototype code to standards, fully test software, and achieve open architecture
- Thread Study – evaluate and document BEAM's representation of uncertainty

BEAM Wargame Support and Play

- Per wargame support: scenario development, support of play and analysis
- Desired improvements: automate data loads, automate strategy calibration, build wargame visualization

Continually improving analytic tool

CONCLUSIONS

Capability for quickly assessing enterprise-level questions

- Ability to evaluate military strategies and force mixes against an adaptive adversary
- Accounts for joint capabilities with cross-domain missions (establishes a common mission format)
- BEAM's capability has been proven in DoD studies

Available at no cost (DoD goal is a community tool)

- AF certified for network use
- Approved release to US, Five Eyes, NATO, FFRDCs, and DoD Contractors
- Expanding users and wide evaluations by analytic centers (across DoD, Foreign Partners, FFRDCs, and Contractors)
- Included in NATO Next Gen M&S Architecture
- Wargamers consider use of BEAM

Enhancements require continued investments by DoD

- Planned for CY24 additional scenario, logistics, and classified performance data
- Continue to enhance capabilities (cyber, search, training, etc.)
- Mature from prototype to production software to achieve open architecture

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(email to request BEAM for free!)
BEAM Program Manager

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ENTERPRISE VERSUS CAMPAIGN MODELS

- Model resolution drives the appropriateness to address issues
- Campaign models (STORM and JIMC) are higher resolution (more detailed) and hence are intended for different questions
  - Model **system performance** in engagements in theater scenarios and estimates the scenario outcomes
    - For example, STORM models the probability of aircraft detection as it flies it along its simulated route
  - The military strategy (campaign phase objectives) is embedded throughout the input files
  - Campaign simulations are used to search the force mix trade-space
  - STORM and JIMC enables insights into what constitutes a **good force structure** for a given scenario (including embedded strategies for both sides)
- BEAM as an enterprise model is more aggregate (less detail)
  - System performance is an input in terms of mission outcomes
    - BEAM inputs include the probability that aircraft will be loss on each type of mission
    - BEAM inputs combine various assessments, such as results that assumed space assets are available and other inputs on satellite availability
  - BEAM users specify the **military strategies** (ends, ways, means, and risks) by combat phase for both sides along with their perceptions of their adversary's strategy
  - Within BEAM both sides **adapt** to best achieve their strategy given their adversary's strategy and forces
  - BEAM enables searching the strategy and force mix trade-space
    - Searches include ends and their thresholds, mission performance, survivability, arrival of forces and bed-down of forces
    - For example, what if an allied nation participates or not in the scenario
  - BEAM assess the scenario outcomes including achieving the phase objectives
  - BEAM provides insights into both sides' military strategies and the **demand for forces** by type in a theater scenario
- BEAM can provide more rigorous assessments or preparation for theater war games
- **BEAM can investigate military theater campaign strategy, which are not addressed by any other model**