Ground Systems Survivability Robustness Analysis through Model- Based Systems Engineering (MBSE)

Final Capstone Presentation

4 June 2013

Presented by:

David Basala
Bill Berklich
Christine Brennan
Steve Mazza
Joe Rambousek
Donna Ray
Dan Torres

SE311-114G Vehicle Survivability

AGENDA

- Introduction
- MBSE methodology
- Systems architecture
- Model Development
- Model Execution
- Baseline Results
- OMOE and CAIV Results
- Conclusions

BACKGROUND

Combat vehicles have historically balanced the iron triangle of survivability, lethality, and mobility in design to meet the requirements of affordable force effectiveness. To date, increasing protection has meant adding armor (or other technologies such as soft and hard-kill active protection and signature management) adding weight which decreased mobility and adding significant cost. The idea that increasing lethality or mobility would also increase survivability has been supported with professional military judgment, but no analytic metrics have been developed that can trade the weight of armor protection for increased mobility or increased lethality.

PRIMITIVE NEED

The U.S. Army Maneuver Center of Excellence (MCoE) has interest in analytically understanding the interplays and interactions with respect to the integrated survivability of a combat unit. More specifically they need to understand how the addition or subtraction of specific capabilities impact the overall unit survivability and mission success.

PROBLEM STATEMENT

This Team will design and analyze a company-level ground combat mounted maneuver unit in a combined arms scenario, with the intent of providing clear, quantitative understanding of the design trade-space. The trade-space consists of the combat vehicle and its infantry squad and relates to other mission capabilities such as mobility, lethality, networked communications, and others as they apply to survivability outcomes. The design solutions will include the breadth of DOTMLPF considerations.

RESEARCH QUESTIONS

- Can a relationship be demonstrated between survivability of a small, task organized combined arms unit and improvements in lethality, mobility, and situational awareness through quantitative simulation analysis?
- Can the trade-space among key input variables (lethality, mobility, etc.) be quantified and understood?
- What are appropriate analytic metrics that can indicate the potential impact on combat infantry vehicle survivability due to increased mobility or increased lethality?

PROBLEM SPACE BOUNDARIES

- focused on defining a process to assess combat vehicle survivability within the context of the combined arms unit.
- did not address force protection and assumed in the context of the model that if a vehicle did not survive its crew also did not survive.
- basis for the model development in this paper was, *Alternative approach for the development of future Ground Combat System specification* (Tobias Treml 2013) and Treml's concurrent supporting model
- model and model analysis is unclassified and contained no classified or For Official Use Only (FOUO) data

MBSE PROCESS DEVELOPMENT

- Analyze the combat unit Survivability through requirements, architecture and simulation modeling to identify factors and trade-space performance that affect the SoS measures of survivability effectiveness
  - Functional performance requirements and MOEs
  - SoS functional performance factors that affect MOE
  - SoS Systems Architecture identifying interrelationships of functional and physical systems
  - Define the range of the performance factors that will be tested
  - Operational Model execution to evaluate configuration performance

- Utilized a set of integrated tools, not through physical integration but integration of the data through the MBSE process.
  - Excel
  - MANA
  - JMP
  - CORE
  - Reduces rework, moves from document based to model based, allows the ability to see change impacts to the elements within the system and enables repeatability

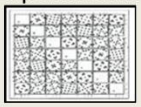
"Model-based systems engineering (MBSE) is the *formalized application of modeling to support system requirements, design,* analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."

Army Survivability Project Using MBSE

Real Environment

Operational Simulation Model

Design of Experiments



Operational Surrogate Model of Simulation

$$y(\mathbf{x}) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=k+1}^{2k} \beta_i x_i^2 + \sum_{i=1}^{k-1} \sum_{j>i} \beta_{i,j} x_i x_j + \varepsilon$$

Simulation Inputs (x)
Enemy Behavior
Weather
Friendly Behavior
…

Environmental / Operational Factors

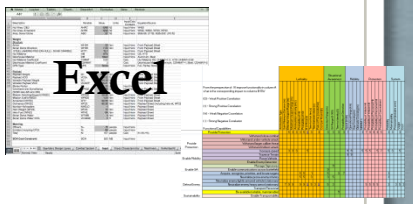
Design Parameters

Simulation Inputs (x)	Synthesis Inputs (x)
Mobility (vehicle speed)	C^2 System
Lethality (weapon range, weapon type, P(K))	Sensor Type
Lethality (weapon type)	# of Guns
SA (detection range, P(detect)	Gun Type
Tactics…	…

*Map simulation inputs to synthesis inputs using heuristics, regression analysis or directly.

Design-To Specifications

Synthesis Model



Physical Surrogate Model of Synthesis

$$y(\mathbf{x}) = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=k+1}^{2k} \beta_i x_i^2 + \sum_{i=1}^{k-1} \sum_{j>i} \beta_{i,j} x_i x_j + \varepsilon$$

Synthesis Outputs (DOTMLPF)

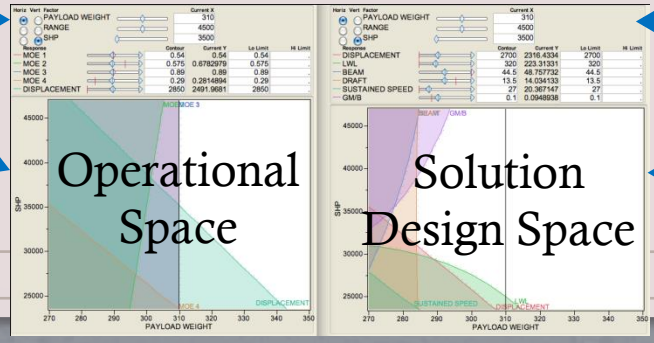
MOEs

Simulation Outputs y(x)
Survivability
Force Exchange Ratio
Mission Success

Operational Constraints

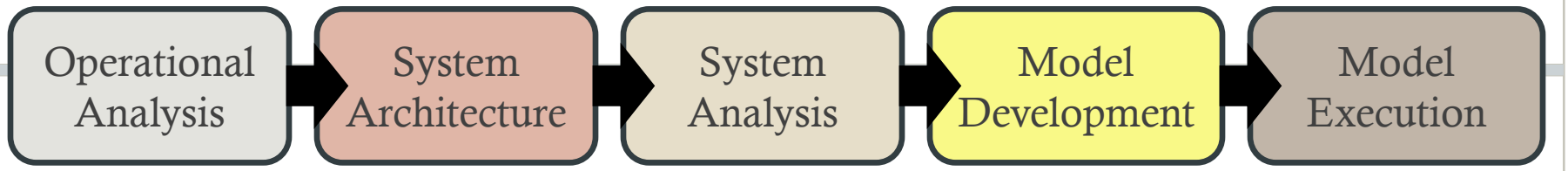
Trade Space

Physical Constraints



Synthesis Outputs y(x)
Doctrine changes
Organization changes
Materiel (Bradley, Abrams, etc)
Personnel, Training
Deployability
Cost

PROCESS



Operational Analysis	System Architecture	System Analysis	Model Development	Model Execution
•Define unit operations •Develop Use Cases •Develop MOEs	•Define functionality •Determine flows •Identify MOPs	•Gather data Specify analysis Identify data requirements	•Architecture defines SoS •Build simulation	•Execution Use Case •Evaluate data
•Outputs: Scenarios for analysis, Unit for Analysis	•Outputs: Operational Architectures, Use Cases, MOEs	•Outputs: Architectures	•Outputs: Model with data requirements and System Metrics	•Outputs: Baseline Results, Alternative Configuration Results

* Tailored version of the DoD SE "V" and the current process being implemented within the PEO CS&CSS Product Manager Contingency Basing Infrastructure

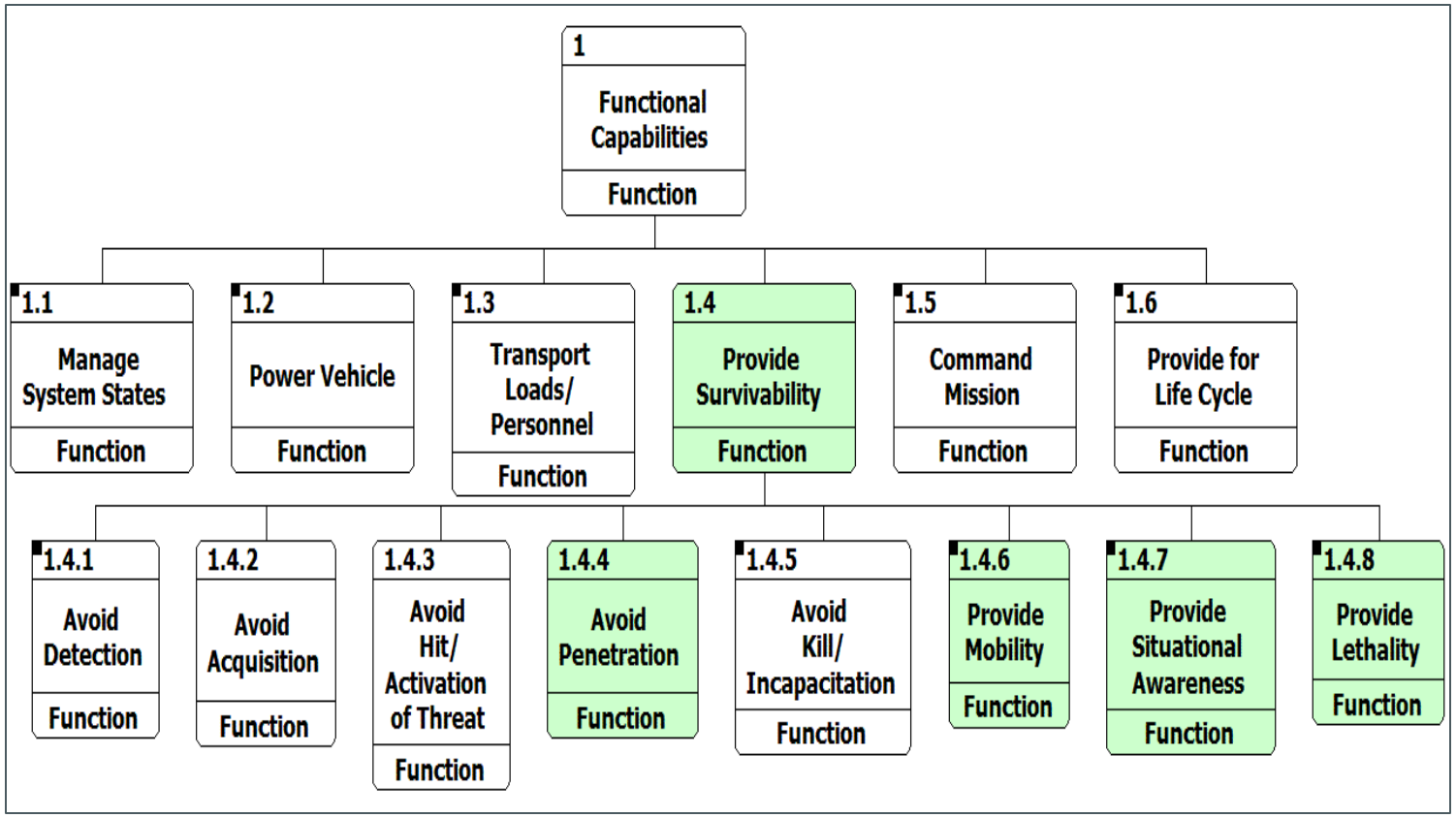
STAKEHOLDERS

Project Role	Name	Expectation
SPONSOR		
RDECOM Sponsor	Mr. Dale Ormond, Director RDECOM	Applicable product, demonstration of systems engineering and model based systems engineering techniques to address difficult problems
RDECOM Representative	Ryan McCullough, HQ RDECOM	Applicable product
USERS		
MCoE Representative	Thadusz (Ted) Macuiba, Deputy Director, MCoE	Applicable product to provide analytical underpinnings to capability decisions for survivability trade-space alternatives
PEO CS&CSS Representative	Roberta Desmond, APEO SEI	Applicable product to provide insight to current systems and potential implications of capability improvements
PEO GCS Representative	Anthony Desmond, APEO SEI	Applicable product to provide insight to current systems and potential implications of capability improvements

