

Development of a Structured Approach for Establishing Mission Engineering Requirements

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Outline

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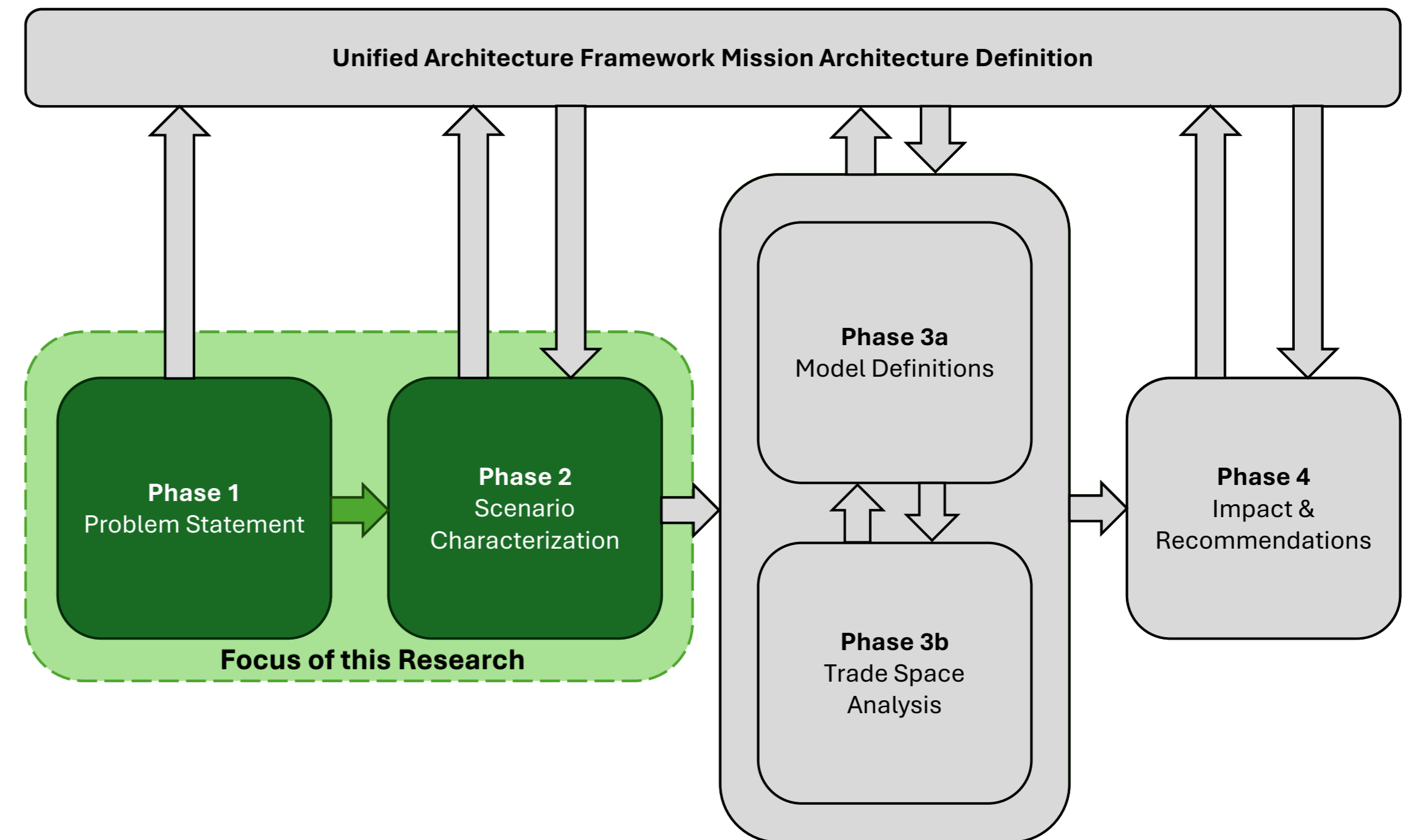
Motivation



Problem: New aircraft acquisition programs begin with nebulous/absent requirements

Gap: Mission engineering assumes objectives are understood¹; requirements engineering assumes customer needs are known²

Need: A structured, traceable method to derive requirements from mission intent in the absence of customer input



How can mission effectiveness be systematically defined or approximated when customer requirements are incomplete or unavailable?

