Contested Agile Combat Employment

A Site-Selection Methodology

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The Agile Combat Employment concept relies on foreign country access and infrastructure to generate airpower. Yet numerous factors complicate site-selection decisions including peer-to-peer threats, complex geopolitics, and resource requirements. Multicriteria decision analysis can help strategists appropriately account for competing objectives and maintain a competitive advantage with theater adversaries. This paper presents a site-selection decision framework that evaluates agile combat employment basing alternatives using a geographic information system, analytic hierarchy process, and unclassified, publicly available data. This framework identifies existing airports best suited for strategic utilization. The methodology could support combatant commands as they optimize agile combat employment infrastructure, preserve resources, and minimize risk to US Armed Forces.

Adapt or perish, now as ever, is nature's inexorable imperative.

H. G. Wells, *Mind at the End of Its Tether*

Civilization's survival has hinged on humans' capacity to innovate and evolve amid difficult circumstances. Today, the sentiment rings true for the US Air Force and its pacing adversary. The People's Republic of China (PRC) continues to develop its military capabilities considerably, driving the Air Force to "accelerate change or lose."[1] Complex geopolitical landscapes, resource limitations, and other competing objectives require the service to adapt its strategy, policy, and forces to deter factions threatening global peace and prepare for future global conflict.

Accordingly, the Air Force developed a modernized power-projection approach, agile combat employment (ACE). The foundation of this concept, adaptive basing, utilizes "alternate basing options to enable flying operations" and "calls for forces to disaggregate

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1. Charles Q. Brown Jr., *CSAF Action Orders: To Accelerate Change across the Air Force* (Washington, DC: Department of the Air Force (DAF), December 2020), https://www.af.mil/.

capabilities from a single base and disperse forces and capabilities to many locations for operational maneuver."[2] But the US military is predominately postured at large main operating bases, which is detrimental to ACE strategy.[3] Therefore, barring any major force changes, the service must leverage strategic infrastructure in foreign countries to support ACE.[4]

Efforts to establish strategic ACE operating sites are underway in the Pacific Air Forces and the US Air Forces in Europe.[5] Yet, what happens if these operating sites become compromised at the onset of conflict? The People's Liberation Army recognizes foreign country access, resource logistics, and limited defensibility as vulnerabilities to the agile combat employment concept.[6] China may undermine ACE by denying the Air Force access to these locations through diplomatic, economic, or kinetic action, thereby reducing the survivability of air operations. These factors prompt the question: how can the service adapt ACE if its access to predetermined hubs and spokes becomes compromised?

This article proposes the ACE site-selection framework, a selection methodology that, with existing airport infrastructure, evaluates decision criteria and facilitates rapid decision making for ACE site selection. The methodology can be applied to post-attack scenarios to provide reactionary decision-making capabilities for adaptive basing. Additionally, the framework is suitable to help guide strategic or just-in-time decision making, including in wargaming or as a way to increase political-military engagement at strong candidate locations.

The ACE site-selection framework combines geographic information system analysis and decision analysis to provide a flexible, scalable, expedient, and reproducible framework offering planning capabilities at multiple strategic levels by evaluating prospective sites and informing decisionmakers. The proposed framework methodology uses the Pacific Air Forces area of responsibility to demonstrate its utility.

DoD, US Air Force, and ACE Doctrine

Great power competition, a principal priority outlined in the unclassified *Summary of the 2018 National Defense Strategy*, has been a catalyst for modern-day military doctrine and strategy. The Department of Defense recognizes China's ambition to fulfill the "great

2. Patrick Mills et al., *Estimating Air Force Deployment Requirements for Lean Force Packages: A Methodology and Decision Support Tool Prototype* (Santa Monica, CA: RAND Corporation, 2017), 22, https://www.rand.org/.

3. Patrick Mills et al., *Building Agile Combat Support Competencies to Enable Evolving Adaptive Basing Concepts* (Santa Monica, CA: RAND Corporation, 2020), https://www.rand.org/.

4. Miranda Priebe et al., *Distributed Operations in a Contested Environment: Implications for USAF Force Presentation* (Santa Monica, CA: RAND, 2019), https://www.rand.org/.

5. Brian W. Everstine, "PACAF Surveyed Every 'Piece of Concrete' in the Pacific for Agile Combat Employment," *Air Force Magazine*, November 25, 2020, https://www.airforcemag.com/.

6. Derek Solen, "The PLA's Critical Assessment of the Agile Combat Employment Concept," China Brief 21, no. 14, Jamestown Foundation (website), July 16, 2021, https://jamestown.org/.

rejuvenation of the Chinese nation," including the unprecedented expansion and modernization of the People's Liberation Army.[7] China's military development spans numerous domains, but the rapid growth of its nuclear forces and long-range precision strike capabilities are of particular concern to the US Air Force.