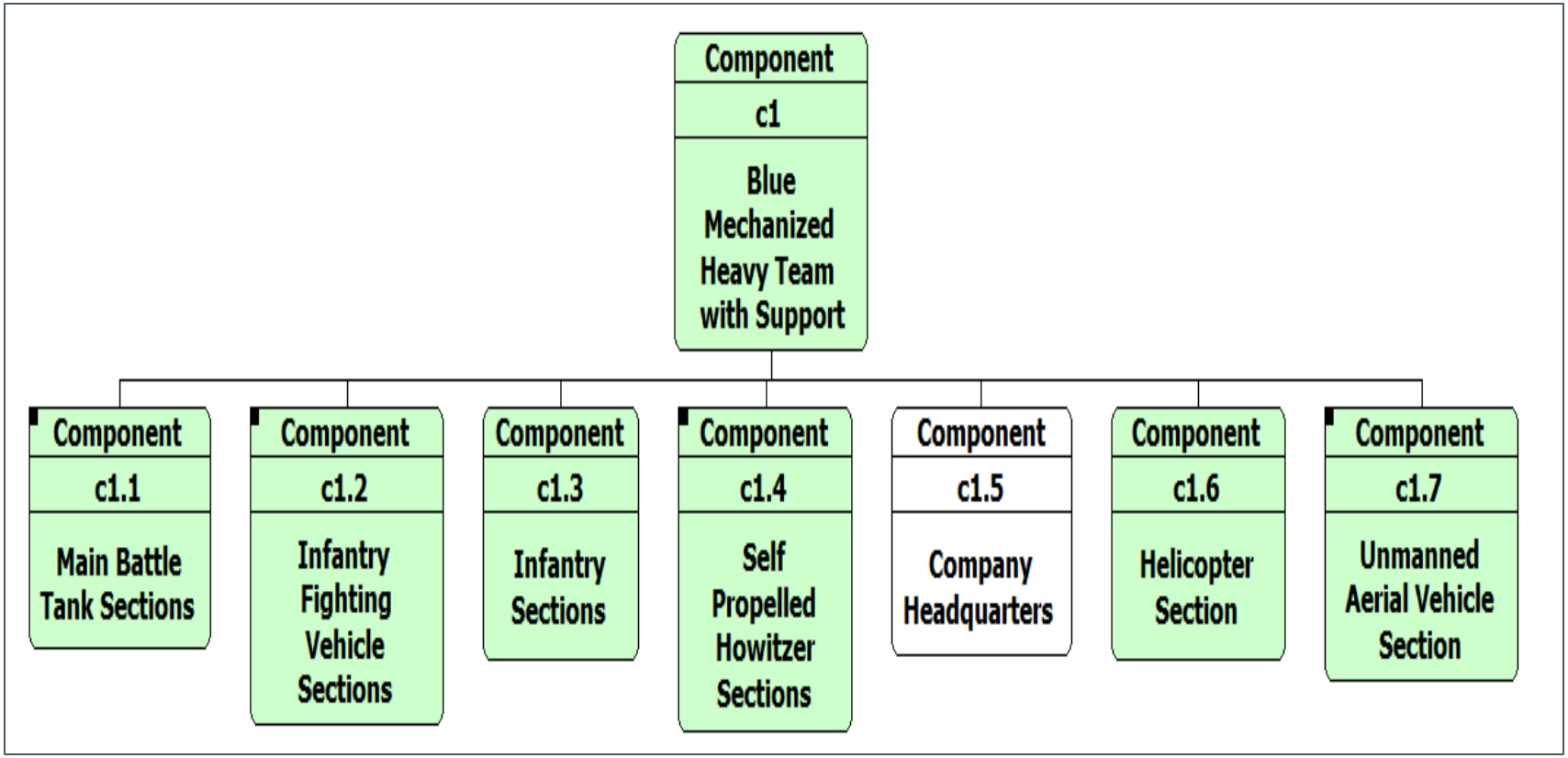
SYSTEM ARCHITECTURE

DAN TORRES

FUNCTIONAL DECOMPOSITION



PHYSICAL DECOMPOSITION



SYSTEMS ANALYSIS

- Model Development - Joe
- Execution - David

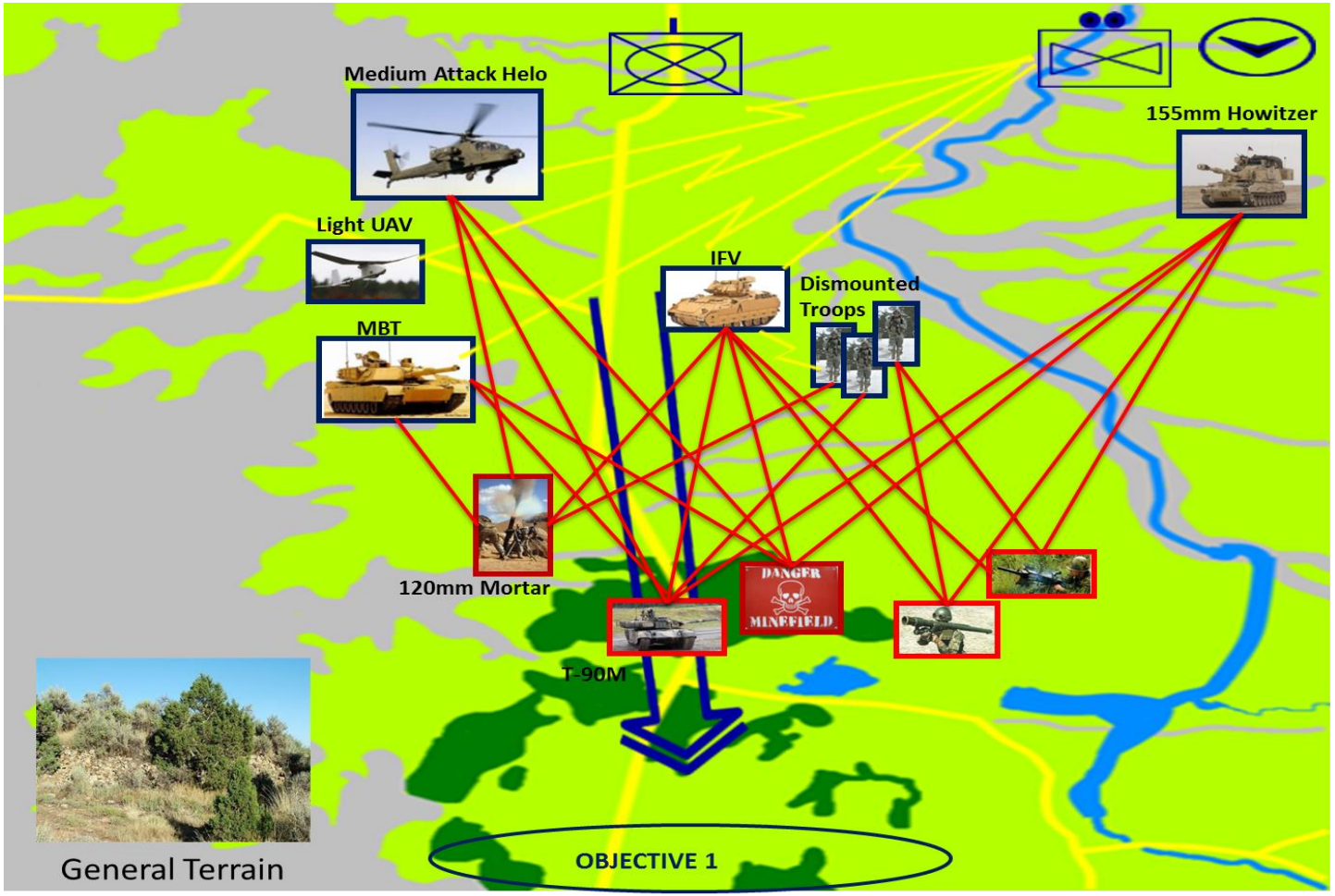
Baseline Mission Scenario

BLUE Force is a balanced company team (1 mech platoon, 1 tank platoon) of a Combined Arms Battalion which attacks along a major highway 30 kilometers south to take Objective 1 as prerequisite for the future attack of the Battalion against Objective HAWK.

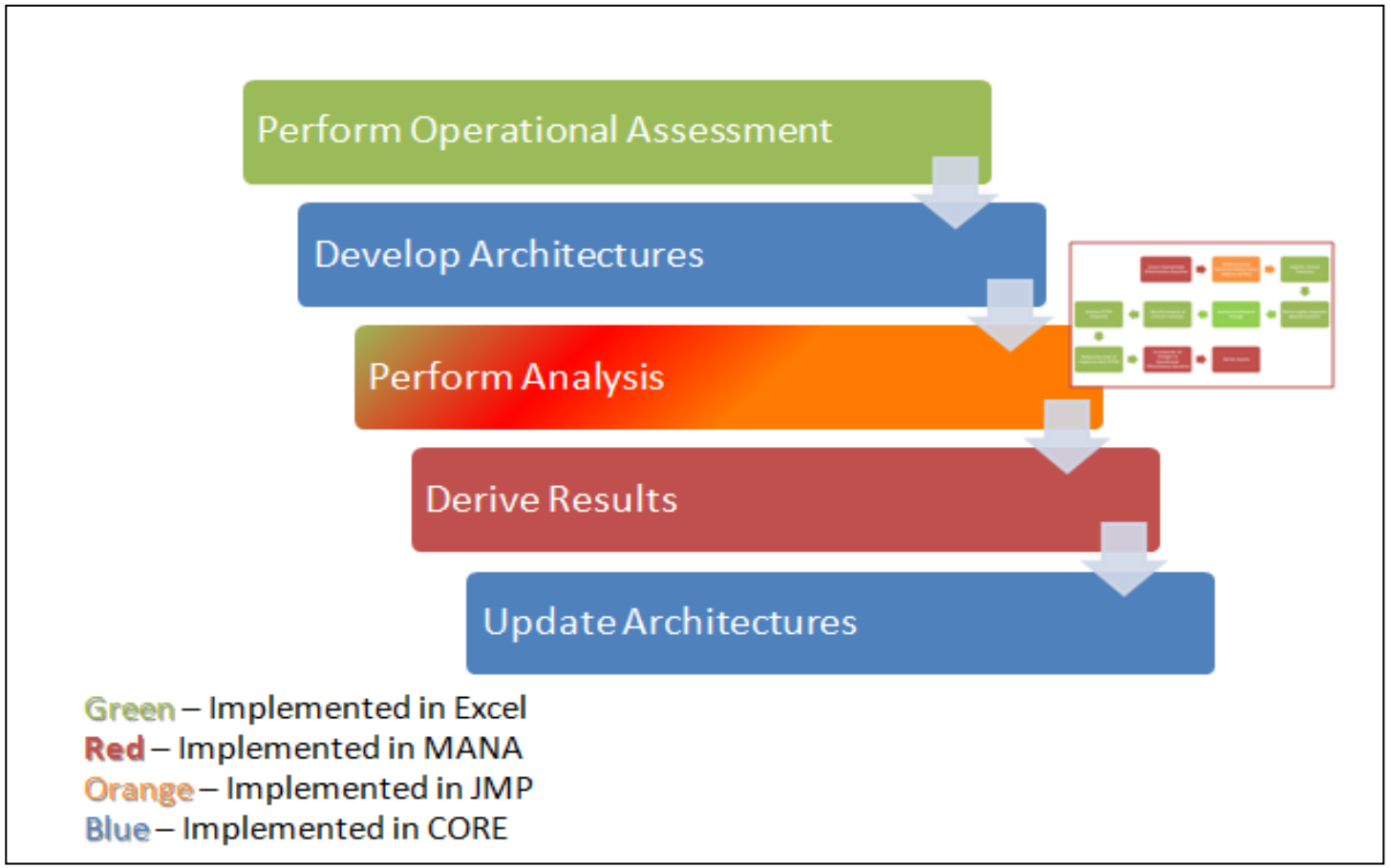
The company is the major effort with priority indirect fire support and is the main focus of the Battalion UAV reconnaissance effort. Apache attack helicopters will provide close air support and additional reconnaissance capabilities.

The Battalion Commander's intent for the company team is to maintain as much offensive momentum as possible to keep the enemy off balance but also to destroy detected enemy in the area of operations. After reaching Objective 1 the company team will secure the objective until follow-on forces attack over own positions to Objective HAWK.

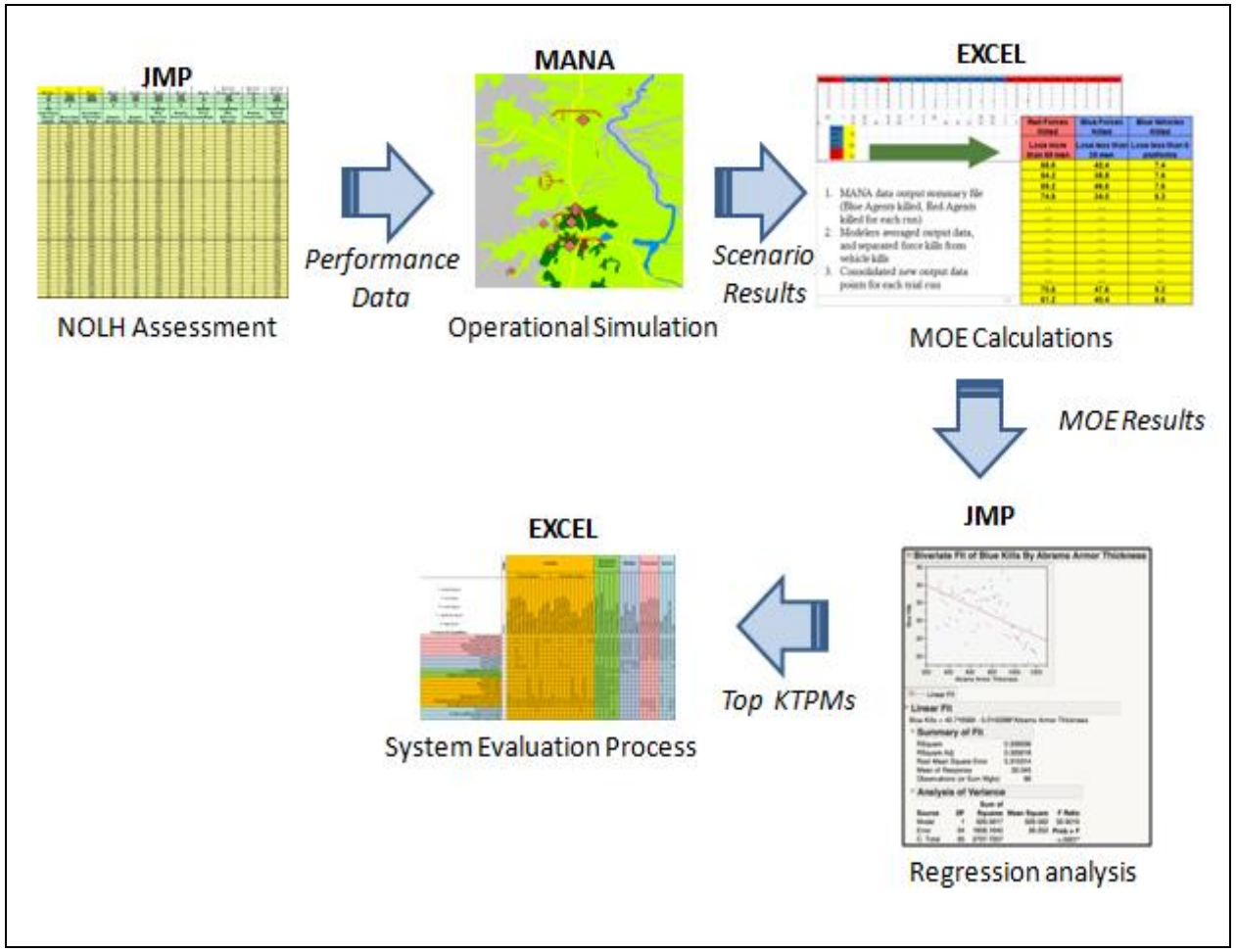
OV-1


Medium Attack Helo
155mm Howitzer
Light UAV
IFV
Dismounted Troops
MBT
120mm Mortar
DANGER MINEFIELD
T-90M
General Terrain
OBJECTIVE 1

MODEL DEVELOPMENT



MODEL DEVELOPMENT (cont.)