1: USD(R&E), "Mission Engineering Guide 2.0," Guide, Office of the Under Secretary of Defense for Research and Engineering, Oct. 2023.

2: Hirshorn, S. R., "NASA Systems Engineering Handbook," Special Publication SP-2016-6105, National Aeronautics and Space Administration, 2016.

Literature Review



Existing research covers individual components of the solution but does not fully bridge the gap between nebulous mission intent and traceable requirements

- **Mission Engineering** provides a process to analyze objectives, capability gaps, and system-of-systems effects, but assumes needs are already well-defined¹
- **Requirements Engineering** provides structure for deriving, managing, and tracing requirements, but relies on known customer desires or stakeholder perspective²
- **Model Based Systems Engineering** provides architecture and modeling structures for linking context, performers, functions, exchanges, constraints, and requirements^{3,4}
- **Best-Worst Scaling** survey methods supports processes where qualitative expert judgment must be converted into quantitative weights⁵
- **Multi-Attribute Utility Theory** supports utility evaluation under uncertainty, enabling technology impacts to be assessed relative to their mission value⁶

1: USD(R&E), "Mission Engineering Guide 2.0," Guide, Office of the Under Secretary of Defense for Research and Engineering, Oct. 2023.

2: Hirshorn, S. R., "NASA Systems Engineering Handbook," Special Publication SP-2016-6105, National Aeronautics and Space Administration, 2016.

3: Madni, A. M., and Sievers, M., "Model-Based Systems Engineering: Motivation, Current Status, and Research Opportunities," *Systems Engineering*, 2018.

4: OMG, "UAF — Unified Architecture Framework," Version 1.3, 2026; OMG, "SysML® — OMG Systems Modeling Language," 2024/2025.

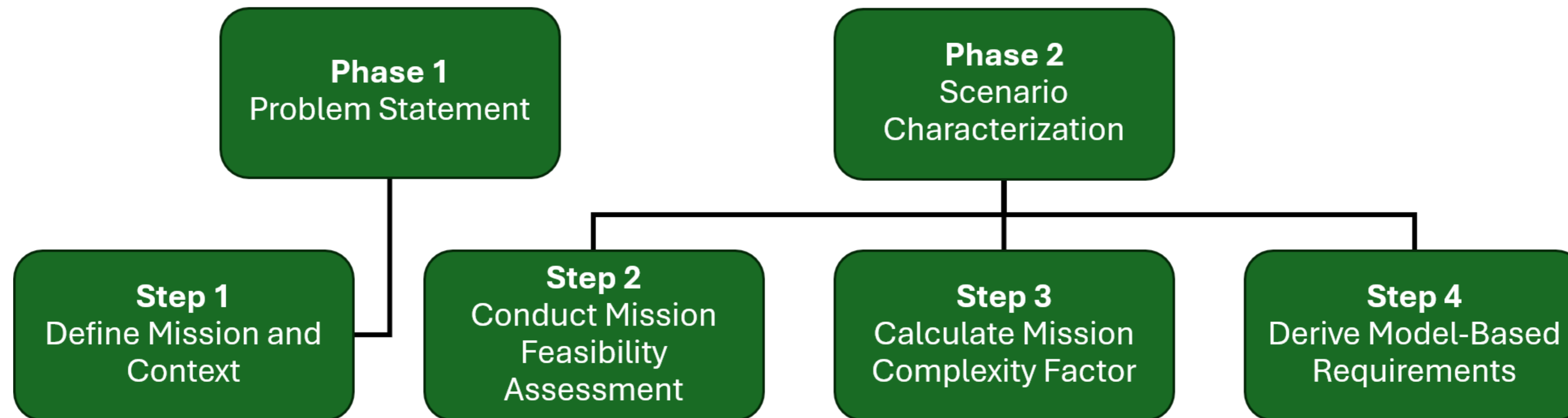
5: Louviere, J. J., Flynn, T. N., and Marley, A., *Best-Worst Scaling: Theory, Methods and Applications*, 2015.

