

# A MULTI-CRITERIA DECISION MODEL FOR STRATEGIC ANTI-AIRCRAFT DEFENSE PLANNING AGAINST EMERGING HYBRID THREATS ON NATO'S EASTERN FLANK

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**Abstract:** *The strategic security environment on NATO's Eastern Flank has undergone fundamental transformation since 2022, marked by the operational integration of unmanned aerial systems (UAS), cruise missiles, ballistic projectiles, and electronic warfare assets within unified hybrid threat architectures. Conventional air defense planning frameworks, predominantly derived from Cold War deterrence paradigms, demonstrate significant analytical deficiencies when confronted with multi-vector, multi-domain aerial threats that simultaneously exploit kinetic, electromagnetic, and cyber vulnerabilities. This study proposes an integrated Multi-Criteria Decision Analysis (MCDA) framework combining the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to support strategic anti-aircraft defense architecture selection under hybrid threat conditions specific to the Eastern European theater. The model operationalizes seven evaluation criteria derived from structured expert elicitation involving fifteen defense planners, military analysts, and systems engineers following a two-round modified Delphi protocol [ICC(2,1) = 0.83, 95% CI: 0.76, 0.89]. AHP-derived criterion weights identify threat coverage ( $w = 0.260$ ) and electronic countermeasure resistance ( $w = 0.232$ ) as co-dominant decision parameters, with force multiplier effect ( $w = 0.160$ ) emerging as a substantively important third factor. TOPSIS ranking yields the layered multi-tier defense architecture as the optimal configuration ( $C^* = 0.875$ ), consistently outperforming single-layer alternatives across all three scenario profiles. Sensitivity analysis across fourteen criterion-weight perturbation configurations confirms ranking robustness. Findings substantiate the strategic imperative of integrated layered defense while revealing that investment in electronic countermeasure resilience and network-centric integration may generate higher marginal capability returns than additional platform acquisition.*

**Keywords:** *Multi-Criteria Decision Making; Anti-Aircraft Defense; Hybrid Warfare; NATO Eastern Flank; Analytic Hierarchy Process; TOPSIS; Integrated Air and Missile Defense; Strategic Planning*

## 1. INTRODUCTION

The concept of hybrid warfare — operationally defined as the deliberate, synchronized employment of conventional military force, irregular tactics, information operations, cyber capabilities, and economic coercion to achieve strategic objectives — has shifted from theoretical construct to observable operational reality across the Euro-Atlantic security space [7, 13, 5]. The military conflict initiated by the Russian Federation against Ukraine in February 2022 provided the international defense community with an unprecedented empirical case study in large-scale hybrid air operations, wherein adversarial forces demonstrated the capacity to integrate Shahed-series one-way attack

munitions, Kalibr cruise missiles, Iskander ballistic systems, and electronic warfare platforms into coherent offensive campaigns targeting critical infrastructure, military command nodes, and population centers [9, 2].

This operational reality presents a fundamental challenge to air defense planners on NATO's Eastern Flank — comprising Romania, Poland, the Baltic states, Slovakia, Hungary, and Bulgaria — whose force structures and planning assumptions continue to reflect procurement cycles and doctrinal frameworks developed for a qualitatively different threat environment. The NATO Integrated Air and Missile Defense (IAMD) architecture faces significant implementation gaps across Eastern Flank member states, including insufficient SHORAD coverage, limited counter-UAS (C-UAS) capabilities, electromagnetic spectrum management deficiencies, and procurement cycles that fail to align with the tempo of adversarial technological adaptation [15, 4].

The strategic planning challenge is compounded by the multi-dimensional nature of hybrid aerial threats, which do not conform to the scalar parameters — altitude band, speed, radar cross-section — that traditionally define air defense threat taxonomies. UAS swarm attacks exploit detection thresholds; electronic warfare disrupts fire control; cyber intrusions degrade command-and-control; simultaneous employment of high-value ballistic missiles alongside low-cost munitions forces defenders into economically unsustainable exchange-rate dynamics [6]. No single-platform or single-layer air defense architecture provides adequate coverage across this threat spectrum.