MODEL EXECUTION

Squad Element (Troop Strength)	Helo	IFV	MBT	155mm Howitzer	UAV	Blue forces	Tank	Mortars (120mm)	Mortars (60mm)	Missiles	Grenade Launcher	Red Forces
Minefield												
IED												
Helo (2)	2					4						
IFV (3)		1				3						
Infantry (7)						7						
Infantry (16)												16
MBT (4)			4			16						
HQ												
155mm Howitzer				1		4						
UAV					1							
Infantry (7)						7						
Infantry (7)						7						
Infantry (7)						7						
IFV (3)		1				3						
IFV (3)		1				3						
IFV (3)		1				3						
Infantry (16)												16
Infantry (16)												16
60mm (1)									3			3
120mm (5)								1				5
Milan (1)										2		2
SA-18 (1)										2		2
T-90M (4)							4					16
HQ												
AGS (1)											4	4
Milan (1)								4				4
SUM	2	4	4	1	1	64	4	5	3		4	84

DESIGN FACTORS

Design Factor	Baseline	Minimum	Maximum
Top Sustained Speed of IFV (mph)	35	35	80
Primary Detection Range of UAV (m)	10000	1000	15000
Secondary Detection Range of UAV (m)	6000	4000	10000
MBT Armor Thickness (mm)	1000	300	1200
IFV Armor Thickness (mm)	500	200	800
MBT Primary Weapon Max Effective Range (m)	4000	1000	8000
MBT Primary Weapon Armor Penetration (mm)	1000	500	1200
MBT Primary Weapon Rate of Fire (rounds/min)	10	6	18
IFV & MBT Secondary Weapon Max Effective Range (m)	1200	200	1500
IFV & MBT Secondary Weapon Armor Penetration (mm)	10	5	12
IFV & MBT Secondary Weapon Rate of Fire (rounds/min)	1000	500	4000

TRACEABILITY

Stakeholder Values	Functional Capabilities	Design Factor
Maximize Mobility	Increase Speed Traverse Terrain	**Top Sustained Speed of IFV**
Maximize Protection Maximize Lethality	Enable Detection of Enemy Acquire Targets Recognize Targets Prioritize Targets Locate Targets	**Primary/Secondary Detection Range of UAV**
Maximize Protection	Withstand Close Combat Attack Withstand Indirect Attack Withstand Large Caliber Threat Withstand Under-vehicle Attack	**MBT/IFV Armor Thickness**
Maximize Lethality	Neutralize Prone Enemy Infantry Neutralize Enemy - Light Armor Neutralize Enemy - Heavy Armor	**MBT/IFV Primary/Secondary Weapon Max Effective Range**
Maximize Lethality	Neutralize Prone Enemy Infantry Neutralize Enemy - Light Armor Neutralize Enemy - Heavy Armor	**MBT/IFV Primary/Secondary Weapon Armor Penetration**
Maximize Lethality Maximize Protection	Neutralize Prone Enemy Infantry Neutralize Enemy - Light Armor Neutralize Enemy - Heavy Armor	**MBT/IFV Primary/Secondary Weapon Rate of Fire**

BASELINE SIMULATION

	IFV	UAV	UAV	Tank	IFV	Tank	Tank	Tank	All (7.62mm) - IFV & Tank	All (7.62mm) - IFV & Tank	All (7.62mm) - IFV & Tank
MINIMUM	**35**	**1000**	**4000**	**300**	**200**	**1000**	**500**	**6**	**200**	**5**	**500**
MAXIMUM	**80**	**15000**	**10000**	**1200**	**800**	**8000**	**1200**	**18**	**1500**	**12**	**4000**
BASELINE	**35**	**10000**	**6000**	**1000**	**500**	**4000**	**1000**	**10**	**1200**	**10**	**1000**
Configuration	**Top Sustained Speed (mph)**	**Detection Range (m)**	**Secondary Detection Range**	**Armor Thickness**	**Armor Thickness**	**Primary Max Effective Weapon Range (m)**	**Armor Penetration**	**Rounds Fired (round/min)**	**Secondary Max Effective Weapon Range (m)**	**Armor Penetration**	**Secondary Rounds Fired (round/min)**
1	70	8538	9631	826	791	2615	748	14	400	10	1038
2	41	7677	8431	978	615	2292	575	17	1340	8	3838
3	63	6815	5846	1006	200	7785	1049	9	900	11	1792
4	65	7031	8154	1034	726	7462	1114	11	820	8	769
5	39	13492	8338	688	320	7569	737	9	1360	9	1469
…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…
62	66	8969	9908	785	338	1000	532	12	1140	6	2331
63	57	13708	6215	355	274	5092	683	16	280	7	1254
64	36	10477	6585	1048	800	4554	672	8	1180	6	3085
65	43	2723	4646	757	283	6492	543	14	460	9	1954
66	38	1431	6400	674	689	5954	974	15	1460	8	1577

NON-MATERIEL CONFIGURATIONS

MINIMUM	2	2	1	1	1	2
MAXIMUM	6	6	4	4	4	6
BASELINE	3	3	1	1	2	4
Factor Name	Infantry Fighting Vehicle	Infantry Squads	Unmanned Aerial Vehicles	155mm Howitzers	Helicopters	Tanks
Run #						
1	3	3	4	3	2	5
2	5	5	4	3	4	4
3	6	6	2	3	3	6
4	3	3	2	3	1	2
5	5	5	4	3	2	3
6	3	3	2	4	3	5
7	4	4	1	4	1	5
8	4	4	2	1	3	6
9	4	4	4	1	3	3
10	2	2	3	2	4	3
11	4	4	1	2	3	3
12	3	3	3	3	4	5
13	3	3	1	2	2	4
14	5	5	2	4	4	3
15	5	5	3	4	2	4
16	6	6	1	2	1	4
17	5	5	3	2	2	6
18	2	2	3	1	1	5
19	6	6	2	2	3	2
20	4	4	3	1	2	4
21	2	2	3	3	3	2

MATERIEL CONFIGURATIONS

		Factors				
1 – minimal impact 3 – low impact 5 – some impact 7 – significant impact 9 – high impact	**Functional Capabilities**	**Priority**	Effective Weapon Range (m)	Probability of Kill (Armor Penetration)	Primary Detection Range (m)	Probability of Vehicle Kill (Armor Thickness)
Provide Protection	Manage Signatures	**8**				3
	Withstand close combat	**2**	3		3	9
	Withstand under-vehicle attack	**3**			3	9
	Withstand larger caliber threat	**2**	3		3	9
	Withstand indirect attack	**2**	3		3	9
Enable Mobility	Increase speed	**6**	1			5
	Traverse Terrain	**9**	1			
	Power Vehicle	**5**	5		3	
Enable SA	Enable Detection of Enemy	**4**			9	
	Enable communications across battiefield	**4**			9	
Defeat Enemy	Acquire targets	**7**			5	
	Recognize targets	**7**			5	
	Prioritize targets	**7**			5	
	Locate targets	**7**			5	
	Neutralize prone enemy infantry	**5**		5	3	
	Neutralize enemy lightly armored vehicle (stationary)	**1**	9	9	5	5
	Neutralize enemy heavy armor (stationary)	**1**	9	9	5	5
Enable Sustainability	Transport Personnel	**10**				
	Enable available (reliable, maintainable)	**10**				
	Enable Transportability	**10**				

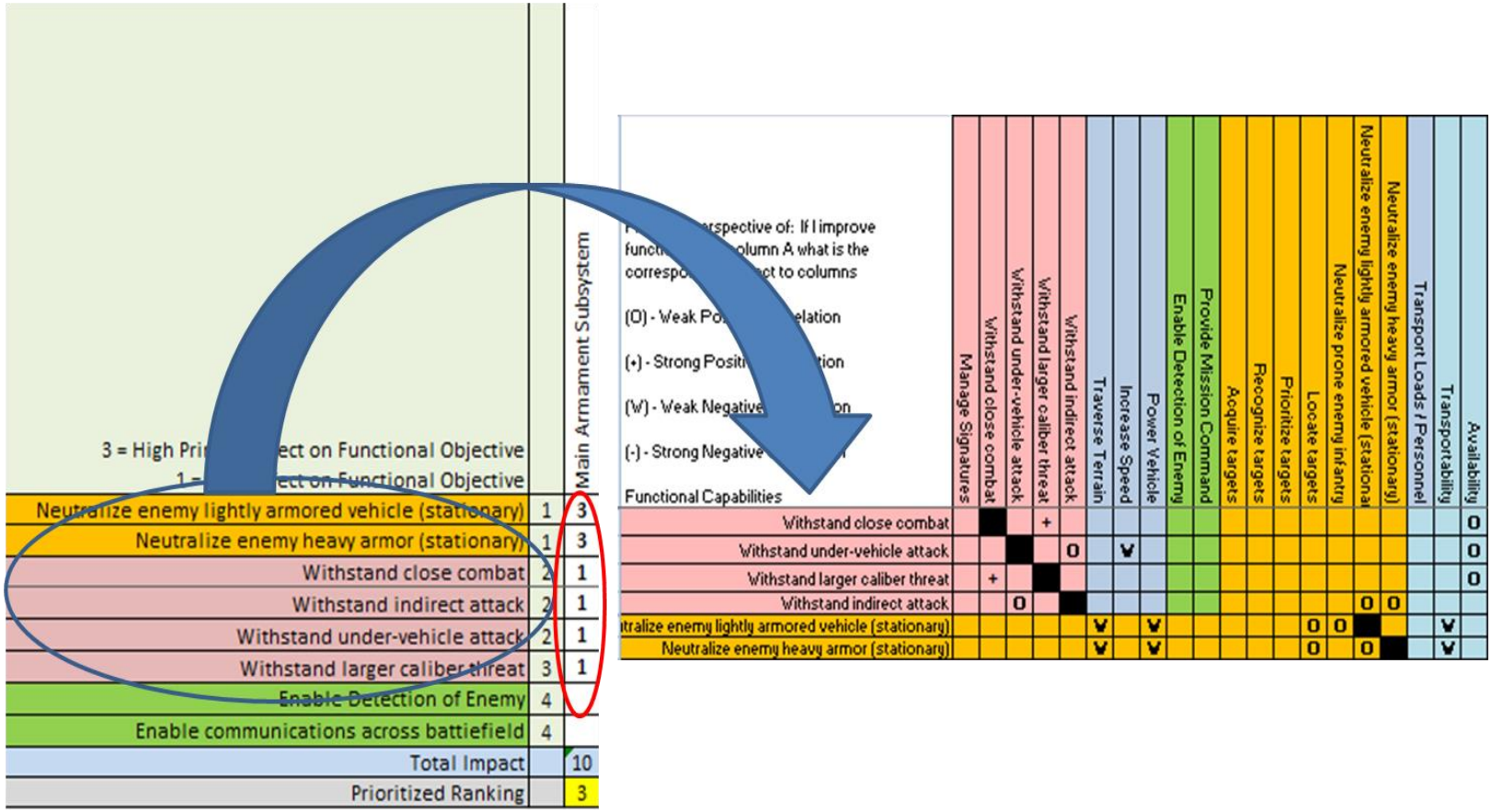
MATERIEL CONFIGURATIONS (cont…)

3 = High Primary effect on Functional Objective 1 = Low effect on Functional Objective.		Armor (Protection Suite)	Hull/Frame/Body/Cab (Recommend Out of Scope)	Defensive Aid Suite	Signature Management	Interior Force Protection (Recommend Out of Scope)	IED Countermeasures	Survivability System Control	Running Gear	Power Package/Drivetrain	Auxiliary Power	Environmental Control System	Navigation	Auxiliary Automotive Electronics	Communications	Mission Command Software	Main Armament Subsystem	Secondary Armament	Commander's Independent Weapons Station	Missile System	Non-Lethal Weapon System	Ammunition Handling System	Fire Control	Turret Assembly	Stowage	Crew Accommodations
Neutralize enemy lightly armored vehicle (stationary)	1	1															3	1	3	3		1	3	1		
Neutralize enemy heavy armor (stationary)	1	1															3			3		1	3	1		
Withstand close combat	2	3	3			3	3										1			1				1		
Withstand indirect attack	2	3	3	3		3											1			1				1		
Withstand under-vehicle attack	2	3	3			3	3		1								1			1				1		
Withstand larger caliber threat	3	3	3	3		3											1			1				1		
Enable Detection of Enemy	4			3							3				1	3			1							
Enable communications across battiefield	4			3				3					3		3	3		3	3		3					
Total Impact		14	12	12	0	12	6	3	1	0	3	0	3	0	4	6	10	4	7	10	3	2	6	6	0	0
Priortized Ranking		1	2	2	10	2	5	7	9	10	7	10	7	10	6	5	3	6	7	3	7	8	5	5	10	10