6: Girard, P. E., O'Connor, M. F., and Ulvila, J. W., "Modeling Choice Under Uncertainty in Military Systems Analysis," 1991.

Framework Overview



- Proposed framework codifies early Mission Engineering phases
- Clearly identifies data products for integration into an MBSE architecture
- Uses a **close air support mission** as notional example of the process



Step 1: Mission Definition



Goal: provide all components that help to tell the story of a mission

Mission: *singular task to be accomplished*

Mission context: *the who, what, when, where, why that tells the full story*

Mission thread: *digital engineering product that defines and documents the mission context¹; includes all steps and events that must occur to successfully complete a mission*

- Define the mission objective, context, and thread
- Create an OV-1 to generically visualize all relevant elements and interactions for the mission²

1: USD(R&E), "Mission Engineering Guide 2.0," Guide, Office of the Under Secretary of Defense for Research and Engineering, Oct. 2023.

2: DoD CIO, "DoDAF Viewpoints and Models," Website, Accessed on 2025/11/14. URL https://dodcio.defense.gov/Library/DoDArchitecture-Framework/dodaf20_viewpoints/.

Define Mission and
Context

Conduct Mission
Feasibility
Assessment

Calculate Mission
Complexity Factor

Derive Model-Based
Requirements

Step 1: Close Air Support Example



Mission objective: provide close air support to ground units

Ground troop mission: advance to the next ridge

Operational performance: provide close air support to ground unit

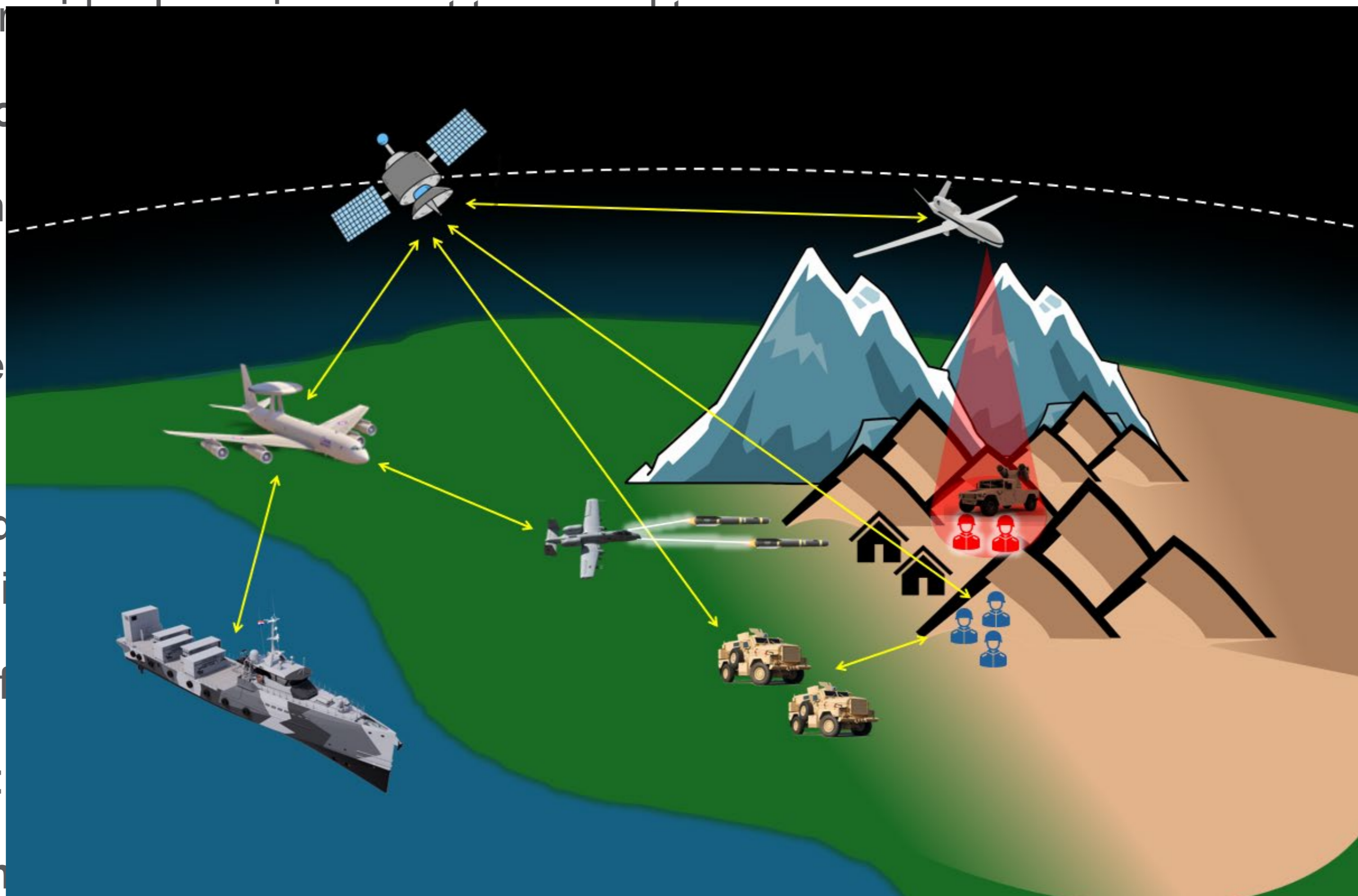
Threat context: adverse weather conditions, enemy locations