These advancements pose a significant threat to the service's conventional basing strategy that currently relies on large main operating bases to sustain airpower in contested, degraded, and operationally limited environments. Accordingly, the *2018 National Defense Strategy* calls for investments in forces "that can deploy, survive, operate, maneuver, and regenerate in all domains while under attack" and a transition from "large, centralized, unhardened infrastructure to smaller, dispersed, resilient, adaptive basing."[8]

These realities prompted the Air Force to adopt agile combat employment.[9] Missiles, and to a lesser extent, aircraft, represent the most significant risk to Air Force installations, particularly in the Pacific theater.[10] ACE helps mitigate these threats by dispersing forces throughout the theater using hub-and-spoke basing configurations, offering the service unpredictability and requiring the People's Liberation Army to expend more missiles to reduce US Air Force airpower effects.[11]

Several significant challenges accompany the ACE concept and site selection. First, due to the hub-and-spoke structure, dispersed operations will inevitably increase operational costs and complicate agile combat support activities.[12] Thus, a balance must be struck between optimally disaggregating aircraft operations and effectively supporting these sites with resources.

Second, foreign country access is an essential enabler to ACE operations.[13] This factor is particularly challenging since peacetime partnerships and agreements could be negated at the onset of conflict. Therefore, establishing overt and covert agreements that support ACE is prudent, provided planners recognize their unpredictability and posture contingency plans.

Finally, the current agile combat employment concept relies on prepositioned assets.[14] Should the People's Republic of China conduct anti-access/area-denial (A2/AD) at these locations, ACE operations would require repositioning to under-resourced operating

7. Office of the Secretary of Defense (OSD), *Military and Security Developments Involving the People's Republic of China: Annual Report to Congress* (Washington, DC: OSD, November 3, 2021), 1, https://media.defense.gov/.

8. James N. Mattis, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (Washington DC: OSD, January 2018), 6, https://dod.defense.gov/.

9. DAF, Air Force Doctrine Publication (AFDP) 3-99, *The Department of the Air Force Role In Joint All-Domain Operations* (Maxwell AFB, AL: LeMay Center for Doctrine Development and Education (LeMay Center), October 8, 2020), Appendix B, https://www.doctrine.af.mil/.

10. Priebe et al., *Distributed Operations*.

11. Mills et al., *Adaptive Basing Concepts*.

12. Priebe et al., *Distributed Operations*.

13. Priebe et al.

14. DAF, AFDP 3-99, Appendix B.

sites. Planners would have to obtain assets from the host nation because airlift capabilities will be preoccupied, and traditional combat support will be unpredictable.[15] The proposed ACE site-selection framework simplifies the decision-making process and supplies leaders with a flexible, scalable, expedient, and reproducible framework to support data-driven site-selection decisions.

Methodologies, Tools, and Techniques

Multicriteria decision analysis (MCDA) can simplify complicated decisions by combining user preferences with decision alternatives, criteria, and constraints to meet a defined objective.[16] Analytic hierarchy process (AHP) is a prevalent MCDA technique in literature.[17] Analytic hierarchy process utilizes a simple and flexible system of scoring and weighting parameters based on a criterion's relative significance compared to other criteria through pairwise comparison.[18] This process is the most applied MCDA method to construction disciplines and the study of site-selection optimization and has been proven effective in former military site-selection frameworks.[19]

GIS can be an essential enabler for site-selection methodologies. A 2018 MCDA site-selection review highly recommended integrating GIS software and spatial data in site-selection analysis because complex geographic constraints are a significant factor for this type of optimization.[20] Site-selection methods are primarily concerned with geospatial data, and GIS-based methods provide a reliable and pragmatic tool for integrating constraints, analyzing data, and producing visualizations.[21] The prevalence of GIS-based

15. DAF.

16. Gilberto Montibeller and L. Alberto Franco, "Multicriteria Decision Analysis for Strategic Decision Making," in *Handbook of Multicriteria Analysis*, ed. Constantin Zopounidis and Panos Pardalos (Berlin: Springer, 2010), 25–48.

17. Ernest H. Forman and Saul I. Gass, "The Analytic Hierarchy Process—an Exposition," *Operations Research* 49, no. 4 (July–August 2001), https://www.jstor.org/.

18. Ali Jozaghi et al., "A Comparative Study of the AHP and TOPSIS Techniques for Dam Site Selection Using GIS: A Case Study of Sistan and Baluchestan Province, Iran," *Geosciences* 8, no. 12 (December 2018), https://www.mdpi.com/.

19. Daniel Jato-Espino et al., "A Review of Application of Multi-Criteria Decision Making Methods in Construction," *Automation in Construction* 45 (September 2014), https://www.sciencedirect.com/; Jeremy Yee Li Yap, Chiung Chiung Ho, and Choo-Yee Ting, "A Systematic Review of the Applications of Multi-Criteria Decision-Making Methods in Site Selection Problems," *Built Environment Project and Asset Management* 9, no. 4 (2019), https://www.emerald.com/; and Bahar Sennaroglu and Gulsay Varlik Celebi, "A Military Airport Location Selection by AHP Integrated PROMETHEE and VIKOR Methods," *Transportation Research Part D: Transport and Environment* 59 (March 2018), https://www.emerald.com/.