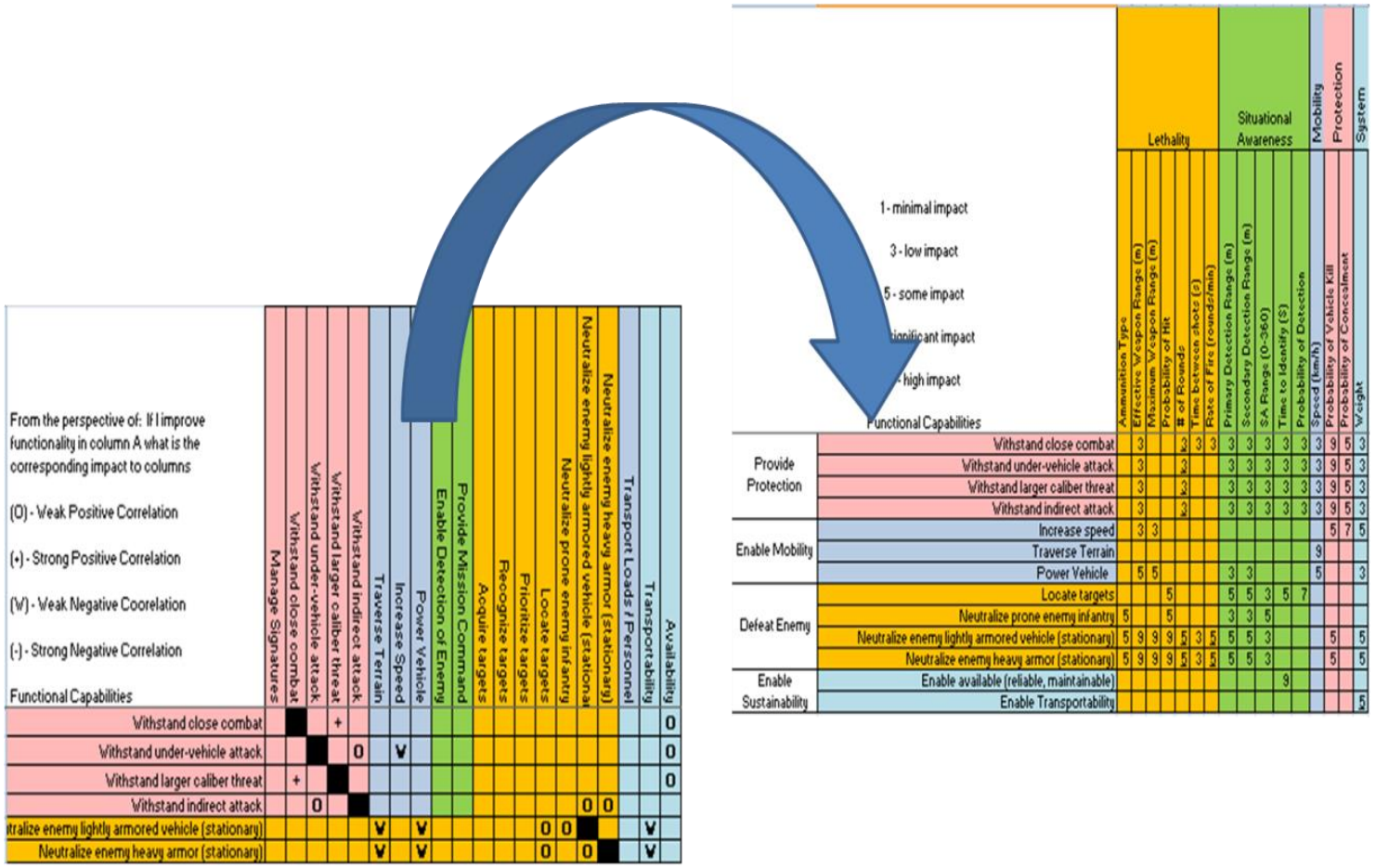
MATERIEL UPGRADES

Physical System / Specific Technology	Composite Armor	Active Protection System	TRAPS	Foliage Penetrating Radar	EM Gun	125mm tank gun	Infrared Camera	105mm on IFV	SIVAN	STARLite (AN/ZPY-1)	XM-19 ARAT	KE cartridge for armor penetration(12	Guided NLOS course corrected muniti	Airburst munitions
Armor (Protection Suite)	X	X	X								X			
Detection System				X			X		X	X				
Main Armament Subsystem					X	X		X				X		
Missile System														X

TECHNOLOGY IMPROVEMENTS



TECH IMPROVEMENTS (cont…)



RESULTS

- Baseline Results - Donna

BASELINE RESULTS APPROACH

- Each of the 66 x 11 (factors) design points from the DoE matrix was replicated 35 times in the MANA simulation for a total of 66 times 35 = 2310 runs
- Results data for Red Losses and Blue Losses used to derive Force Exchange Ratio MOE

$$FER_{Blue} = \frac{\left(n_{BlueLosses} \div N_{BlueTotal}\right)}{\left(m_{RedLosses} \div M_{RedTotal}\right)}$$

- Blue Vehicle Losses, Objective Squad Goal Completion and Time to Complete Mission used as additional MOE
- Initial screen for universally important factors and data clusters using partition tree analysis
- Regression models using the MOE responses to the design inputs were too complicated for practical use and each was dominated by factors concerning the design of the Main Battle Tank

REGRESSION ANALYSIS

- The wide range of the MBT input factor levels in the 66 x 11 DOE overwhelmed the possibility of any other factors significantly influencing the response
  - Large model parameter range for Armor Thickness (300 – 1200 mm) and the Weapon Range (1Km – 8Km) and Armor Penetration (500 – 1200 mm)
- Analysis of DOE subsets based on indicator cutoff values from the partition tree analysis
  - Indicator set for MBT with high performance attributes for Armor thickness and Weapon Range brought out secondary interactions with the UAV (Personnel) Detection Range and MBT Primary Weapon Armor Penetration
  - Indicator set for MBT Survivable but one with reduced lethality begins to demonstrate a significant impact from the IFV attributes for Rate of Fire and Weapon Range

BASELINE ANALYSIS

- Extremely capable MBTs can overwhelm the enemy to the point that the performance capabilities of the supporting assets are insignificant. However, it should be noted that this significance is based on extreme variations in MBT capabilities, and these patterns may disappear if the solution space is restricted.
- Given these trends, indicator variables were developed that grouped the data based on the splits identified by the partition trees.
- When the MBT is extremely capable, the Force Exchange Ratio becomes dependent on the UAV Secondary Detection Range (which provides target information to the MBTs) as well as the MBT Primary Weapon Armor Penetration (which increases the lethality of the Main Battle Tank).

- **Primary Maximum Effective Weapon Range**
- **Probability of Kill (Armor Penetration**
- **Detection Range**
- **Probability of Vehicle Kill (Armor Thickness)**

OMOE and CAIV RESULTS

CHRISTY BRENNAN

ALTERNATIVE CONFIGURATIONS

MINIMUM	2	2	1	1	1	2
MAXIMUM	6	6	4	4	4	6
BASELINE	3	3	1	1	2	4
Factor Name	Infantry Fighting Vehicle	Infantry Squads	Unmanned Aerial Vehicles	155mm Howitzers	Helicopters	Tanks
Run #						
1	3	3	4	3	2	5
2	5	5	4	3	4	4
3	6	6	2	3	3	6
4	3	3	2	3	1	2
5	5	5	4	3	2	3
6	3	3	2	4	3	5
7	4	4	1	4	1	5
8	4	4	2	1	3	6
9	4	4	4	1	3	3
10	2	2	3	2	4	3
11	4	4	1	2	3	3
12	3	3	3	3	4	5
13	3	3	1	2	2	4
14	5	5	2	4	4	3
15	5	5	3	4	2	4
16	6	6	1	2	1	4
17	5	5	3	2	2	6
18	2	2	3	1	1	5
19	6	6	2	2	3	2
20	4	4	3	1	2	4
21	2	2	3	3	3	2

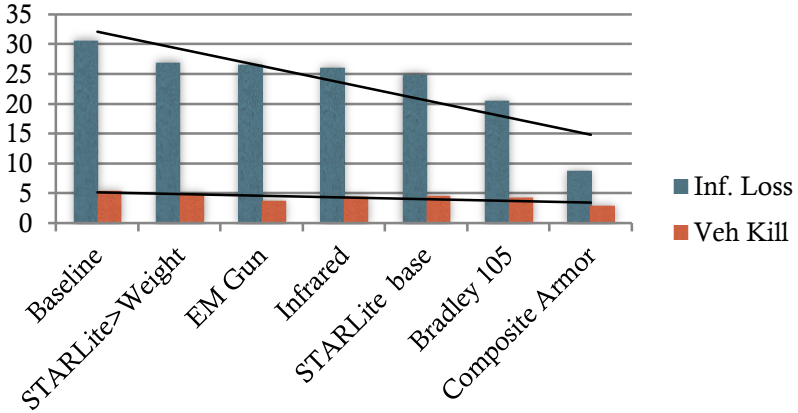
Non-Materiel Changes

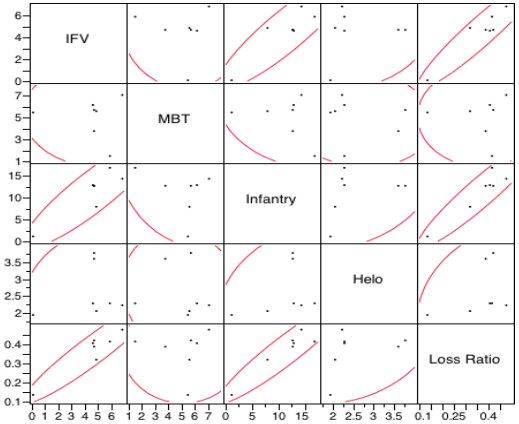
	UAV	UAV	UAV	UAV	UAV	UAV	UAV	UAV						
baseline	10000	6000	360	5	0.5	0.005	No change	0.1						
factor name	Primary Detection Range (m)	Secondary Detection Range (m)	SA Range (degrees)	Time to Identify (s)	Primary P(detect)	Secondary P(detect)	Angular Movement (in absence of enemy)	Weight (arb units)	Red Force Losses	Blue Force Losses	Vehicles Kiled	FER	Squad Goal	Time
STARLite w/ Weight Change	40000	40000	360	1	0.75	0.01	Look in direction of movement	0.25	73.1	26.9	5	0.483	0.886	24967.4

Materiel Changes

- Evaluated 6 alternative Technologies
  - EM Gun performed best overall
- Evaluated 21 alternative unit composition configurations by varying the existing platform numbers
  - Configuration 6 performed best and consisted of 3 IFVs and dismounted squads, 2 UAVs, 3 helicopters, 4 Howitzers and 5 MBTs.
- Assessed configurations in MANA against the 5 MOEs

ALTERNATIVE CONFIGURATIONS





- Each configuration was evaluated against the 5 MOE criteria to determine the best performance
- Measures of Effectiveness:
  - Blue Force losses: *The number of blue forces lost*
  - Red Force losses: *The number of red forces lost*
  - Force Exchange Ratio: *The ratio of blue force losses to red force losses*
  - Blue Force mission success or squad goal: *The completion of the mission, in this scenario it is the successful arrival of at least one MBT to Objective 1 in the simulation*
  - Blue Force vehicle losses: *The number of blue force vehicles deadlined and unable to continue the mission*

OVERALL MEASURES OF EFFECTIVENESS (OMOE)

Configuration	Weighting	Force Exchange Ratio	Squad Goal	Red Force Losses	Blue Force Losses	Vehicles Killed	Total	OMOE	Ranking
		0.3	0.3	0.1	0.1	0.2			
2		22	6	22	22	22	17.20	0.782	3
6		18	21	17	18	20	19.20	0.873	1
14		20	18	16	20	21	19.20	0.873	2

- Each configuration was ranked 1-22 within each category to assess the highest performer
- Each MOE was given a weighting factor, based on stakeholder input, to be leveraged when identifying the most effective configuration
- All totals were summed and then normalized to identify the OMOE
- Based solely on the assessment of performance as it relates to the identified MOEs, configurations 6, 14 and 2 were the top non-materiel performers

OVERALL MEASURES OF EFFECTIVENESS (OMOE)

Configuration	Weighting	Force Exchange Ratio	Squad Goal	Red Force Losses	Blue Force Losses	Vehicles Killed	Total	OMOE	Ranking
		0.3	0.3	0.1	0.1	0.2			
STARlite (no extra weight)		5	7	2	5	3	4.90	0.700	2
STARlite (Extra weight)		2	3	6	2	2	2.70	0.386	6
EM Gun		4	6	7	3	6	5.20	0.743	1
M68A2 105mm		6	2	5	6	5	4.50	0.643	4
Infrared Camera		4	5	4	4	4	4.30	0.614	5
Composite Armor		7	2	1	7	7	4.90	0.700	2
Baseline		1	5	3	1	1	2.40	0.343	7

- Performed same assessment on the materiel configurations
- Evaluated the same technology assuming a weight gain on one system to examine the impacts secondary effects have on the mission
- For the materiel configuration changes the composite armor, EM gun and STARlite detection system (assuming no additional weight) provided the best performance

COST AS AN INDEPENDENT VARIABLE (CAIV) ASSESSMENT

- "CAIV is a strategy that entails setting aggressive, yet realistic cost objectives when defining operational requirements and acquiring defense systems and managing achievement of these objectives…As system performance and cost objectives are decided (on the basis of cost-performance trade-offs), the requirements and acquisition processes will make cost more of a constraint, and less of a variable, while nonetheless obtaining the needed military capability of the system" (Young 2012, 27).