Deconfliction considerations: friendly aircraft, autonomous vehicles, how deconflict

Abort criteria: loss of communication, fuel exhaustion

Target prioritization: enemy positions, vehicles

Rules of engagement: friendly presence, approval authorities



Joint Air Tasking Order (JATO), Joint Air Tasking Controller (JTAC),

expected threat density and

CAS vehicles, autonomous

presence, approval authorities

Define Mission and Context

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Step 2: Mission Feasibility Assessment



Goal: evaluate the mission difficulty prior to considering any technical solutions

Step 2.1: Narratively Define Success

- Define a qualitative success statement that can be evaluated on a pass/fail basis
- Develop additional success definitions to provide additional context

CAS Mission Example

Success statement: Support is successful if it arrives within the ground commander's decision window, provides the intended munitions and effects, and does not create unacceptable civilian or ground troop risk

Additional success definitions:

- Target validation meets established confidence standards
- Mission abort remains available throughout the duration of the attack window
- Deconfliction with other assets can be maintained at nominal complexity levels

Define Mission and Context

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Step 2: Mission Feasibility Assessment

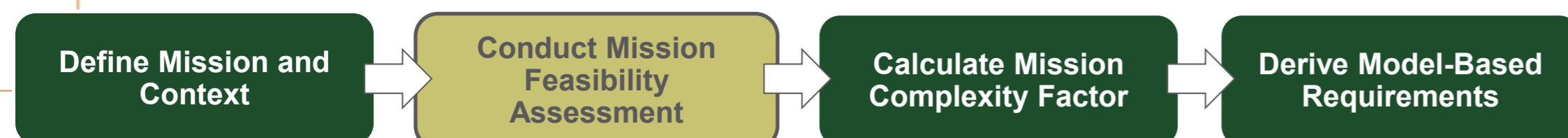


Step 2.2: Define Platform-Agnostic Mission Functions and Constraints

- Decompose into functions required to physically execute the mission objective
- Identify at least one constraint that could hinder execution of each function