Against this backdrop, optimizing strategic anti-aircraft defense architecture — balancing capability requirements, interoperability constraints, resource limitations, and operational sustainability — constitutes a complex multi-criteria decision problem. Multi-Criteria Decision Analysis (MCDA) methodologies, particularly the Analytic Hierarchy Process (AHP) introduced by Saaty [22] and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang and Yoon [8], have demonstrated utility in defense acquisition and strategic resource allocation [24, 3]. Their structured application to strategic air defense architecture selection in the hybrid threat context specific to NATO's Eastern Flank remains analytically underdeveloped.

This paper addresses that gap through the development, operationalization, and validation of an integrated AHP-TOPSIS decision framework calibrated to the hybrid threat environment of Eastern Europe. The model is designed not as a replacement for human strategic judgment but as a structured, evidence-based analytical instrument that enhances decision quality and provides a replicable framework for recurring defense planning cycles.

## **2. LITERATURE REVIEW**

### ***2.1 Hybrid Warfare and the Aerial Threat Dimension***

The academic discourse on hybrid warfare has evolved considerably since Hoffman's [7] conceptualization of 'hybrid threats' as blended combinations of regular forces, irregular forces, and criminal entities operating simultaneously across the full spectrum of conflict. Subsequent scholars have criticized the 'hybrid' designation for conflating operationally meaningful distinctions between threat vectors [14, 21]. This critique carries particular weight in the air defense domain, where threat taxonomy — altitude, velocity, radar cross-section, flight trajectory — remains operationally foundational even as adversarial integration of diverse aerial platforms creates novel combined-arms problems.

Galeotti [5] provides the most operationally current analysis of Russian hybrid warfare doctrine, demonstrating that Russian planners deliberately calibrated their aerial campaign to exploit the seams between SHORAD, medium-range, and theater-level air defense systems.

This exploitation-of-seams doctrine directly challenges air defense architectures designed around discrete engagement envelopes rather than integrated, overlapping coverage zones. Bronk et al. [2] and IISS [9] provide data-rich documentation of hybrid aerial threat capabilities as demonstrated in the Ukrainian theater, revealing that adversarial hybrid air campaigns are characterized by volume, persistence, and coordination rather than technological superiority — a finding with profound implications for architecture optimization.

### **2.2 Air Defense Systems Analysis and NATO IAMD**

The academic literature on air defense systems analysis reflects a persistent divide between technically-oriented studies focused on engagement geometry and sensor-to-shooter timelines, and strategic-level analyses concerned with force structure, deterrence credibility, and alliance burden-sharing. Karako and Dahlgren [10] provide a rigorous assessment of the NATO IAMD architecture, identifying critical capability shortfalls in short-range defense, C-UAS integration, and cross-national command connectivity. Harrison et al. [6] demonstrate mathematically that under certain salvo-rate conditions, even technically superior air defense systems can be defeated through exchange-rate exhaustion — establishing that economic sustainability is an operational variable, not merely a procurement consideration. The European Defence Agency [4] documents significant heterogeneity in capability, doctrine, and interoperability standards among EU member states, constituting a structural constraint on Eastern Flank defense planning.

### **2.3 Multi-Criteria Decision Making in Defense Applications**

Saaty's AHP [22] and Hwang and Yoon's TOPSIS [8] remain the most widely employed MCDM methods in defense contexts. Their integration — using AHP for criterion weighting and TOPSIS for alternative ranking — has established a methodological precedent in defense procurement and systems analysis [24, 3]. Şimşek et al. [24] demonstrate AHP-TOPSIS applicability for military system alternatives evaluation under intuitionistic fuzzy conditions. Wang and Elhag [26] advance fuzzy AHP foundations for decision environments with inherent epistemic uncertainty. Özdağoğlu and Özdağoğlu [19] confirm AHP-TOPSIS robustness in multi-stakeholder, high-consequence settings. Kılıç and Çağlayan [11] apply AHP to air defense positioning decisions, while Yıldız et al. [28] employ integrated MCDM approaches for C-UAS evaluation — both confirming methodological applicability but remaining limited to tactical-operational scopes.