COST AS AN INDEPENDENT VARIABLE (CAIV) ASSESSMENT – NON-MATERIEL

Cost	IFV $ 3,166,000	Bradley Inf Sqd $ 16,301	UAV $ 250,000	155mm Howitzer $ 4,600,000	Helo $ 12,234,586	M1A1 $ 4,300,000	Total Cost	Delta Cost	OMOE
1	3	3	4	3	2	5	70,316,075.00	11,067,699.00	0.559091
2	5	5	4	3	4	4	96,849,849.00	37,601,473.00	0.781818
3	6	6	2	3	3	6	95,897,564.00	36,649,188.00	0.772727
4	3	3	2	3	1	2	68,698,376.00	9,450,000.00	0.054545
5	5	5	4	3	2	3	68,080,677.00	8,832,301.00	0.409091
6	3	3	2	4	3	5	86,650,661.00	27,402,285.00	0.872727
7	4	4	1	4	1	5	65,113,790.00	5,865,414.00	0.622727
8	4	4	2	1	3	6	80,332,962.00	21,084,586.00	0.795455
9	4	4	4	1	3	3	67,932,962.00	8,684,586.00	0.486364
10	2	2	3	2	4	3	78,152,946.00	18,904,570.00	0.586364
11	4	4	1	2	3	3	71,782,962.00	12,534,586.00	0.486364
12	3	3	3	3	4	5	94,535,247.00	35,286,871.00	0.690909
13	3	3	1	2	2	4	60,666,075.00	1,417,699.00	0.3
14	5	5	2	4	4	3	96,649,849.00	37,401,473.00	0.872727
15	5	5	3	4	2	4	76,730,677.00	17,482,301.00	0.613636
16	6	6	1	2	1	4	70,212,978.00	10,964,602.00	0.322727
17	5	5	3	2	2	6	76,130,677.00	16,882,301.00	0.572727
18	2	2	3	1	1	5	64,048,376.00	4,800,000.00	0.368182
19	6	6	2	2	3	2	74,097,564.00	14,849,188.00	0.527273
20	4	4	3	1	2	4	59,748,376.00	500,000.00	0.540909
21	2	2	3	3	3	2	66,218,360.00	6,969,984.00	0.172727
Baseline	4	4	1	1	2	4	59,248,376.00	-	0.368182

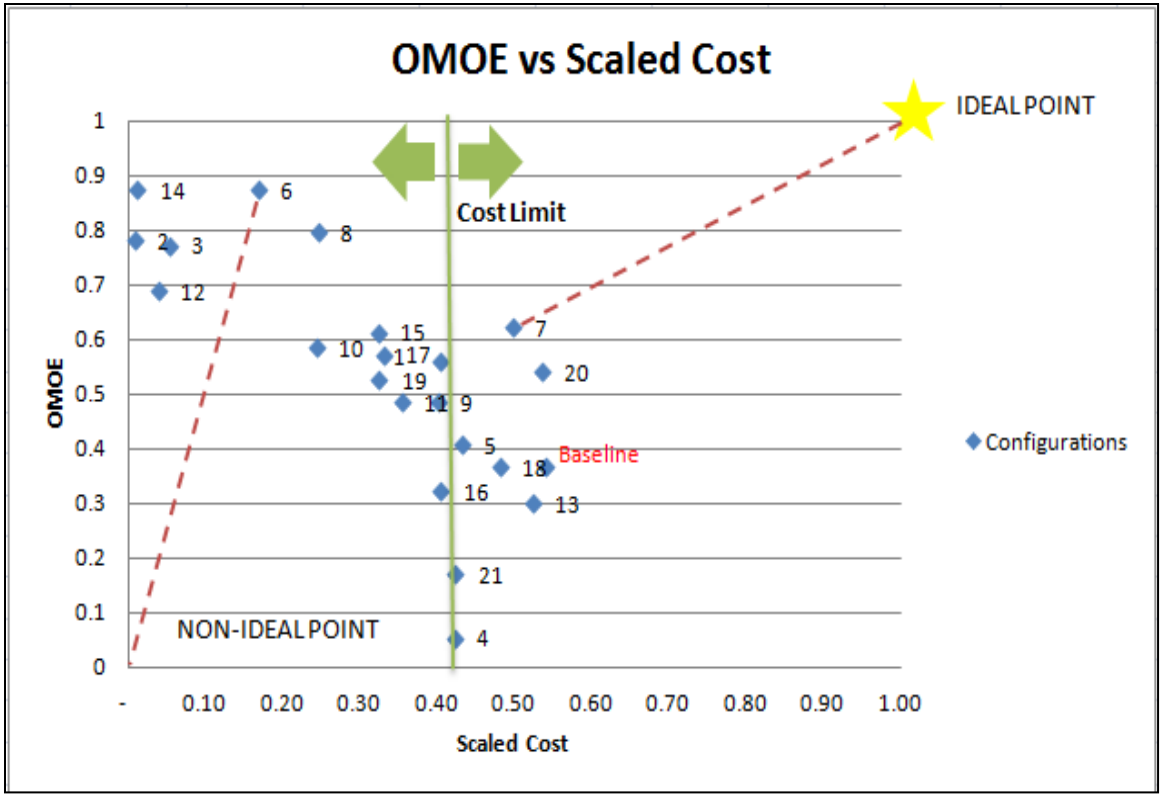
- For the development of the non-materiel solutions cost estimates all the information was obtained from publically accessible websites such as CNN and FAS.
- Each unit cost was multiplied by the number of platforms in a configuration.
- The total amount was determined for the entire unit, based upon the number and cost of each system.
- Costs are only production costs. O&S assessment needs to be follow-on work

COST AS AN INDEPENDENT VARIABLE (CAIV) ASSESSMENT – MATERIEL

	IFV	Bradley Inf Sqd	UAV	155mm Howitzer	Helo	M1A1	Total Cost	OMOE
# of Systems	4	0	1	1	2	4		
STARlite (no extra weight)	0	0	2400000	0	0	0	2,400,000.00	0.700
STARlite (Extra weight)	0	0	2400000	0	0	0	2,400,000.00	0.386
EM Gun	0	0	0	0	0	2300000	9,200,000.00	0.743
M68A2 105mm	1100000	0	0	0	0	0	4,400,000.00	0.643
Infrared Camera	0	0	0	0	0	132000	528,000.00	0.614
Composite Armor	585000	0	0	0	0	702000	5,148,000.00	0.700
Baseline	0	0	0	0	0	0	-	0.343

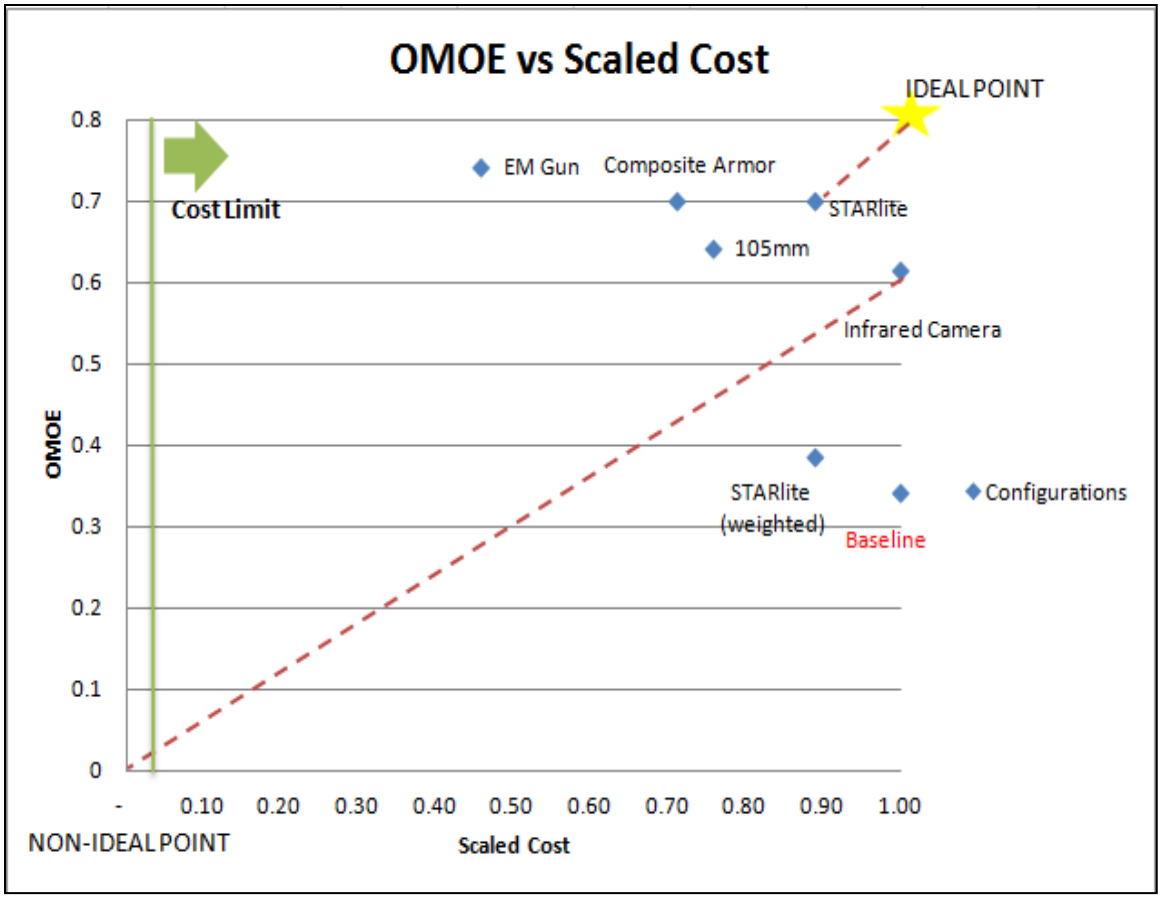
- The cost for each system was then determined and multiplied by the number of platforms it would be deployed on in the given unit.
- This allowed the cost per unit to be determined based solely on production costs.
- Each system cost was determined differently mostly through publically available knowledge or SME information

OMOE AND CAIV RESULTS



- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) evaluation was performed.
- The ideal non-materiel solution was configuration 7
- Configuration 6, which was furthest from the non-ideal point
- The green vertical line identifies the set cost limit for the program as to not exceed budget

OMOE AND CAIV RESULTS



- The results of the CAIV and OMOE assessments suggested that either the lethality of the unit or the detection capability of the unit needed to be improved
- For the materiel solutions, the best solution was either STARlite, assuming no weight gain, or the upgraded GEN III FLIR.
- The comparison of the two different configurations of the STARlite technology provides some insight to the importance of the secondary effects considerations

SUMMARY AND CONCLUSIONS

- Challenges
  - Toolset
  - Data classification
- Follow-on work
  - Dashboard
  - In-depth analysis
  - Emerging technologies
  - Trade-space
- Conclusions
  - Value created by this effort

CHALLENGES

- Lack of integrated MBSE toolset
  - Choice of tools is left up to the engineer
  - Developed process is independent of toolset
- Classified data
  - Prohibited the use of realistic data in many cases
  - Forced several assumptions
  - Forced alteration of some data
  - Developed process is independent of the data

FOLLOW-ON WORK

- Development of dashboard
- Performance of analysis in greater depth
- Investigation of emerging technologies
- Broadening of the trade-space

DASHBOARD

- Direct end-user manipulation of model parameters.
- Extend technical capabilities to a broader audience.
- Provide abstraction on the underlying analysis tools.
- Provide early insight into the effects of design changes.
- Help identify important design parameters.

FURTHER ANALYSIS

- Interactions between MBT armor penetration and IFV maximum effective range.
- Interactions between IFV rate of fire and IFV maximum effective range.
- Lack of effectiveness in the model of IFV armor.
- Detrimental effects in the model of IFV top speed.
- Impact of increased situational awareness.

EMERGING TECHNOLOGIES

- Examples
  - High-energy weapons
  - E-ink camouflage
  - New ground combat systems
- Could be evaluated under the developed process.

TRADE-SPACE

- Currently limited to ground combat
- Opportunities
  - Inclusion of consideration for air support
  - Factor limitations and improvements in logistics
  - Create scenarios for joint operations
- Provide a more complete picture of unit effectiveness and health.

CONCLUSIONS

- Developed a process that is:
  - Effective
  - Repeatable
  - Adaptable
- Lays groundwork for additional research
- Provide support for doctrinal and organizational changes
- Demonstrate importance of SoS factors and effects
- Provide support for feasibility study for emerging technologies