20. Yap, Ho, and Ting, "Site Selection."

21. Jato-Espino et al., "Construction"; and Aleksandar Rikalovic, Ilija Cosic, and Djordje Lazarevic, "GIS Based Multi-Criteria Analysis for Industrial Site Selection," *Procedia Engineering* 69 (2014), https://www.sciencedirect.com/.

MCDA varies across construction disciplines, with the majority applied to energy and logistics facility site selection.[22]

ACE and adaptive basing aim to project airpower from alternate locations, which requires a runway, taxiways, apron space, and supporting infrastructure. Case studies of airport site-selection methodologies provide best practices and selection criteria due to the similarities between airports and US Air Force bases. In 2019, researchers provided an overview of airport site selection, confirming AHP as the most frequently applied method of siting airport infrastructure.[23] Moreover, GIS played a pivotal role in the optimization process, particularly when organizations had inadequate data and financial constraints.

Selection criteria recurrence varied across studies, but accessibility, economic, and environmental considerations were the most common among the literature.[24] Many airport site-selection studies demonstrate the effectiveness of combining AHP and GIS, and provide a breadth of selection criteria and constraints to consider for future decision frameworks.[25] An additional study developed an AHP methodology for a military airport in Turkey, analyzing nine criteria for an objective function, including military-centric parameters.[26] Finally, one recently developed model assesses the utility of four aircraft systems in a distributed basing environment. Notably, the authors used runway characteristics such as runway parameters, parking, munitions, fuel, and warehouse storage to quantify aircraft efficacy at military and civilian airfields.[27]

Despite the significance of the aforementioned site-selection methodologies, no studies address ACE site-selection processes when A2/AD prevents access to established ACE operating sites. Moreover, the nature of ACE and adaptive basing necessitates the integration of DoD- and Air Force-specific criteria. A few studies provide sample criteria to meet military goals, but none concentrate on service needs and DoD objectives.[28]

Contemporary adaptive basing requirements and considerations are necessary to determine the best solutions. Site selection often consists of dynamic variables, competing interests, varying risks, and limited data to support decision making. Accordingly, the proposed ACE site selection framework, based on risk and utility metrics and

22. Yap, Ho, and Ting, "Site Selection."

23. Turan Erman Erkan and Wael Mohamed Elsharida, "Overview of Airport Location Selection Methods" *International Journal of Applied Engineering Research* 14, no. 7 (2019), https://www.researchgate.net/.

24. Erkan and Elsharida, "Selection Methods."

25. Cláudio Jorge Pinto Alves et al., "Towards an Objective Decision-Making Framework for Regional Airport Site Selection," *Journal of Air Transport Management* 89 (October 2020), https://www.sciencedirect.com/.

26. Sennaroglu and Celebi, "PROMETHEE and VIKOR."

27. Patrick Kelly, "Methodology for Including Base Infrastructure in Conceptual System Analysis" (master's thesis, Air Force Institute of Technology, 2019), https://apps.dtic.mil/.

28. Ghassan K. Al-Chaar et al., "Construction Material-Based Methodology for Contingency Base Selection," *The Open Construction & Building Technology Journal* 11 (2017), https://openconstructionbuildingtechnologyjournal.com/; Kelly, "Conceptual System Analysis"; and Sennaroglu and Celebi, "PROMETHEE and VIKOR."

considering a breadth of criteria, applies GIS and AHP to analyze airport alternatives and inform decisionmakers.

Data

GIS-based AHP models require multiple data sources to perform geospatial analysis and evaluate decision variables. An ideal ACE site-selection framework would incorporate open-source and classified data sources to ensure conclusions integrate defense factors appropriately. For instance, data regarding airport coordinates and runway lengths are readily available in open-source environments, while accurate data on peer-to-peer missile threats, state agreements, theater posture plans, and operational plans are stored in classified environments, requiring analysis in controlled areas.

The proposed ACE site-selection framework uses solely open-source data to simplify the analysis, simulate inaccessible variables, and demonstrate the methodology's utility. The proposed ACE site-selection framework uses six data sources to produce geospatial indicators.

The method's principal data source is a global airport dataset.[29] The dataset contains information about medium and large airports, including, but not limited to, location, runway length, and aviation attributes. Airport characteristics are vital for the decision framework because existing runway infrastructure is essential for ACE in a right-of-boom (post-attack) environment. Furthermore, each airport offers varying risk and utility tradeoffs based on multiple factors such as the aircraft utilized, runway length, apron space, and fuel availability. This research utilizes airport location and runway length in the decision framework.

Opportunity exists to add additional decision variables from this dataset such as runway width, surface type, and lighting. For this research, runway length is a primary consideration because it dictates which aircraft can operate at a location and how much risk aviators assume during takeoff and landing. The global dataset includes 576 airports from 26 countries relevant to a Pacific Air Forces-level analysis.