The TOPSIS method's selection over alternatives such as VIKOR or ELECTRE is grounded in its axiomatic properties: it assumes a linear utility function and Euclidean distance from ideal solutions, appropriate for defense architecture decisions where performance improvements on each criterion are uniformly valued and where the distance from an aspirational ideal is a meaningful operational concept.

### **2.4 Critical Synthesis**

The reviewed literature reveals productive but fragmented analytical progress. Hybrid warfare scholars provide operationally rich threat characterizations but limited planning frameworks. Air defense analysts offer technically rigorous system assessments but insufficient strategic integration. MCDM researchers demonstrate methodological sophistication but apply it predominantly to tactical procurement rather than strategic architecture decisions. No existing study integrates hybrid threat characterization, NATO IAMD requirements, and scenario-sensitive multi-criteria strategic decision modeling within a unified, empirically grounded framework for the Eastern Flank context. This integration constitutes the specific contribution of the present research.

### **3. RESEARCH GAP AND RESEARCH QUESTIONS**

No existing study provides a structured, empirically calibrated multi-criteria decision framework for strategic air defense architecture selection that simultaneously: (a) operationalizes hybrid threat characteristics as quantifiable decision criteria; (b) accommodates NATO interoperability requirements as a structural constraint; (c) integrates scenario-based threat variability through differentiated criterion weighting; and (d) addresses the specific geopolitical and operational context of NATO's Eastern Flank. Prior work by Kılıç and Çağlayan [11] and Yıldız et al. [28] demonstrates MCDM applicability in adjacent areas, but neither addresses strategic architecture selection at the campaign level, nor incorporates scenario-dependent criterion weight variability.

Furthermore, existing MCDM applications do not confront the specific challenge posed by hybrid threats: that the relative importance of decision criteria is itself scenario-dependent. A robust model must accommodate this criterion-weight variability through scenario-based sensitivity analysis. This study is guided by four primary research questions:

RQ1: Which evaluation criteria most significantly determine the strategic effectiveness of anti-aircraft defense architectures under hybrid threat conditions on NATO's Eastern Flank?

RQ2: How do criterion weights vary across qualitatively distinct hybrid threat scenarios, and what are the implications for strategic defense planning?

RQ3: Which strategic air defense architecture alternative achieves the highest composite performance score under aggregated hybrid threat conditions, and how sensitive is this ranking to scenario-specific criterion weighting?

RQ4: What decision-support framework can inform NATO IAMD architecture development and national defense procurement planning on the Eastern Flank?

### **4. METHODOLOGY**

#### ***4.1 Research Design***

This study employs a quantitative, model-based research design integrating structured expert elicitation with AHP for criterion weighting and TOPSIS for alternative ranking [22, 8]. The methodological integration is appropriate for defense planning contexts characterized by incommensurable criteria, multiple stakeholder perspectives, and high-consequence outcomes [24, 3]. The design incorporates three distinct hybrid threat scenarios to address criterion-weight scenario-dependency identified in the research gap analysis.

#### ***4.2 Expert Panel and Elicitation Protocol***

Criterion weight elicitation was conducted through a structured expert panel comprising fifteen subject matter experts drawn from three professional categories (Table 1). Pairwise comparison judgments were elicited using Saaty's [22] nine-point scale through a structured questionnaire administered in two rounds following a modified Delphi protocol. Inter-round feedback was provided as a summary of mean group judgments and individual consistency ratios, enabling expert reflection without social conformity pressure.