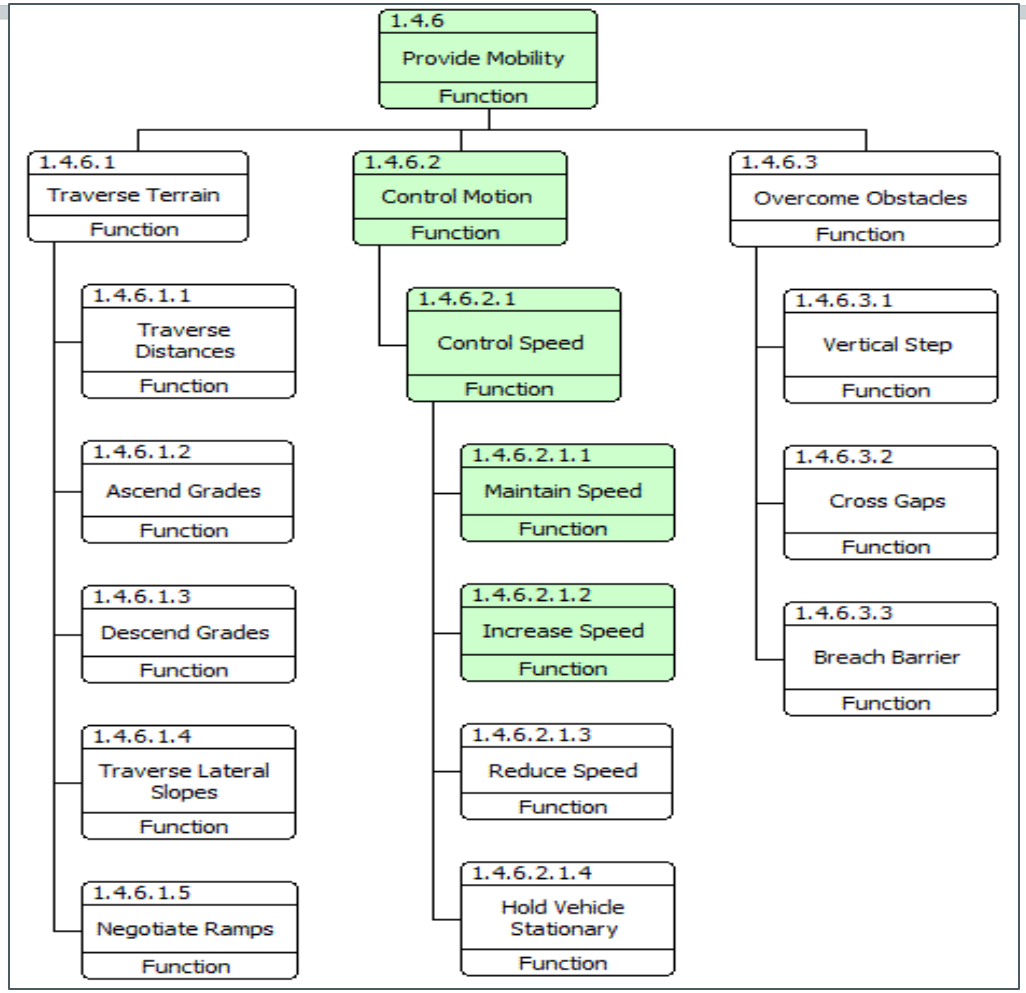
QUESTIONS

Back up

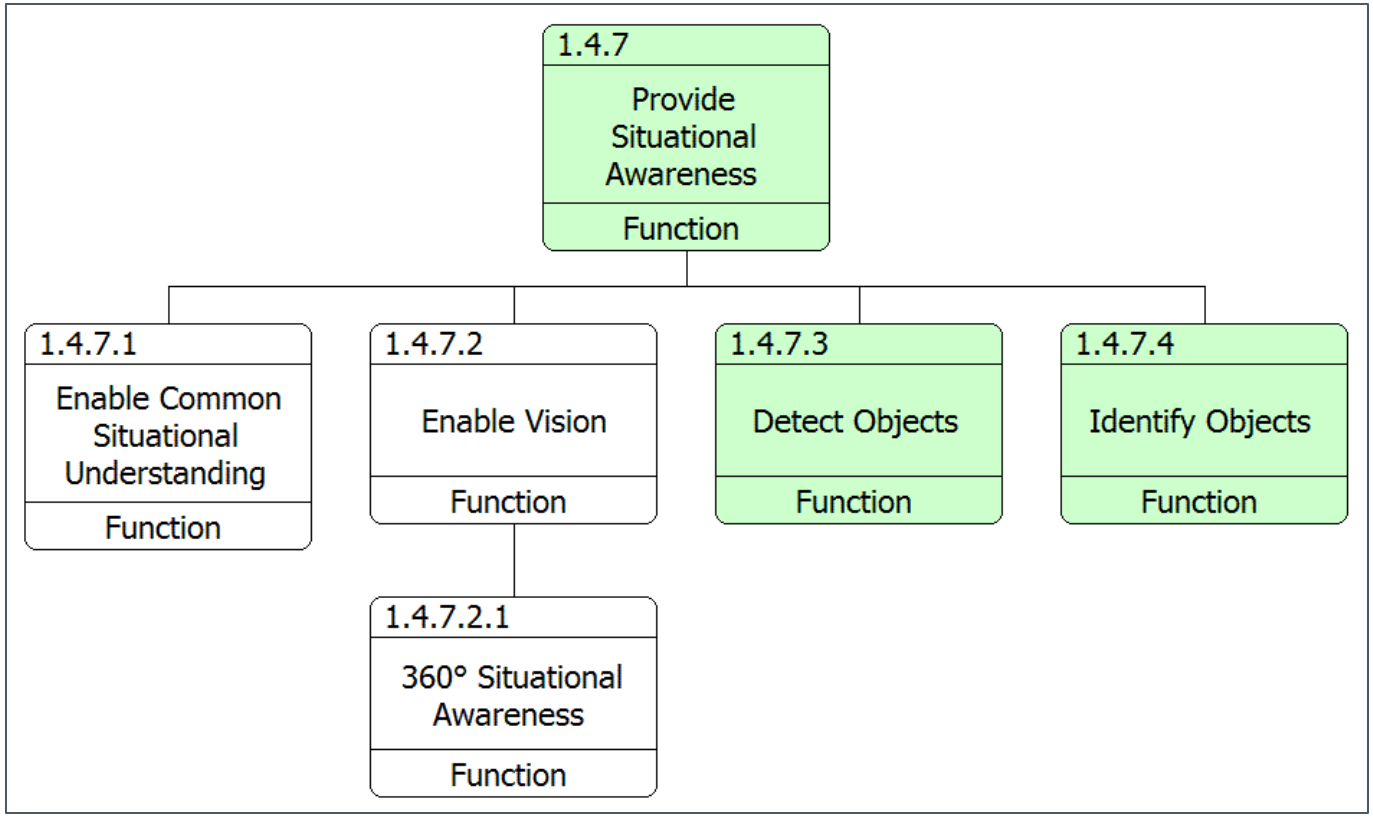
OVERALL MEASURES OF EFFECTIVENESS (OMOE)

Configuration	Weighting	Force Exchange Ratio	Squad Goal	Red Forces Killed	Blue Forces Killed	Vehicles Killed	Total	OMOE	Ranking
		0.3	0.3	0.1	0.1	0.2			
1		14	13	15	11	8	12.30	0.559	12
2		22	6	22	22	22	17.20	0.782	3
3		21	13	13	21	17	17.00	0.773	5
4		1	1	3	1	1	1.20	0.055	22
5		9	7	10	8	12	9.00	0.409	16
6		18	21	17	18	20	19.20	0.873	1
7		13	13	14	13	16	13.70	0.623	7
8		17	20	21	17	13	17.50	0.795	4
9		15	3	19	14	10	10.70	0.486	15
10		10	18	8	9	14	12.90	0.586	9
11		12	9	10	12	11	10.70	0.486	14
12		19	6	20	19	19	15.20	0.691	6
13		8	6	7	7	5	6.60	0.300	20
14		20	18	16	20	21	19.20	0.873	2
15		16	8	18	15	15	13.50	0.614	8
16		6	13	4	4	3	7.10	0.323	19
17		11	20	11	10	6	12.60	0.573	11
18		4	18	2	5	4	8.10	0.368	17
19		3	18	1	16	18	11.60	0.527	10
20		7	22	12	6	7	11.90	0.541	13
21		2	2	6	2	9	3.80	0.173	21
Baseline		5	18	5	3	2	8.10	0.368	17