CAS Mission Example

	Mission Function	Function Definition	Constraint	Constraint Level
	Assess	Enter contested mission area	Airspace permissiveness	High
	Coordinate	Talk to JTAC + C2 + other assets	Human dependency	High
	Sense	Collect intelligence	Environment severity	Low
	Decide	Prioritize and authorize engagements	Information quality	Medium
	Deliver	Apply effects	Collateral damage	High
	Recover	Return to base	Failure tolerance	Medium



Step 2: Mission Feasibility Assessment



Step 2.3: Rate Mission Inherent Difficulty

- Transform constraint levels from Step 2.2 to 1-5 scale, with 5 the most difficult
- Rank operational complexity, uncertainty, and consequence of failure on 1-5 scale
- Score the mission's total difficulty by:

$$D = \frac{S_{constraints} + S_{mission\ factors}}{S_{max}}$$

CAS Mission Example

Using the constraint levels from 2.2 and assuming scores of 3, 4, and 5 for operational complexity, uncertainty, and consequence of failure respectively, the normalized mission inherent difficulty level is:

$$D = \frac{22 + 12}{30 + 15} = 0.755$$

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Step 2: Mission Feasibility Assessment








Step 2.4: Rank Critical Dimensions

- Identify mission-relevant critical dimensions (-ilities)¹
- Survey experts to choose most and least important dimensions using MaxDiff scaling method²
- Use Hierarchical Bayes multinomial logit model to find mission-level utility weights for each dimension

CAS Mission Example

For five relevant critical dimensions, a full set of rank-ordered weights is calculated to be used as mission effectiveness attributes in the subsequent steps

Critical Dimension i	Latent Utilities v_i	Exponential $\exp(v_i)$	Weight w_i
 Survivability	1.2	3.3201	0.329
 Agility	0.6	1.8221	0.181
 Lethality	0.8	2.2255	0.221
 Affordability	0.2	1.2214	0.121
 Maneuverability	0.4	1.4918	0.148

1: Defense Acquisition University, "DAU Glossary of Defense Acquisition Acronyms and Terms," Website

2: Louviere, J. J., Flynn, T. N., and Marley, A., "Chapter Five: Basic models," *Best-Worst Scaling: Theory, Methods and Applications*, Cambridge University Press, 2015,

Define Mission and Context

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Step 3: Mission Complexity Factor



Goal: understand the impact of enabling technologies on mission success

Essential factors to provide context to all technology assumptions: confidence levels¹ & evidence standards

Technology evaluations based on Multi-Attribute Utility Theory (MAUT)²

Step 3.1: Define the Mission Utility Model

- Define piecewise performance utility curves, $u(x)$, for operational mission effectiveness attributes

- Calculate the baseline mission utility using: $U_{\text{base}} = \sum_{j=1}^m w_j u_j(x_j)$

CAS Mission Example

For an attribute related to agility, $x = \text{minutes from call to first effects on target}$, where a smaller value is better performance, a potential utility curve could be:

$$u(x) = \begin{cases} 1, & x \leq 5 \\ 1 - 0.3 \frac{x - 5}{5}, & 5 < x < 10 \\ 0.7 - 0.4 \frac{x - 10}{10}, & 10 < x < 20 \\ 0.3 - 0.3 \frac{x - 20}{10}, & 20 < x < 30 \\ 0, & x \geq 30 \end{cases}$$

Define Mission and Context

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1: Office of the Director of National Intelligence, "JCAT Intelligence Guide," Website

2: Girard, P. E., O'Connor, M. F., and Ulvila, J. W., "Modeling Choice Under Uncertainty in Military Systems Analysis," NOSC TD 2216, Naval Ocean Systems Center, Nov. 1991.