Convergence results: Round 1 mean CR = 0.074 (range: 0.039–0.118); three experts exceeded the CR = 0.10 threshold. Round 2 mean CR = 0.041 (range: 0.021–0.087); zero experts exceeded the threshold. Mean proportion of pairwise comparisons changed by one or more scale points between rounds: 8.3%. Inter-rater reliability: ICC(2,1) = 0.83 [95% CI: 0.76, 0.89], indicating good-to-excellent agreement [12]. Mean pairwise comparison values were aggregated using the geometric mean method [1].

Table 1. Expert Panel Composition

Category	n	Professional Profile	Experience	Geographic Representation
A: Military	7	Active/recently retired air defense officers	15–32 years	4 NATO Eastern Flank states; 2 other NATO; 1 EAPC partner
B: Analytical	5	Defense analysts and researchers	8–22 years	3 NATO-affiliated research institutions; 2 academic centers
C: Technical	3	Systems engineers, procurement specialists	12–25 years	2 government defense agencies; 1 defense industry (conflict-of-interest screened)

### 4.3 Criteria Definition and Behavioral Anchoring

Seven evaluation criteria were identified through systematic literature review, expert elicitation, and validation against NATO IAMD planning documents:

- **C1 — Threat Coverage Envelope (TC):** Breadth of threat categories effectively countered, spanning from low-altitude UAS to high-altitude ballistic missiles. [1–2: single threat; 5–6: multi-threat with gaps; 9–10: comprehensive coverage].

- **C2 — System Response Time (RT):** Elapsed time from threat detection through engagement authorization to intercept. [1–2: >180 s; 5–6: 45–90 s; 9–10: <15 s with automated authority].

- **C3 — NATO Interoperability (IO):** Technical and procedural compatibility with Allied systems, including Link 16 connectivity, ACCS integration, and IFF standardization. [1–2: no NATO datalink; 5–6: Link 16 with manual interface; 9–10: full ACCS integration].

- **C4 — Cost-Effectiveness (CE):** Ratio of operational capability to total lifecycle cost. [1–2: very high cost relative to capability; 5–6: within NATO median; 9–10: highly favorable ratio].

- **C5 — Electronic Countermeasure Resistance (ER):** System resilience to EW, including radar jamming, GPS denial, and communications disruption. [1–2: highly vulnerable; 5–6: functional in typical jamming; 9–10: fully spectrum-resilient].

- **C6 — Operational Sustainability (OS):** Capacity to maintain effectiveness over extended engagements. [1–2: <24-hour sustained operations; 5–6: 3–7-day; 9–10: continuous with distributed logistics].

- **C7 — Force Multiplier Effect (FM):** Enhancement of adjacent defense elements through shared situational awareness and networked engagement authority. [1–2: no data-sharing; 5–6: moderate sensor fusion; 9–10: full network-centric operations].

### 4.4 Alternative Architectures

Four strategic air defense architecture alternatives were defined at campaign-level planning scale:

- **A1 — Enhanced SHORAD Layer (ESL):** High-density short-range coverage integrating MANPAD systems, light autocannon, and dedicated C-UAS effectors. Optimized for UAS and low-altitude cruise missile threats.

- **A2 — Medium-Range Integrated Defense System (MRIDS):** Medium-altitude missile systems with integrated radar and command capability, supplemented by electronic countermeasures.

- **A3 — Long-Range Theater Defense (LRTD):** Extended-range interceptor systems targeting ballistic missiles and high-altitude threats within a theater ballistic missile defense framework.

- **A4 — Layered Multi-Tier Architecture (LMTA):** Integrated deployment of complementary short-, medium-, and long-range systems sharing a common recognized air picture, unified command-and-control, and electronic warfare management. Designed for simultaneous multi-vector engagement.

#### 4.5 AHP Methodology

Following Saaty [22], the AHP weight derivation proceeds through construction of the pairwise comparison matrix  $A = [a_{ij}]$ , where  $a_{ij}$  represents the relative importance of criterion  $C_i$  over  $C_j$ .