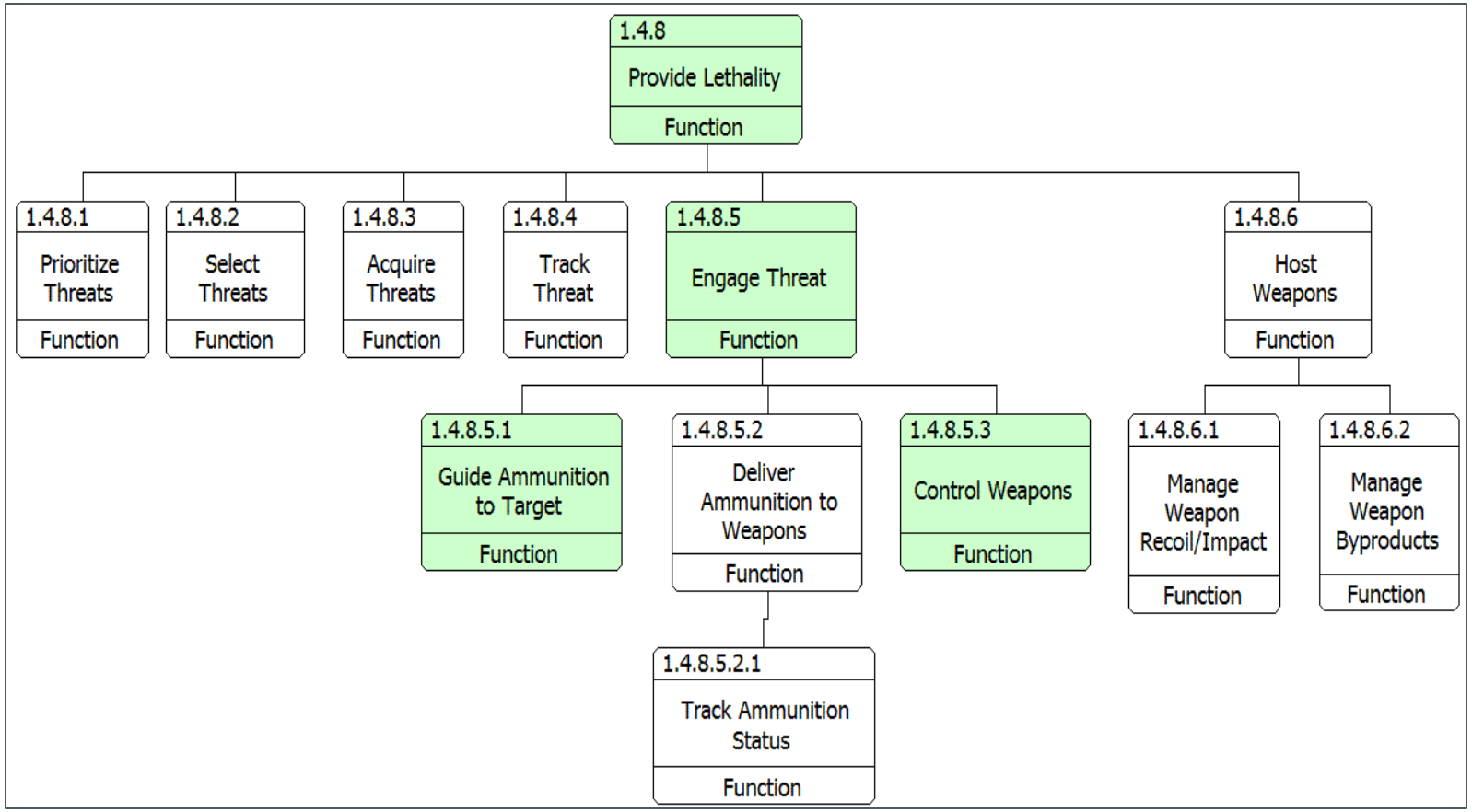
FUNCTIONAL DECOMPOSITION



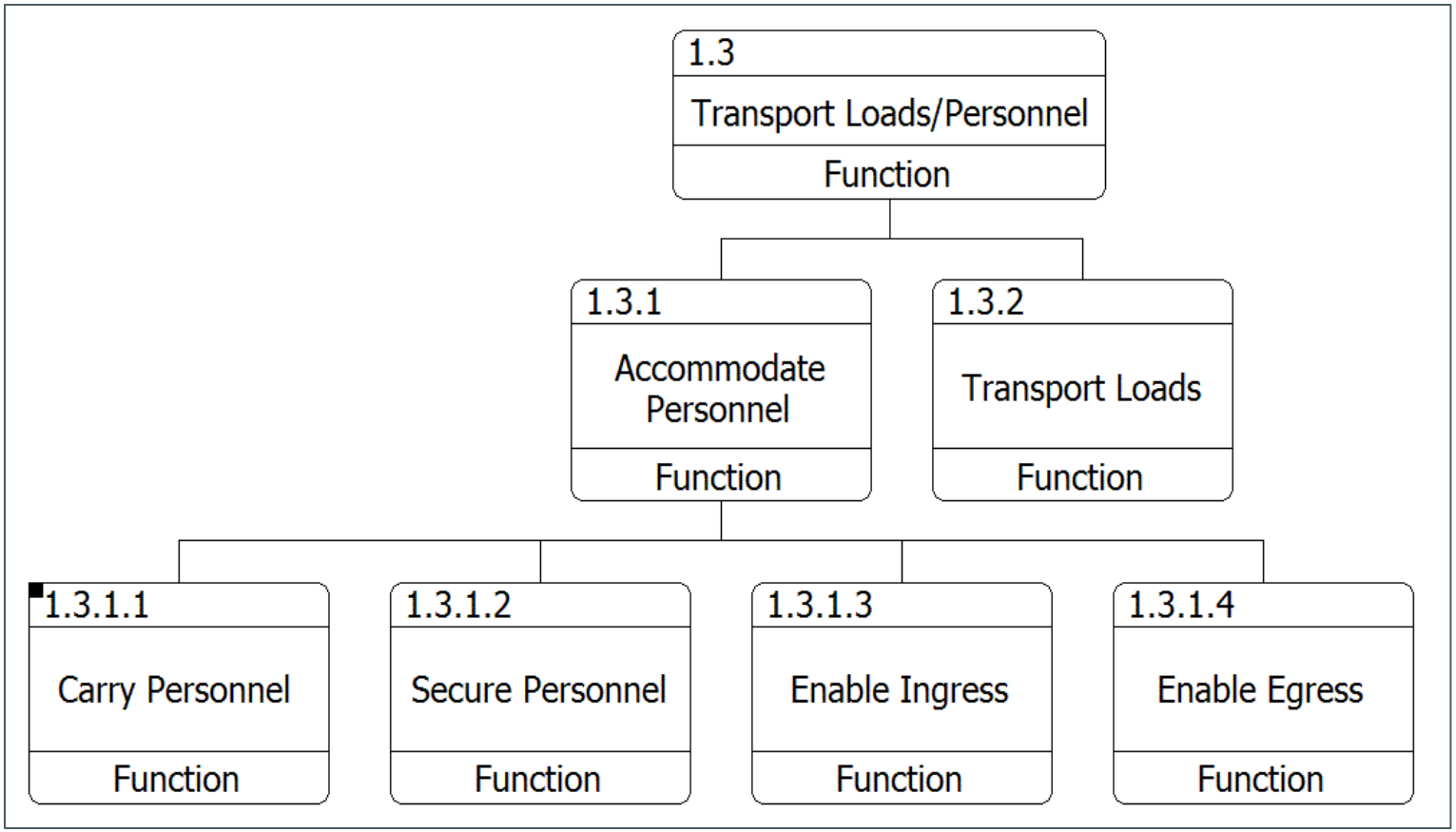
FUNCTIONAL DECOMPOSITION



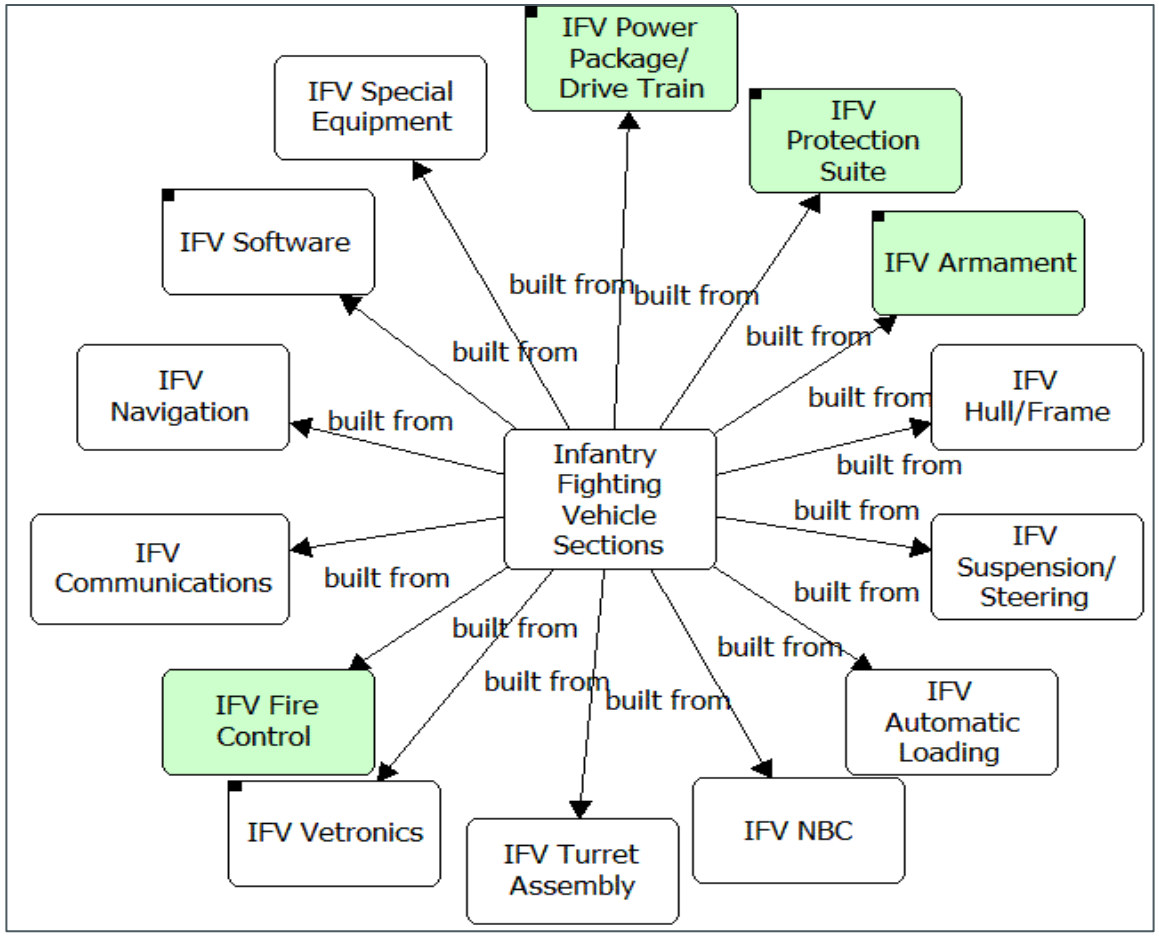
FUNCTIONAL DECOMPOSITION



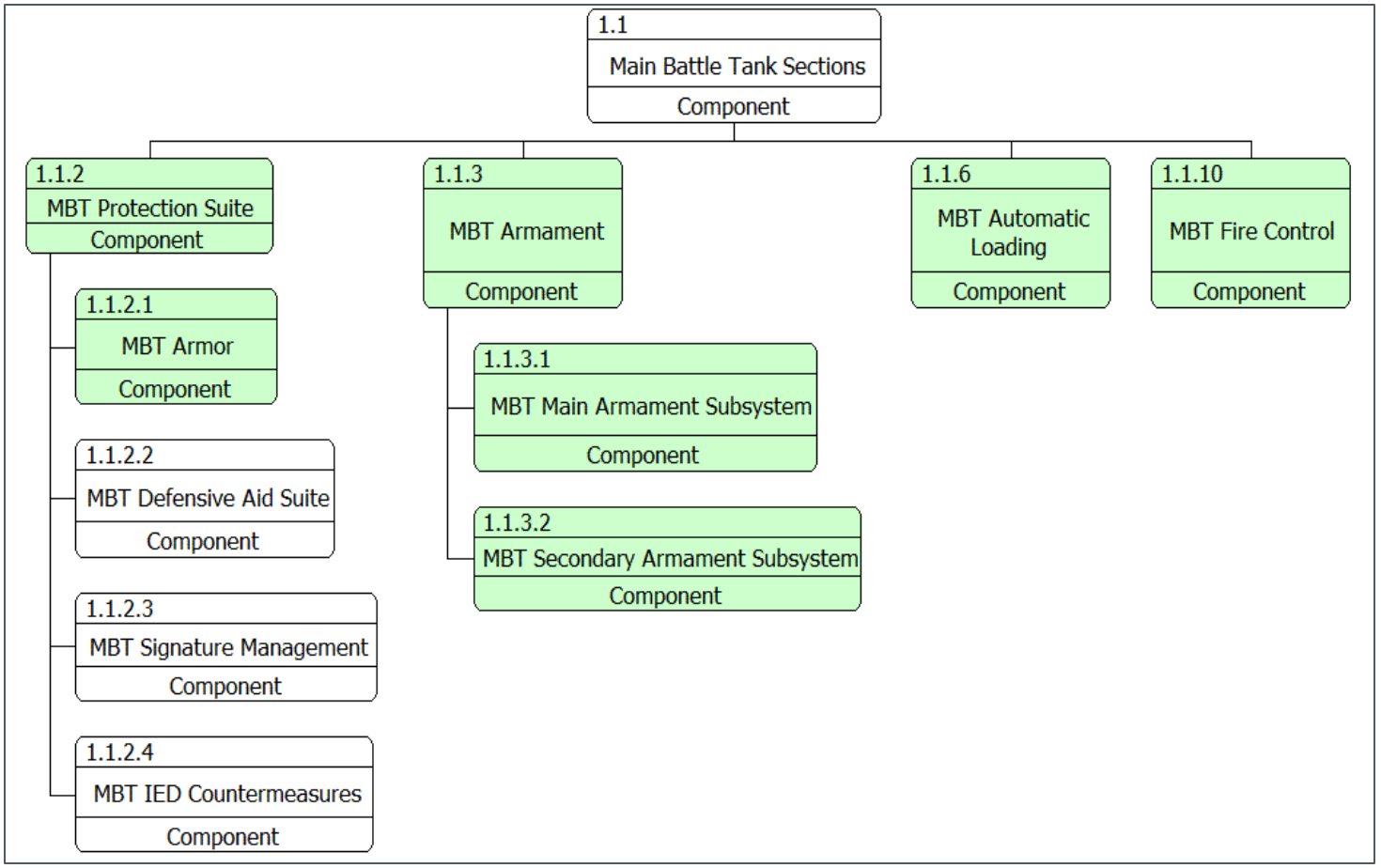
FUNCTIONAL DECOMPOSITION



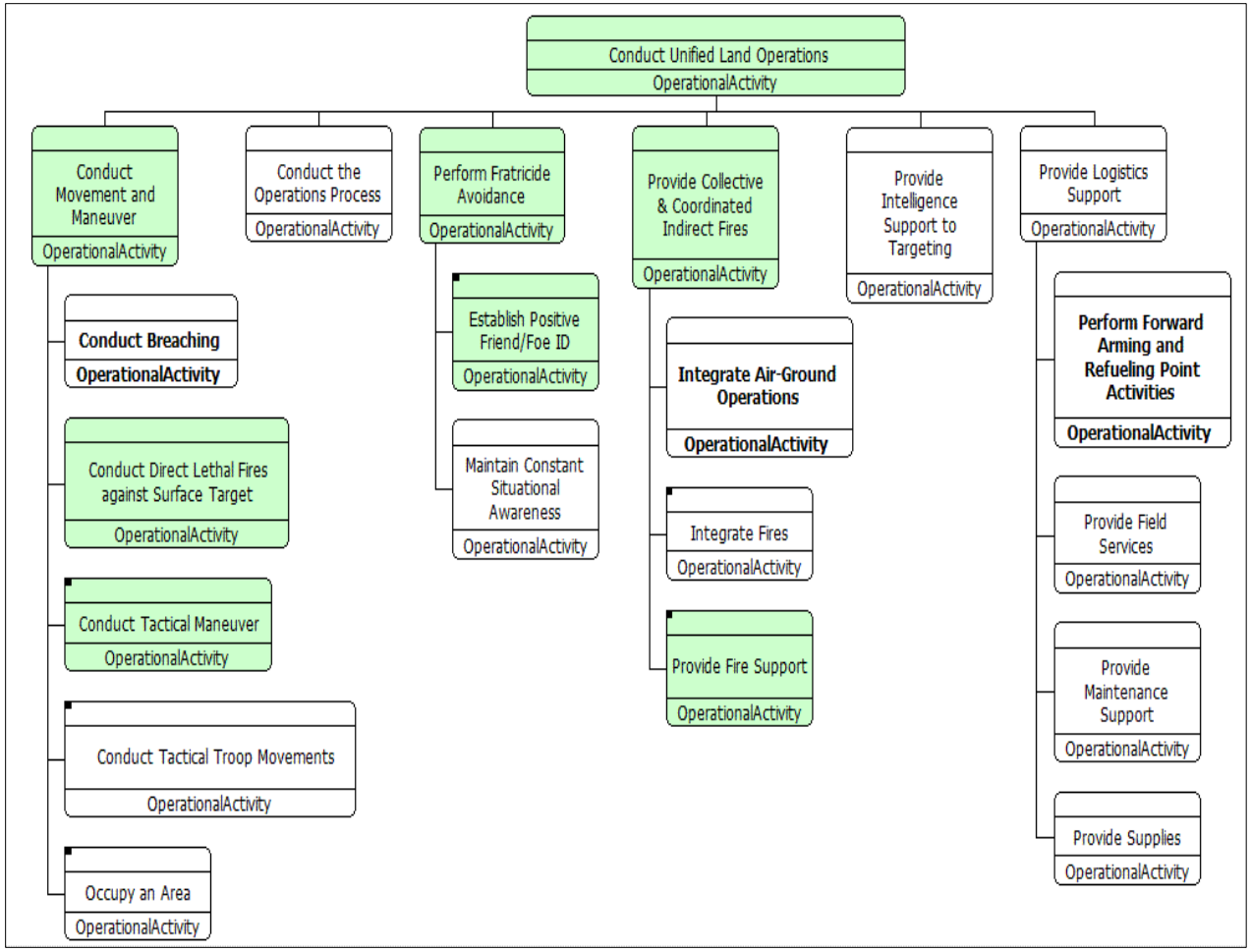
PHYSICAL DECOMPOSITION



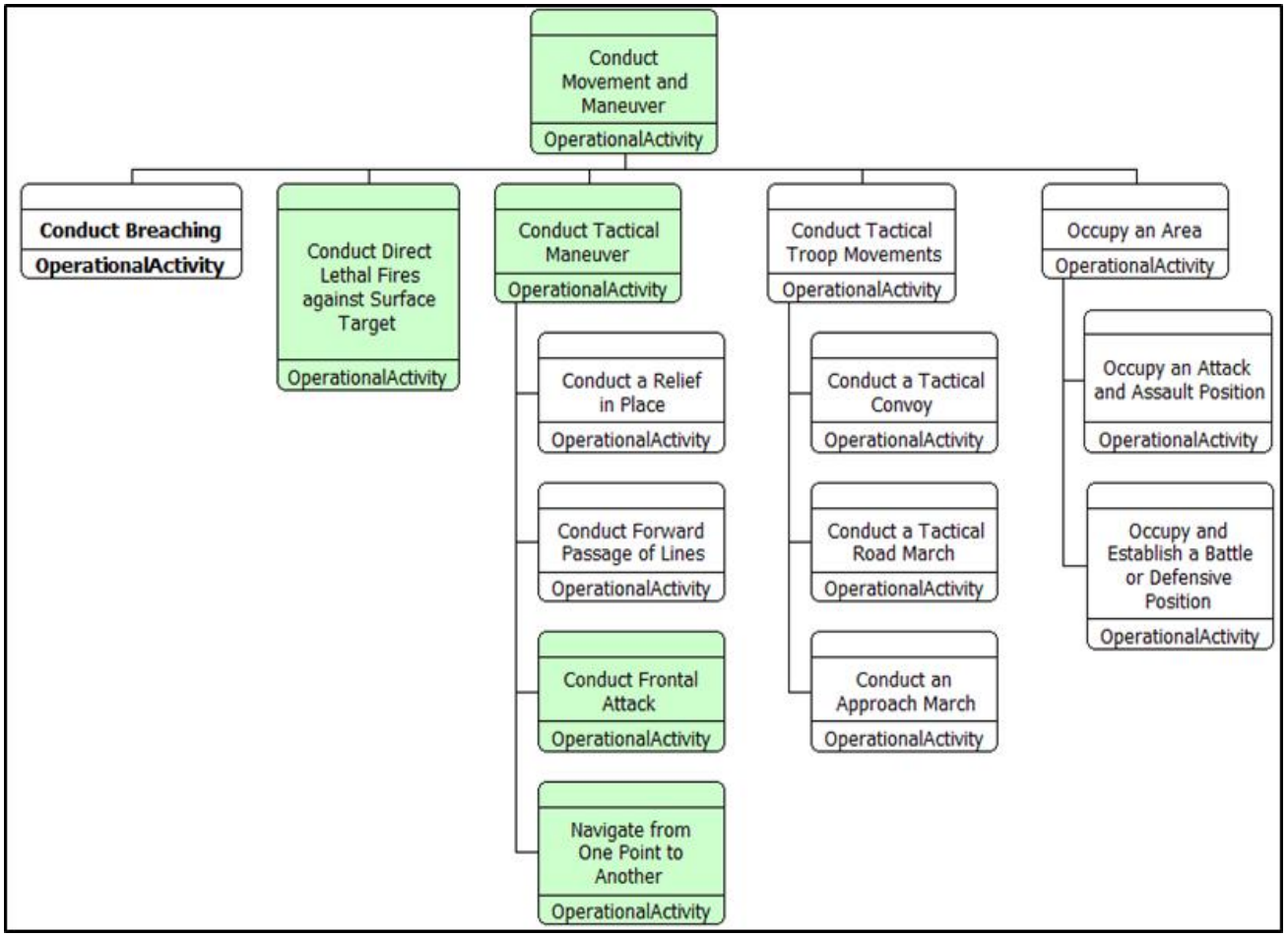