Host-country attributes are integral to ACE effectiveness. Historically, the US Air Force postures its main operating bases in countries with strong diplomatic ties, stable governments, and robust economies such as Germany, Japan, and the Republic of Korea. Accordingly, overt and covert state agreements greatly influence ACE site feasibility. But incorporating and scaling this variable (overt and covert agreements) for the ACE site selection framework is challenging due to its uncertainty and confidentiality.

As a surrogate, the ACE site-selection framework applies the Fragile States Index to simulate accessibility and quantify country viability based on each state's peace and fragility

29. Environmental Systems Research Institute (Esri) Deutschland, "World Airports," dataset, info on May 5, 2020, https://hub.arcgis.com/.

environment.[30] The Fragile States Index scores and ranks 178 countries based on 12 indicators encompassing cohesive, economic, political, and social conditions.[31] But several prospective states (e.g., Palau and New Caledonia) do not have scores because the Fund For Peace only evaluates countries that are members of the United Nations and capable of generating the necessary data to perform its analysis.[32]

The final data subgroup includes 26 Pacific countries with their respective index score and contributing indicators. Incidentally, the use of the Fragile States Index as a surrogate is not infallible. For example, a stable regime does not necessarily imply willingness to provide basing in a peer-to-peer conflict especially in the Pacific theater.[33] Therefore, future iterations of the framework should include the latest information about political willingness to partner and not just a notional stability index.

The distance an aircraft will need to fly to accomplish its mission is an integral variable to ACE operations. Agile combat employment sited further from threats is exposed to less risk but could require refueling support, allowing adversaries additional time to prepare and respond when aircraft scramble. Conversely, ACE sited closer to adversaries enables a swifter and less predictable strategy but is more exposed to various risks such as short-range ballistic missiles.

Therefore, a sortie distance decision variable must strike a delicate balance between risk and utility. The proposed ACE site-selection framework facilitates adaptability by including an expected sortie distance variable, allowing planners to customize results based on known or probable mission requirements. For this analysis, an arbitrary coordinate in China was selected for sortie distance calculations.

Should ACE strategy require a shift to undetermined airfields, support assets will require airlift to these sites. Some materials and equipment are more manageable to airlift than others, but heavy construction equipment needed to assemble structures, perform repairs, or move assets would be impractical. Therefore, the proposed ACE site-selection framework includes access to construction equipment as a decision-making component.

When a contingency requires heavy equipment, crisis managers often use Air Force assets, such as war reserve materiel, to prepare, respond, and recover, which is prospectively impracticable in a right-of-boom ACE environment. Alternatively, ACE planners could acquire necessary equipment from construction vendors within the host nation's footprint. Accordingly, the framework uses dealer and rental locations for Caterpillar,

30. Fund for Peace (FFP), *Fragile States Index: Annual Report 2021* (Washington, DC: FFP, 2021), https://fragilestatesindex.org/.

31. FFP, *Fragile States Index Methodology and CAST Framework* (Washington, DC: FFP, 2017), https://fragilestatesindex.org/.

32. FFP, "Annual Report 2021."

33. Bonny Lin et al., *Regional Responses to U.S.-China Competition in the Indo-Pacific* (Santa Monica, CA: RAND Corporation, 2020), https://www.rand.org/; and Stacie L. Pettyjohn et al., *Access Granted: Political Challenges to the U.S. Overseas Military Presence, 1945-2014* (Santa Monica, CA: RAND Corporation, 2016), https://www.rand.org/.

Komatsu, Hitachi, and Volvo to quantify construction equipment proximity and availability.[34] A multistep data-collection process was exercised to collect construction equipment dealer geographic coordinates, yielding 565 construction equipment dealers across 26 countries.

The ACE site-selection framework includes water access in the decision framework because it is a high-priority resource in military operations. Presumably, potable water sources are readily available at medium and large airports, but military planners assume a degree of risk relying on host nations for this resource in contingency environments. Reverse osmosis water purification units can mitigate this risk and provide potable drinking water to forces if engineers can access a water source within a reasonable distance from their operating site. The World Water Bodies dataset provides the geospatial components needed to balance this tradeoff, and the methodology uses each of the dataset's water resource categories subset to the 26 countries included in the analysis.[35]

Finally, peer military capabilities represent a strategic risk for ACE because proximity to these threats can limit the service's ability to counteract and jeopardize mission execution. China's missile capabilities are particularly concerning in the theater because they control one of the world's largest, most far-reaching missile arsenals. Since the research is limited to unclassified sources, the methodology uses a generalized missile threat variable in its approach.

In 2020, researchers developed a spatial representation of the PRC's missile capabilities based on declassified Central Intelligence Agency documentation, DoD reports, and various research publications.[36] This data source acts as a surrogate data set to more accurate, classified intelligence. Rather than speculating missile capabilities at each location, the framework utilizes three missile risk profiles assuming each launch site has either short-range ballistic missiles, medium-range ballistic missiles, or intermediate-range ballistic missiles.[37] Should the Air Force adopt the proposed framework, ACE planners could improve the missile threat decision variable by incorporating more accurate coordinates, armament types, and estimated ranges.