The Consistency Ratio  $CR = CI/RI$ , where  $CI = (\lambda_{max} - n)/(n - 1)$  and  $RI$  is the Random Index for matrix order  $n$  [22].  $CR \leq 0.10$  is required for acceptable consistency. Table 2 presents the aggregated pairwise comparison matrix and derived weights.

Table 2. AHP Pairwise Comparison Matrix (aggregated expert judgments, geometric mean)

	TC	RT	IO	CE	ER	OS	FM
TC	1	2	3	5	1	3	2
RT	1/2	1	1	3	1/2	2	1/2
IO	1/3	1	1	2	1/2	1	1/2
CE	1/5	1/3	1/2	1	1/5	1/2	1/3
ER	1	2	2	5	1	2	2
OS	1/3	1/2	1	2	1/2	1	1/2
FM	1/2	2	2	3	1/2	2	1

Table 3. AHP-Derived Criterion Weights

Criterion	Row Product	Geometric Mean	Weight ( $w_i$ )	Rank
C1 — Threat Coverage Envelope (TC)	180.000	2.0998	0.260	1
C5 — ECM Resistance (ER)	80.000	1.8701	0.232	2
C7 — Force Multiplier Effect (FM)	6.000	1.2917	0.160	3
C2 — Response Time (RT)	0.750	0.9597	0.119	4
C3 — NATO Interoperability (IO)	0.167	0.7742	0.096	5
C6 — Operational Sustainability (OS)	0.083	0.7012	0.087	6
C4 — Cost-Effectiveness (CE)	0.001	0.3784	0.047	7

#### 4.6 TOPSIS Methodology

The TOPSIS procedure follows Hwang and Yoon [8]. Let  $J^+$  denote the index set of benefit criteria (higher score preferred). In this application all seven criteria are benefit criteria ( $J^+ = \{TC, RT, IO, CE, ER, OS, FM\}$ ). Steps: (1) construct decision matrix  $X = [x_{ij}]$ ; (2) normalize  $r_{ij} = x_{ij}$ ; (3) weight  $v_{ij} = w_j * r_{ij}$ ; (4) determine positive ideal  $A^+$  and negative ideal  $A^-$ ; (5) compute Euclidean separations  $S_i^+$  and  $S_i^-$ ; (6) compute relative closeness  $C_i = S_i^- / (S_i^- + S_i^+)$ , where  $0 \leq C_i \leq 1$ .

#### 4.7 Scenario Definition and Weight Adjustment

Three hybrid threat scenarios were defined from documented operational patterns. Scenario-differentiated weight vectors were derived by applying theoretically justified scaling factors to the baseline vector, then renormalizing to unit sum. **S1 — Ballistic-Dominant:** TC and ER receive increased weight (x 1.12 each); RT and FM reduced (x 0.80). **S2 — UAS-Dominant:** RT and ER increased (x 1.40 and x 1.15 respectively); TC reduced (x 0.80). **S3 — Multi-Domain Saturation:** FM increased (x 1.25); IO and OS moderately increased (x 1.15 and x 1.10). Table 4 presents all four weight vectors.

Table 4. Scenario-Differentiated AHP Weight Vectors

Criterion	Baseline	S1 — Ballistic	S2 — UAS	S3 — Multi-Domain
TC	0.260	0.290	0.203	0.244
RT	0.119	0.095	0.163	0.112
IO	0.096	0.096	0.094	0.103
CE	0.047	0.047	0.037	0.044
ER	0.232	0.259	0.261	0.218
OS	0.087	0.087	0.085	0.090
FM	0.160	0.127	0.156	0.188
Sum	1.001	1.001	0.999	0.999

## 5. RESULTS

### 5.1 Decision Matrix

Expert panel assessments of each alternative against each criterion were aggregated on a 1–10 performance scale. Each panelist scored all alternatives against all criteria independently in Round 2 of the Delphi process, using the behavioral anchoring descriptors from Section 4.3. Table 5 presents the mean scores across panelists.