Step 3: Mission Complexity Factor



Step 3.2: Identify Discriminating Technologies

- Define technologies whose performance affects mission utility and feasibility
- Along with the technology, define technology readiness level, mission function, attributes, dependencies, integration requirements, alternatives, and evidence standards

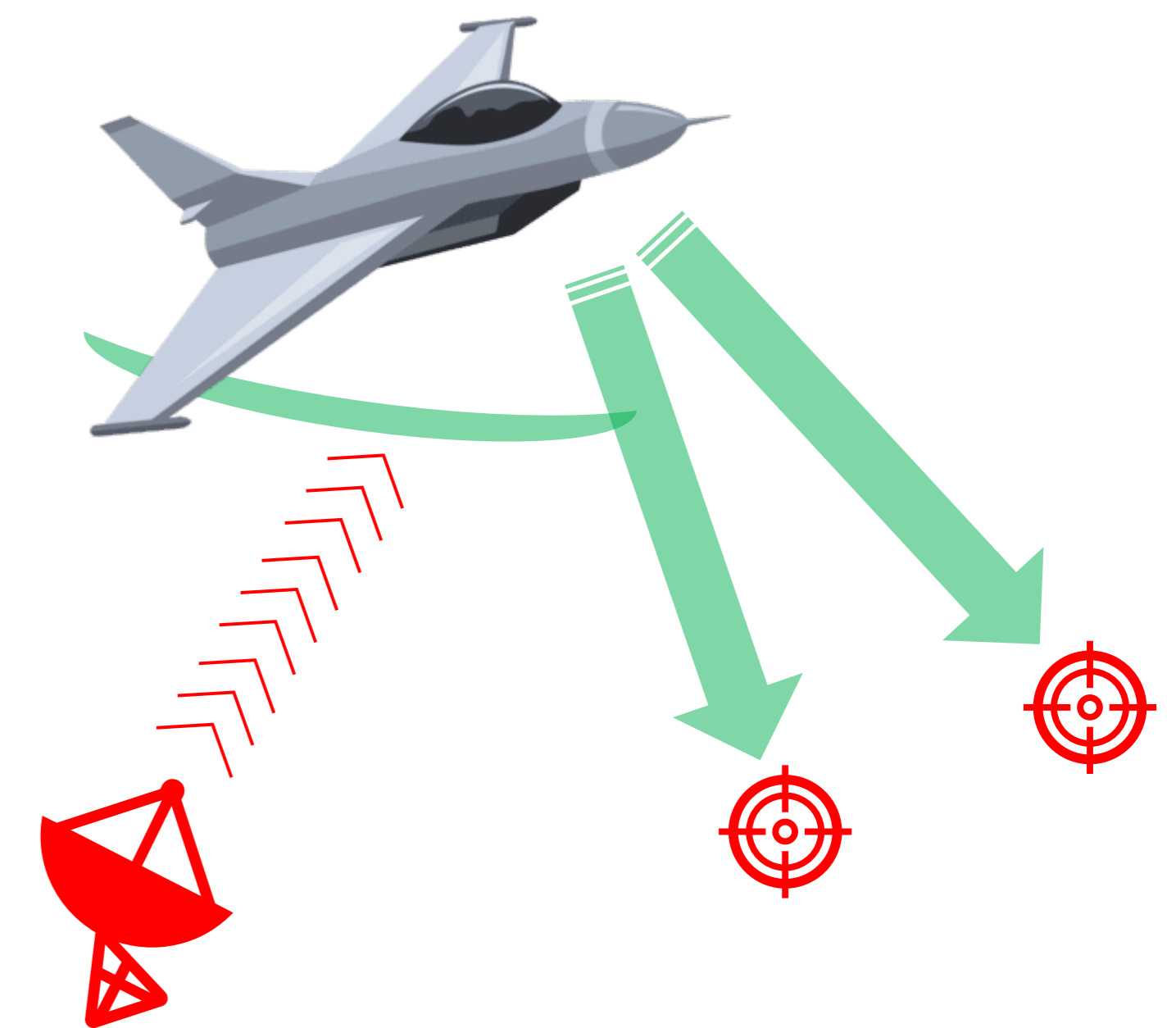
CAS Mission Example

Technology: jamming-resilient C2 and targeting

Impacted attributes: survivability, lethality

Impacted mission functions: coordinate, decide

TRL: 5



Define Mission and Context

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Step 3: Mission Complexity Factor