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34. "Caterpillar - Rental Store Locations," The Cat Rental Store (website), 2021, https://www.catrentalstore.com/; "Hitachi - Dealer Locator," Hitachi, Hitachi Construction Machinery Global (website), 2021, https://www.hitachicm.com/; "Komatsu - Dealer Locator," Komatsu (website), 2021, https://www.komatsu.jp/; "Volvo - Global Dealer Locator," Volvo Construction Equipment Global (website), 2021, https://www.volvogroup.com/.

35. Esri, "World Water Bodies," dataset, data on October 15, 2021, https://hub.arcgis.com/.

36. Decker Eveleth, "Mapping the People's Liberation Army Rocket Force," A Boy and His Blog, March 29, 2020, https://www.aboyandhis.blog/.

37. Missile Threat: Center for Strategic and International Studies (CSIS) Missile Defense Project, "Missiles of China," "Missiles of the World," CSIS (website), last updated April 12, 2021, https://missilethreat.csis.org/.

Methods

While the proposed ACE site-selection framework requires a variety of geospatial analysis tools to perform the analysis, it employs two primary tools to collect spatial indicators: distance and buffer. Three indicators (sortie distance, construction equipment, and water sources) are predicated upon distance from an airport to another location. Two indicators (runway length and the Fragile States Index) are inherent to each airport's location. The remaining indicator, missile threat, was evaluated utilizing a buffer around missile locations at three threat levels: short-range (1,500 km), medium-range (3,000 km), and long-range (5,500 km).[38] The chosen GIS includes built-in tools to calculate these distances and aggregate/subset the data based on these and other conditions.

Like many optimization problems, the case study's decision variables have different units or scales. Multi-attribute utility theory provides a way to modify these variables and present them on the same scale prior to analysis. Put simply, utility functions convert the statistics to a score between 0 and 1. Higher scores (1) represent qualities beneficial or desirable for the objective, and lower scores (0) represent qualities unfavorable or undesirable for the objective. Utility values are beneficial to the framework because Air Force leaders and planners can customize them based on mission needs, mission limitations, and leadership preferences.

For example, each airport's runway length does not produce constant utility to ACE operations: F-16 aircraft and B-52 aircraft have distinct takeoff and landing requirements and a 7,000-foot runway would be sufficient for the former and not the latter. Utility functions allow practitioners to define these scales, which is beneficial for strategies involving unique aircraft, resource requirements, and geospatial factors. The case study develops the utility functions based on background information, research committee input, and general intuition.

Additionally, not all ACE site-selection factors are equally important. For instance, although water accessibility is vital for troop sustainability, an inadequate runway will completely undermine ACE site operability. Analytic hierarchy process enables the model to form a hierarchy among the decision criteria by performing a pairwise comparison of each variable.

In practice, AHP pairwise comparison as an organization is preferable because it usually moderates selection bias. Group brainstorm sessions or surveys involving subject matter experts are both excellent means to gather these inputs. The case study forms pairwise comparison inputs from the research's primary stakeholders including Air Force civil engineers and 800th RED HORSE Group leadership (RED HORSE is the Air Force's heavy construction unit tasked with building in remote environments).

While a few pairwise comparisons deviate from the trend, the general priority consensus was (1) runway length, (2) Fragile States Index, (3) sortie distance, and a tie: (4) distance from construction equipment dealers and (5) distance from water. Using these

38. CSIS, "Missiles of China."

priorities, the primary stakeholders determined weighted values for each indicator for the initial analysis:

1. Runway length: 40 percent
2. Fragile States Index: 25 percent
3. Distance from China (sortie distance): 16 percent
4. Distance from construction equipment dealers: 10 percent
5. Distance from water sources: 10 percent

The final step applied these weights to the utility values of airport alternatives. This process scales the utility values based on established preferences and then aggregates weighted decision criteria to generate efficacy scores for each airport. The equation that follows shows the aggregation equation for the model's AHP scores. Sorting the data by this metric exhibits a ranked catalog of airport alternatives based on the risk and utility they offer ACE operations.

$$Ax = (u1 \times w1) + (u2 \times w2) + (u3 \times w3) + (u4 \times w4) + (u5 \times w5)$$

Where: Ax is the combined efficacy score for each airport x; wn is the determined AHP weight for each selection criteria n; and un is the utility score for each of the five selection criteria.

Results

The ACE site-selection framework results can be represented visually based on each airport's combined efficacy score. Figure 1 illustrates the spatial distribution of each airport's score by quartile. The most suitable airports are green, while the most unfit airports are red. This method highlights the airports, countries, and regions that present the most utility to ACE operations. Additionally, ACE planners can interpret each airport's utility more holistically by adding missile threat rings to the map. For example, leaders could define projected missile ranges as high, medium, moderate, or low risk and reduce alternatives based on their risk appetite and an airport's inclusion within the rings.