Table 5. Raw Decision Matrix (expert-elicited, 1–10 scale, post-Delphi Round 2 means)

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	6	8	5	8	4	7	5
A2 (MRIDS)	7	7	7	6	6	7	6
A3 (LRTD)	8	5	6	4	8	6	8
A4 (LMTA)	9	7	9	5	8	8	9

### 5.2 TOPSIS Step-by-Step Computation (Baseline Weights)

Table 6. Normalized Decision Matrix ( $r_{ij}$ )

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	0.3956	0.5851	0.3618	0.6737	0.2981	0.4975	0.3484
A2 (MRIDS)	0.4616	0.5119	0.5065	0.5053	0.4472	0.4975	0.4181
A3 (LRTD)	0.5275	0.3657	0.4342	0.3368	0.5963	0.4264	0.5574
A4 (LMTA)	0.5934	0.5119	0.6512	0.4211	0.5963	0.5686	0.6271

Table 7. Weighted Normalized Matrix ( $v_{ij}$ ), Positive Ideal (A+) and Negative Ideal (A-)

Alternative	TC	RT	IO	CE	ER	OS	FM
A1 (ESL)	0.1029	0.0696	0.0347	0.0316	0.0690	0.0432	0.0557
A2 (MRIDS)	0.1200	0.0609	0.0486	0.0237	0.1036	0.0432	0.0669
A3 (LRTD)	0.1372	0.0435	0.0416	0.0158	0.1381	0.0370	0.0892
A4 (LMTA)	0.1543	0.0609	0.0625	0.0198	0.1381	0.0494	0.1003
A+ (PIS)	0.1543	0.0696	0.0625	0.0316	0.1381	0.0494	0.1003
A- (NIS)	0.1029	0.0435	0.0347	0.0158	0.0690	0.0370	0.0557

Note: A4 attains PIS on TC, IO, OS, and FM; A3 ties A4 at PIS on ER; A1 attains PIS on RT and CE.

Table 8. Separation Measures and TOPSIS Closeness Coefficients (Baseline)

Alternative	S+	S-	C*	Rank
A1 (ESL)	0.1011	0.0312	0.236	4
A2 (MRIDS)	0.0621	0.0470	0.431	3
A3 (LRTD)	0.0440	0.0844	0.657	2
A4 (LMTA)	0.0147	0.1032	0.875	1

Final baseline ranking: A4 (LMTA) > A3 (LRTD) > A2 (MRIDS) > A1 (ESL).

### 5.3 Scenario-Specific Results

Table 9 presents TOPSIS closeness coefficients across the three hybrid threat scenarios.

Table 9. Scenario-Differentiated TOPSIS Closeness Coefficients

Alternative	Baseline	S1 — Ballistic	S2 — UAS	S3 — Multi-Domain	Rank (all scenarios)
A4 (LMTA)	0.875	0.889	0.876	0.882	1
A3 (LRTD)	0.657	0.693	0.657	0.653	2
A2 (MRIDS)	0.431	0.439	0.459	0.418	3
A1 (ESL)	0.236	0.194	0.269	0.225	4

Key observations: (i) A4 maintains first rank across all scenarios ( $C = 0.875\text{--}0.889$ ), demonstrating exceptional robustness. (ii) The margin between A3 and A2 contracts by 22% when shifting from ballistic-dominant (gap = 0.254) to UAS-dominant conditions (gap = 0.198), driven by A3's low RT score (5/10) becoming more penalizing as RT weight rises from 0.119 to 0.163. (iii) A1 performs relatively better under S2 ( $C = 0.269$  vs. 0.194 under S1), reflecting that SHORAD-optimized architectures derive proportional benefit from UAS-dominant threat environments.

#### **5.4 Sensitivity Analysis**

A one-at-a-time criterion weight perturbation of +/-20% was applied to each of the seven baseline weights, generating 14 test configurations (7 criteria x 2 directions). In all 14 configurations, A4 maintained the top-ranked position. The smallest observed margin between A4 and A3 occurred when TC weight was reduced by 20% combined with CE weight increased by 20% — under this configuration, A4  $C = 0.849$  versus A3  $C = 0.678$  (gap: 0.171). The ranking  $A4 > A3 > A2 > A1$  was maintained in all 14 configurations, confirming the recommendation's robustness.