Step 3.3: Estimate Technology Mission Utility Leverage

- Estimate the change in attribute-level utility due to each technology using: $\Delta u_j = u_j(x_{j,k}) - u_j(x_{j,base})$
- Calculate value the technology provides across the entire mission, technology utility leverage using:

$$L_k = \sum_{j \in A_k} w_j \Delta u_j$$

CAS Mission Example

For the jamming-resilient technology,

- Probability to survive increases from 95% to 97%: $\Delta u_1 = 0.67 - 0.55 = 0.12$
- Probability of effect success increases from 70% to 80%: $\Delta u_2 = 0.75 - 0.60 = .0525$
- Total leverage for this technology: $L_1 = (0.329 * 0.12) + (0.221 * 0.25) = 0.095$

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Step 3: Mission Complexity Factor



Step 3.4: Quantify Technology Complexity

- Calculate the technology's contribution to mission complexity and feasibility using:

$$TC_k = \max(0, L_k) [\alpha M_k + \beta(1 - C_k) + \gamma(1 - E_k) + \delta I_k]$$

Where TC_k is the technical complexity, L_k is the technology leverage, M_k is the maturity deficit, C_k is the confidence level, E_k is the evidence quality, I_k is integration complexity, and $[\alpha, \beta, \gamma, \delta I_k]$ are tunable weights

CAS Mission Example

For the jamming-resilient technology, we assume a moderate confidence with non-operationally demonstrated evidence and moderate integration complexity

Across all parameters, integration complexity is weighted most strongly, followed by maturity deficit

$$TC_1 = \max(0, 0.095) [(0.25 * 0.5) + 0.2(1 - 0.6) + 0.2(1 - 0.80) + (0.35 * 0.55)] = 0.0416$$

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Step 3: Mission Complexity Factor



Step 3.5: Calculate Mission Complexity Factor

- Calculate MCF for each architecture alternative
- $$MCF = 100 \left[\lambda D + (1 - \lambda) \frac{\sum_{k=1}^n TC_k}{\sum_{k=1}^n \max(0, L_k) + \eta} \right]$$

Where λ is a weighting factor between inherent mission difficulty and technology complexity, and η is a very small number to avoid divide-by-zero issues

- Lowest MCF score indicates the least complex solution that can complete the mission objective

CAS Mission Example

Combining previous calculations of mission difficulty, technology complexity, and utility leverage for an architecture with four technologies impacting five critical dimensions, where we weight the technology complexity more strongly than the mission difficulty

$$MCF = 100 \left[(0.4 * 0.755) + (1 - 0.4) \frac{(0.0416 + 0.0106 + 0.0188 + 0.0732)}{(0.095 + 0.033 + 0.038 + 0.11) + 1 * 10^{-6}} \right] = 61.55$$

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Step 4: Model-Based Requirement Derivation



For Tier 1 requirements, least complex architecture alternative (lowest MCF) for a given mission objective develops the requirements and KPPs

- Example: a mission could use stealth or overwhelming force to accomplish the same task, but with very different platform requirements

For Tier 2 requirements, MAUT analysis and utility curves define threshold and objective values for performance variables

- Mission utility leverage values from Steps 3.1 and 3.3 provide reasonable bounds of capability increase that can be allocated above a current baseline

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Conclusions/Future Work



Conclusions

- Proposed a new method to systematically derive Tier 1 and Tier 2 requirements from missing engineering context, especially when customer desires are vague or unknown
- Approach connects early mission definition and requirements by decomposing mission thread elements into MBSE traceable artifacts (see paper for details)
- Pinnacle of approach is the quantification of a mission complexity factor which leverages understanding of both the mission and discriminating technologies

Future Work

- Codify approach into an MBSE environment with all relevant artifacts
- Deeper dive into necessary requirement elements in MBSE approach to ensure full traceability to original intentions, assumptions, and decisions

Thank you!

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Scan me to go to the Herber
Research Group website!