Additionally, geospatial presentation of the results lends additional inferences such as countries the US Air Force would not otherwise consider. For example, based on intuition, the Philippines seems like a candidate country that would present advantages to Air Force ACE operations. But the GIS score representations suggest the Philippines would not be ideal since fewer airports scored highly (green: ≥ 0.62 AHP score). Alternatively, several countries outside the short-range ballistic missile range possess airports with surprising high utility such as India, Indonesia, and Malaysia. The map indicates Japan and South Korea have the highest concentration of high-utility airports, and Australia, New Zealand, and Papua New Guinea have the lowest concentration.

Furthermore, decisionmakers could combine airport identification and missile threat rings to guide decisions. For instance, if ACE planners intend to avoid short-range ballistic missile threats yet are willing to accept medium-range ballistic missile risk, airports between the red and orange threat rings would likely have the most benefits to ACE operations. Alternatively, a more risk-averse strategy could avoid medium-range ballistic missile threats and search for alternatives between the orange and yellow rings. In this case, the northeast coastline of Australia would likely provide the most benefits to ACE operations. This approach could be beneficial to strategists and planners because it is tailorable to preferential inputs and could be altered based on acceptable risk levels at the time of analysis.

Finally, viewing the results spatially allows planners to assess hypothetical basing clusters based on the parameters and additional constraints. For example, one method could involve gauging regions with dense "green" airports. These regions would benefit ACE operations since they would provide planners with the most alternatives to pick from for a basing cluster. Alternatively, ACE planners could add additional data to the visualization to further subset or evaluate base clusters.

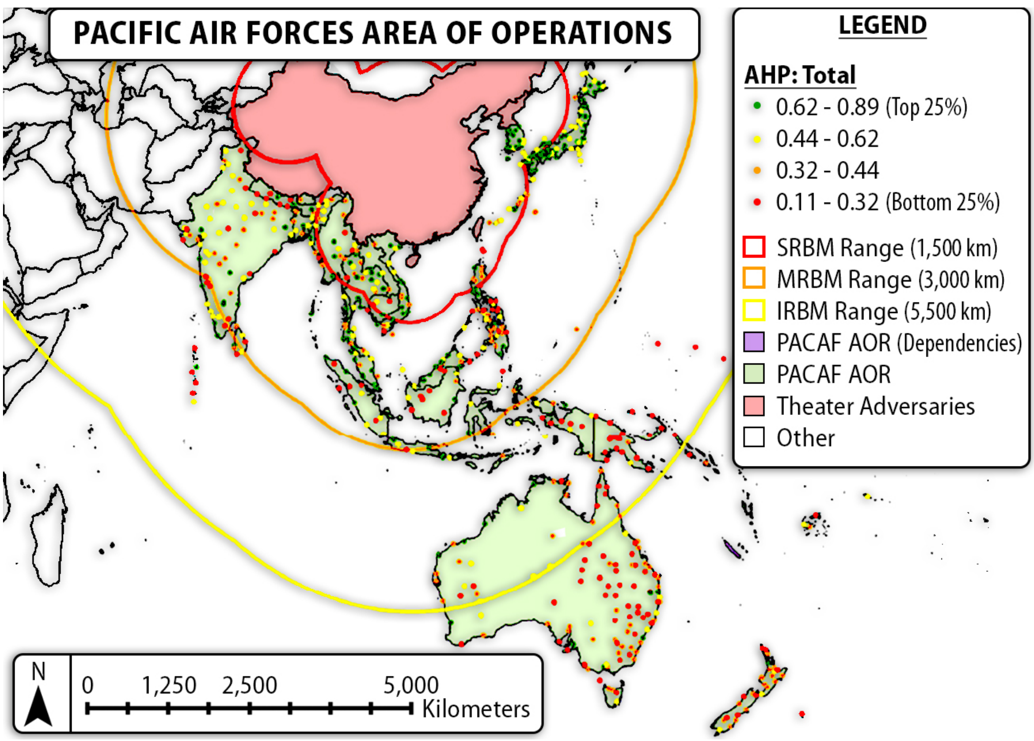

Figure 1: ACE site-selection framework AHP results (Pacific Air Forces area of operations)

GIS representation of the results furthers the methodology by allowing users to perceive ideal alternatives. Furthermore, analytic hierarchy process results can be challenging to assimilate; GIS helps bridge this gap by representing results in a more approachable manner. Most importantly, the technique aligns with the research's goals: to produce a flexible, scalable, expedient, and reproducible framework to conduct ACE site selection analysis.

Using the outputs from the geospatial analysis, a closer examination of the top quartile of identified airfields shows the large influence that missile threat has on the results. There are fewer viable basing options with a lower risk tolerance from missiles. Figure 2 depicts the combined efficacy score of each airfield, iteratively removing locations by missile range and the corresponding breakdown of the top quartile of airfields. The illustration demonstrates the influence missile constraints—the vulnerability of those locations to short- and medium-range ballistic missile attack—assert on the alternatives. The left side of the diagram reflects airport AHP scores, with high-scoring airports on the left and low-scoring airports on the right. The right side of the diagram reflects each country's count of airports in the top quartile of the results.