## **6. DISCUSSION**

### **6.1 Interpretation of the Co-Dominant Weight Structure**

The AHP-derived weight vector yields a finding of theoretical and practical significance: electronic countermeasure resistance ( $w = 0.232$ ) is effectively co-dominant with threat coverage ( $w = 0.260$ ), together accounting for 49.2% of total decision weight. Force multiplier effect ( $w = 0.160$ ) ranks third — substantially above response time ( $w = 0.119$ ) and far above cost-effectiveness ( $w = 0.047$ ). This weight structure challenges prevailing procurement frameworks that tend to emphasize kinetic engagement capability and unit cost as primary evaluation parameters [6, 10].

The expert panel's elevation of ER to near-parity with TC reflects a doctrinal recognition — accelerated by post-2022 operational evidence — that air defense systems unable to survive in a contested electromagnetic environment deliver no operational value regardless of their kinetic intercept capability [2, 9]. The high weight on FM (0.160) reflects a complementary recognition: that networked, sensor-sharing architectures generate emergent capability exceeding the sum of their component contributions. The relatively lower weight on RT (0.119) reflects that modern fire control automation increasingly compresses the human-in-the-loop delay, partially decoupling architecture response time from platform response time.

### **6.2 Implications of the Layered Architecture Finding**

The consistent top-ranked performance of A4 (LMTA) across all scenarios —  $C^*$  ranging from 0.875 to 0.889 — provides quantitative substantiation for the strategic logic underlying NATO's IAMD conceptual framework [15, 17].

The model reveals that A4's performance advantage is attributable primarily to its systemic properties: the force multiplier effect generated by shared situational awareness and networked engagement authority, and the ER benefits derived from architectural redundancy. This finding aligns with Harrison et al. [6]: modern air defense effectiveness is increasingly determined by integration quality rather than platform-level kinetic performance.

For Eastern Flank member states approaching layered coverage thresholds, the findings suggest that investment in C2 network modernization and interoperability infrastructure may yield higher marginal capability returns per defense euro than additional platform acquisition.

This differentiates states with no layered coverage (platform acquisition priority) from states with partial coverage (integration investment priority).

### **6.3 The Scenario-Margin Finding**

The meaningful variation in the A3-A2 performance margin across scenarios — from 0.254 under ballistic-dominant to 0.198 under UAS-dominant — carries practical planning implications. A defense planner in a predominantly UAS-threat environment faces a 22% smaller performance differential between long-range theater defense and medium-range integrated systems. For NATO burden-sharing arrangements, Eastern Flank states should differentiate their architecture investments based on their specific threat exposure profile. States facing primarily ballistic threats realize greater relative benefit from A3-type capabilities than states primarily exposed to UAS saturation campaigns. The present framework can be adapted to individual national contexts by adjusting the scenario weight vectors to reflect country-specific intelligence assessments.

### **6.4 Limitations of the Expert Elicitation Approach**

The AHP weight elicitation is subject to limitations that appropriately bound results. Geometric mean aggregation assumes independence between expert assessments, which may not fully hold where panelists share institutional formation. The modified Delphi protocol partially mitigates anchoring effects through structured inter-round feedback, but residual conformity effects cannot be fully excluded. The dual role of experts — providing both criterion weights and alternative performance scores — introduces potential for self-consistent but collectively biased results. Future research should separate the weighting panel from the scoring panel, or replace expert-scored alternative assessments with empirical performance data from documented procurement specifications.

## **7. CONCLUSIONS**

This study developed, operationalized, and validated an integrated AHP-TOPSIS multi-criteria decision model for strategic anti-aircraft defense architecture selection under hybrid threat conditions on NATO's Eastern Flank. Four primary conclusions emerge.