PHYSICAL DECOMPOSITION



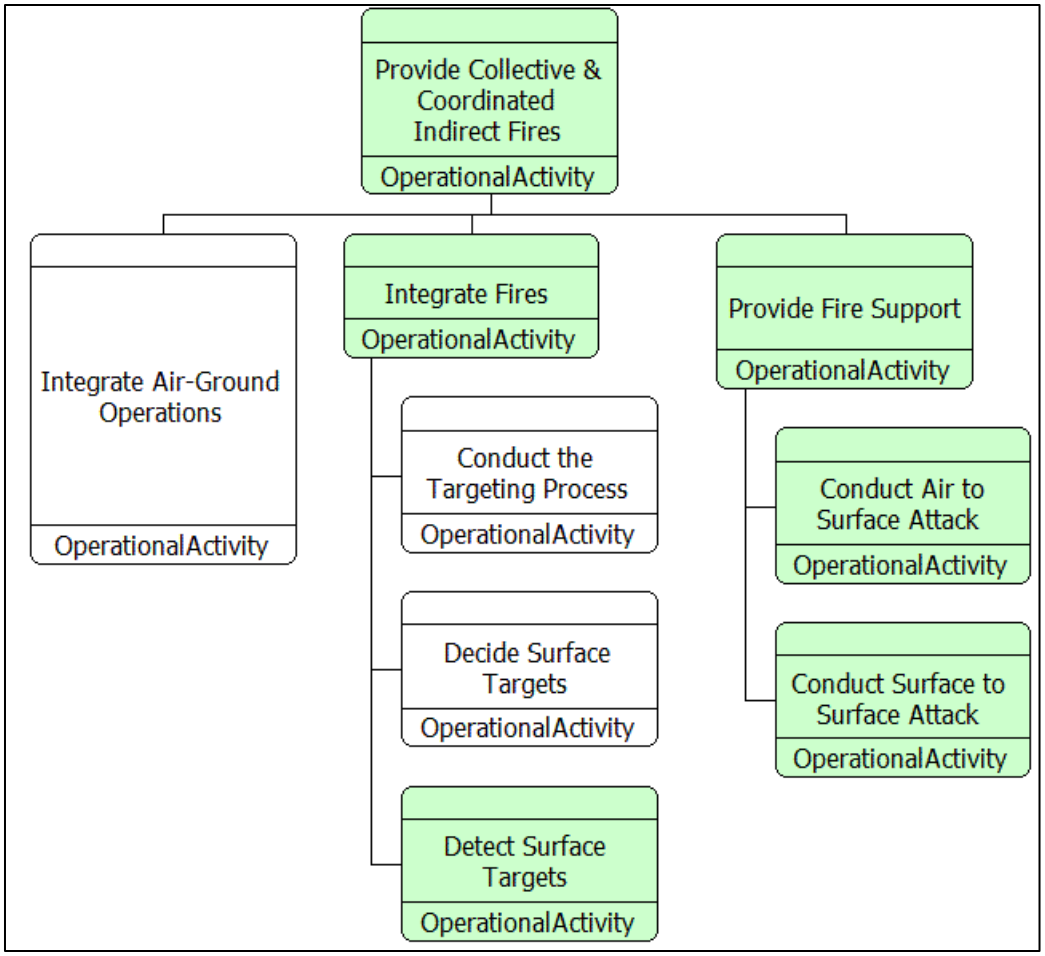
OPERATIONAL HIERARCHY



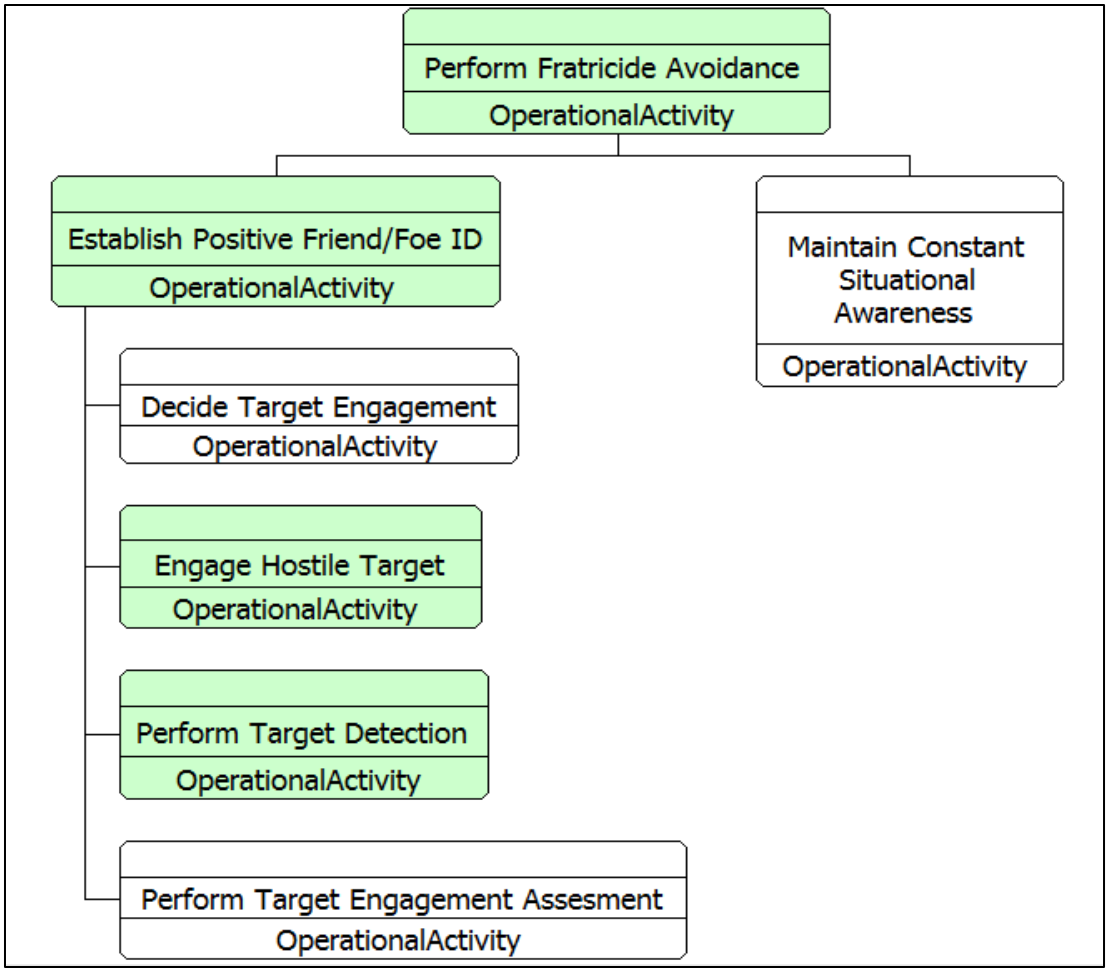
OPERATIONAL HIERARCHY



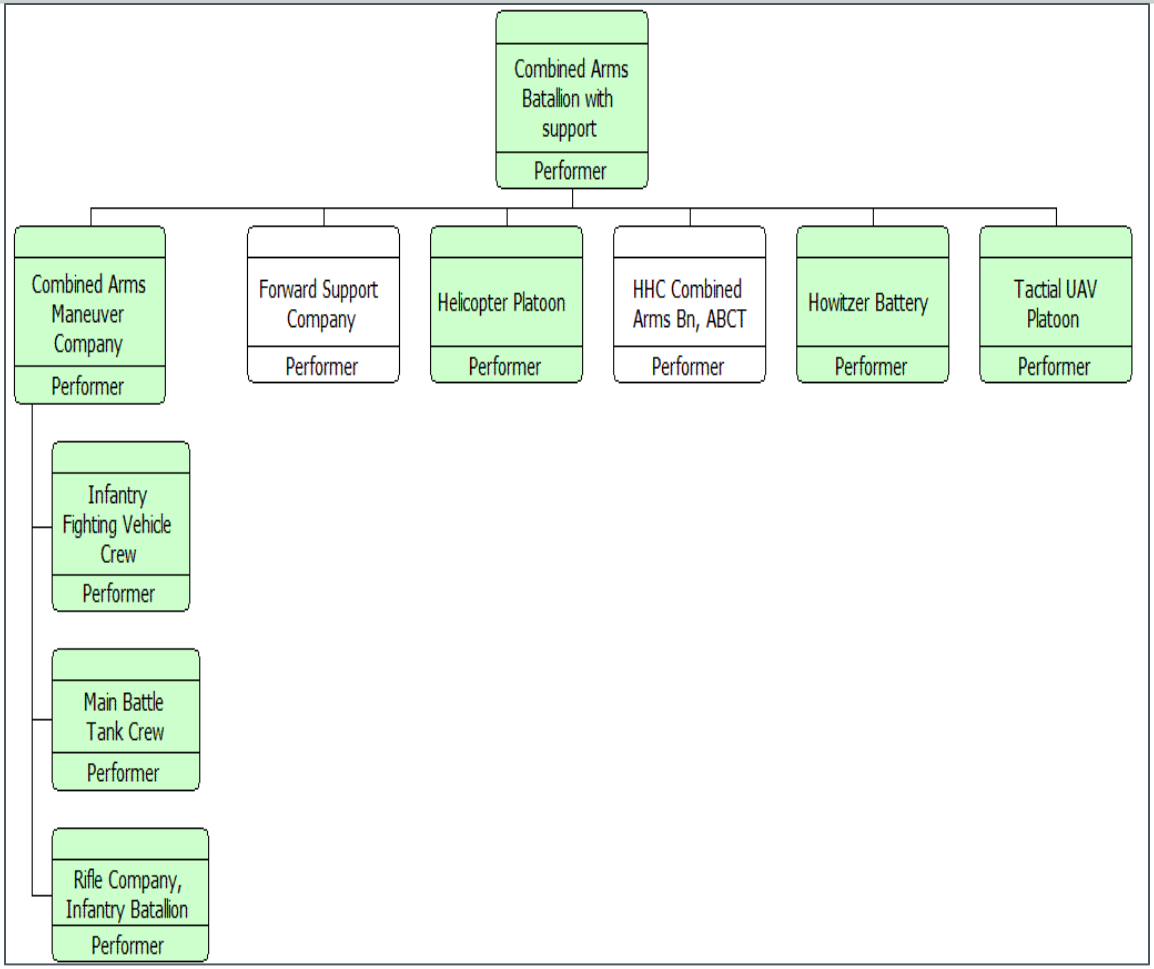
OPERATIONAL HIERARCHY



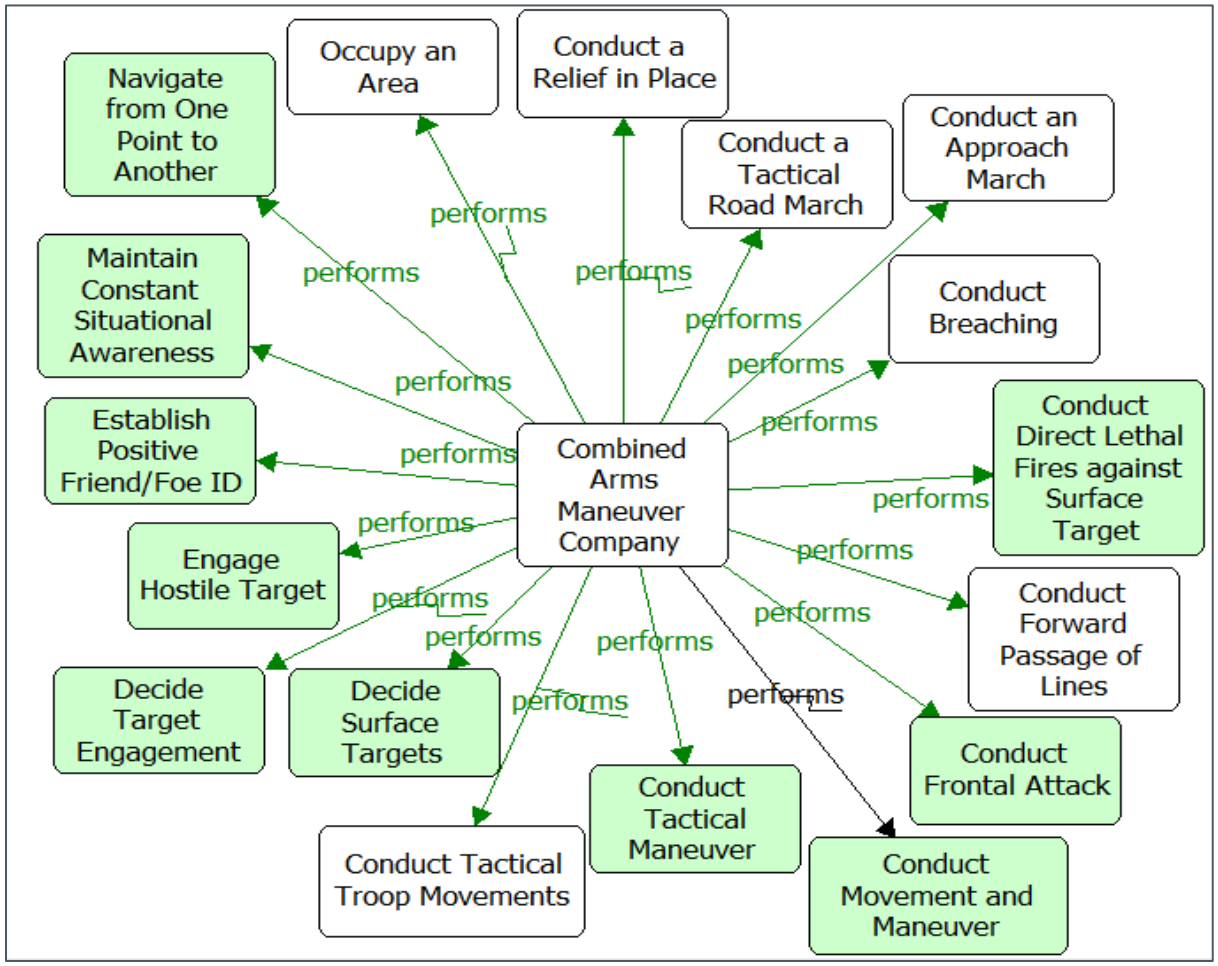
OPERATIONAL HIERARCHY



PERFORMER HIERARCHY



ACTIVITY ALLOCATION



ACTIVITY ALLOCATION