Unsurprisingly, these results show fewer airport alternatives remain as the model is constrained by longer-range missile threats. Moreover, the figure implies the highest-scoring airports begin to disappear noticeably from the model under medium- and intermediate-range ballistic missile (not shown) constraints. At these ranges, only six countries have airports that scored higher than 0.62, which indicates a significant loss of quality alternatives.

The short-range ballistic missile constraint retains 82.3 percent of the analyzed airports with a comparable mean analytic hierarchy process to the overall dataset (0.446 versus 0.467). On the other hand, the medium- and intermediate-range ballistic missile constraints significantly reduce the quantity and quality of the airports, retaining 36.5 percent and 20.1 percent of the alternatives, respectively. The mean AHP score decreases for each of these alternatives to 0.361 and 0.357, respectively. These observations suggest that using the short-range ballistic missile range as a model constraint could help ACE planners reduce risk without losing too many ideal alternatives.

Figure 2 also highlights the important countries within the framework. The ACE site-selection framework indicates Japan, India, Indonesia, and Malaysia have the most high-scoring airports under the short-range ballistic missile constraint. But these alternatives reduce significantly under the medium-range ballistic missile constraint, with India, Indonesia, and Australia representing the majority in that scenario.

Interestingly, the mean AHP score of the top-quartile airports is relatively unchanged as the progressive missile scenarios constrain the model. Each scenario's average AHP score is approximately 0.7. This observation indicates that despite missile constraints removing alternatives, quality airport options that meet the framework's criteria exist further from China (e.g., Australia). Should ACE planners assume a risk-averse strategy to avoid missile threats, several viable options remain based on the selection criteria.

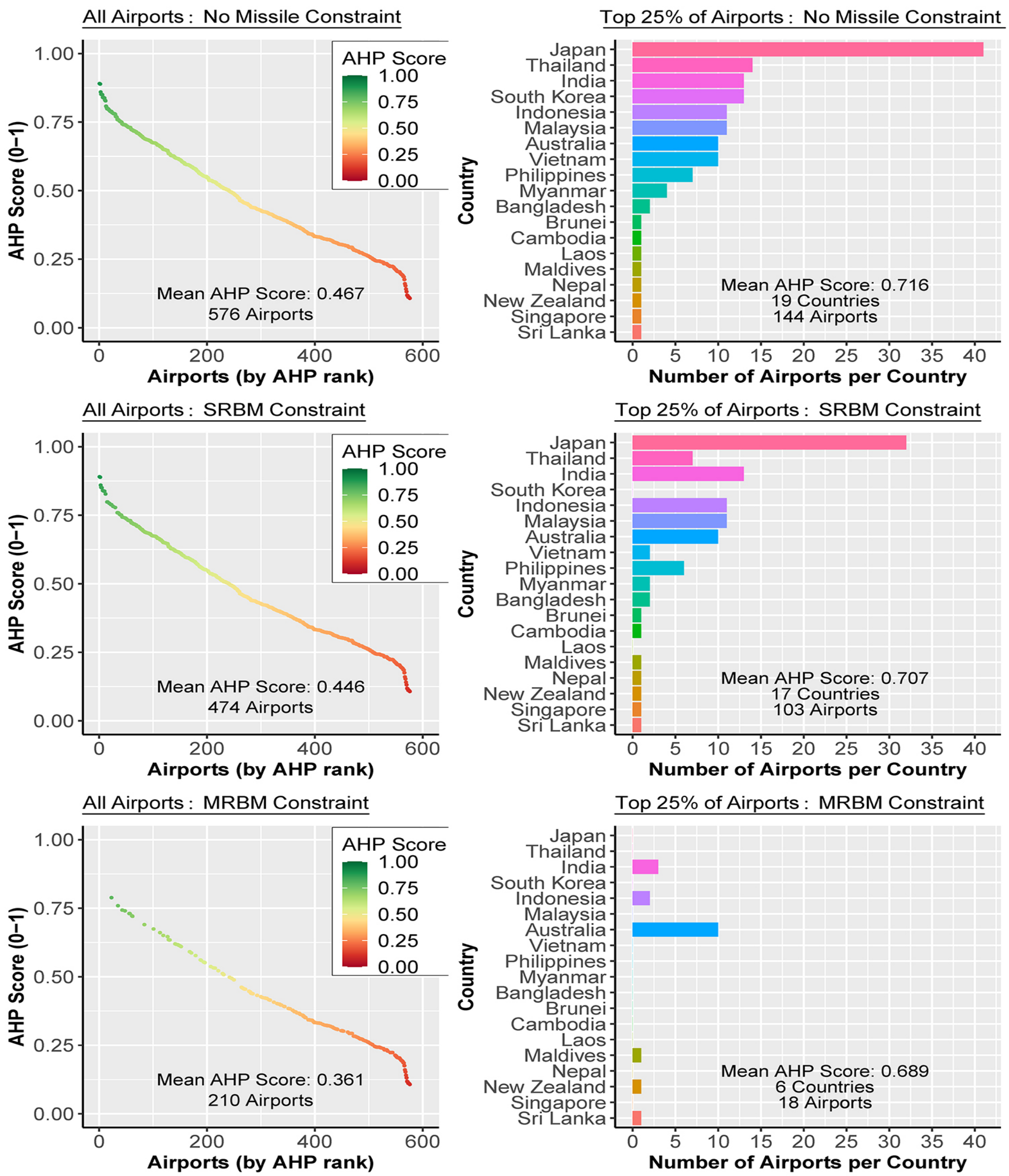

Figure 2: PACAF ACE site selection analysis (missile threat constraint)