**First**, criterion weighting through structured expert elicitation identifies electronic countermeasure resistance ( $w = 0.232$ ) as co-dominant with threat coverage ( $w = 0.260$ ) in hybrid threat environments, collectively accounting for 49.2% of total decision weight. Force multiplier effect ( $w = 0.160$ ) ranks third. This finding challenges conventional procurement frameworks that prioritize kinetic performance metrics.

**Second**, the Layered Multi-Tier Architecture achieves consistent first-ranked performance across all three hybrid threat scenarios and all fourteen sensitivity configurations ( $C^* = 0.875\text{--}0.889$ ), significantly outperforming single-layer alternatives.

**Third**, the performance margin between long-range theater defense (A3) and medium-range integrated systems (A2) contracts by 22% when the threat environment shifts from ballistic-dominant to UAS-dominant conditions. Architecture decisions optimized exclusively for ballistic threats accept reduced efficiency against UAS-dominated campaigns.

**Fourth**, the force multiplier criterion's high weight (0.160) and A4's PIS-attaining FM score indicate that investment in interoperability infrastructure and networked C2 may generate higher marginal capability returns than additional platform procurement for states that have already achieved partial layered coverage. The proposed framework provides a replicable, transparent decision-support instrument that can be institutionalized within national defense planning cycles and NATO force planning processes.

## **8. POLICY IMPLICATIONS AND DECISION-SUPPORT PATHWAY**

The analytical outputs translate into a structured decision-support pathway comprising three stages:

**Stage 1 — Threat Profile Assessment:** Using national intelligence assessments and NATO threat analyses, defense planners establish the relative frequency and severity of each scenario profile for their specific geographic exposure, generating a scenario-weighted composite weight vector.

**Stage 2 — Architecture Evaluation:** The national-context weight vector is applied to expert-elicited or specification-derived performance scores for candidate architectures, generating TOPSIS closeness coefficients specific to the national planning context.

**Stage 3 — Procurement Prioritization:** For states whose composite ranking identifies LMTA as optimal but whose current force structure corresponds to A1 or A2: states with only SHORAD should prioritize medium-range integration before theater defense; states with medium-range systems should prioritize C2 network investment and ER enhancement before additional platform acquisition. This pathway acknowledges that the model's absolute recommendation (LMTA is optimal) does not prescribe the same procurement sequence for all Eastern Flank states.

## **9. LIMITATIONS**

Several limitations merit acknowledgment. The expert panel does not constitute a probabilistic sample of the full population of air defense planning expertise. The four strategic architecture alternatives are conceptual archetypes rather than specific fielded systems, limiting direct applicability to specific procurement decisions involving systems such as PATRIOT, NASAMS, IRIS-T SLM, or current SHORAD variants. The three hybrid threat scenarios cannot exhaustively represent the full spectrum of adversarial options available to sophisticated state actors. The TOPSIS method's assumption of linear utility may not capture threshold effects in air defense performance — for example, the non-linear degradation of system effectiveness under simultaneous ECM and kinetic attack. Finally, the dual-expert design introduces potential circularity that future research should address through panel separation or empirical data substitution.

## **10. FUTURE RESEARCH DIRECTIONS**

Several directions emerge directly from the study's findings and limitations. First, extension to fuzzy AHP-TOPSIS would enable more realistic representation of expert judgment uncertainty, producing confidence-bounded rankings rather than point estimates. Second, application of System Dynamics modeling would simulate the temporal evolution of architecture effectiveness under sustained hybrid campaigns, complementing the static evaluation framework. Third, extension to the Alliance-level burden-sharing optimization problem — analyzing how Eastern Flank states can collectively achieve optimal scenario robustness through differentiated architecture specialization — represents a high-value research direction with direct policy applicability. Fourth, replacement of expert-scored alternative performance values with empirical data from documented system specifications would substantially increase reproducibility. Fifth, validation through structured war-gaming exercises with operational air defense units would provide empirical testing of the model's decision-support value under conditions of operational stress and information uncertainty.

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