Framework Utility and Opportunities

The proposed ACE site-selection framework methodology could benefit strategists and planners significantly in an A2/AD environment. These decisionmakers will be extraordinarily tasked in a right-of-boom scenario and will be required to make frequent life and death decisions with little to no turnaround. The ACE site-selection framework could be an effective tool as the framework is scalable, flexible, expedient, and generates informative results and visualizations.

Several features make the framework scalable. First, the framework could be applied to any area of responsibility, despite the research concentrating on Pacific theater. Besides the missile and construction equipment decision variables, each data source extends across the globe and could be incorporated into other AOR-specific analyses. Pending data availability concerning the alternatives, criteria, and constraints, the proposed framework can be applied based on the needs of the service.

Second, the framework could incorporate additional selection criteria to balance a more comprehensive mission profile. This research concentrates on more general ACE requirements and assesses criteria based on five broader requirement categories. But these categories could be broken down further into subcategories to assess the airports further within the hierarchy.

For instance, the airport requirements category could include multiple criteria, such as runway length, runway width, apron space, lighting systems, and more. In this case, repeating the AHP process within the hierarchy would ensure holistic aviation requirements are met. Adding hierarchies within some or all the criteria categories will require further effort from users due to the additional pairwise comparisons, but these efforts would provide users more certainty that the airports will meet ACE requirements and maximize suitability to operations.

Use of analytic hierarchy process and geographic information systems by the proposed ACE site-selection framework provides significant flexibility for ACE planners. Planners might disagree with the criteria chosen for this research and wish to analyze other criteria. Alternatively, different base functions could require different requirements and constraints, which are easily retooled inside the AHP process. The framework can adapt to these considerations by adding, removing, or substituting criteria or constraints as needed.

Additionally, ACE planners might want to adjust utility functions and AHP criteria weights based on emerging knowledge or changes in resource availability. The framework can facilitate modifications if leaders and planners reach a consensus that satisfies AHP consistency ratio requirements.

Furthermore, the methodology's expedient nature would benefit ACE planners in right-of-boom environments. For example, before a conflict, ACE planners could prepare criteria, weights, and scores and utilize them when country access becomes more apparent. This practice would allow planners to make minor changes to the criteria and constraints and support site choices based on predetermined decision preferences.

Lastly, the proposed framework could aid ACE planners by providing informative results and visualizations to help guide strategic or just-in-time decision making. For instance, planners could run a simulation during peacetime to determine the countries with high-scoring airports. Planners could use this knowledge to posture diplomatic engagements and develop host-nation agreements.

Alternatively, combatant commanders or planners could use the results to inform just-in-time decisions. ACE planners will better understand which countries will allow US Air Force operations when conflict begins. This knowledge could be used to constrain the proposed ACE site-selection framework results and select ACE operating sites that optimally support ACE requirements and strategic outcomes.

Limitations and Future Work

This article does not identify where to go for ACE after an A2/AD incident. Instead, the methodology proposes how to decide where to go if the requirement arises. Should combatant commands choose to employ the decision framework, several improvements are recommended to maximize the proposed ACE site-selection framework potential and accuracy.

First, a fully enabled ACE site-selection framework should analyze alternatives on a classified network to incorporate classified criteria, constraints, and site alternatives. While this paper demonstrates the framework's utility using unclassified data sources, classified information such as missile quantities and coordinates, overt and covert state agreements, ACE infrastructure requirements, and proposed resource storage locations would enhance the results significantly.

Implementing classified features ensures the framework optimizes and accounts for critical national security factors. For example, an expanded construction parameter could include specific equipment and building material if infrastructure requirements were known. The thought process could be applied to many data sources, including the airport alternatives. In general, a mix of classified and unclassified data will provide ACE planners with the ideal information to support site-selection decisions.

Second, the proposed ACE site-selection framework does not include a cost component in its selection criteria. A cost parameter would be advantageous for ACE site selection because the service is subject to budget constraints and aspires to implement fiscally responsible strategies. (This research could not produce this variable due to time and resource constraints.) Traditionally, the Air Force conducts site visits to estimate cost and resource requirements for aircraft beddowns, which is time-consuming and probably unfeasible in a right-of-boom scenario.

Alternatively, area cost factors are a way to compare relative construction costs between regions or countries, and the Air Force could implement a similar metric to quantify the cost. The US Army Corp of Engineers produces area cost-factor data, but the data is currently not comprehensive for the Pacific theater. Should cost be a parameter the service desires for A2/AD ACE site selection analysis, the Air Force could generate or invest in data sources that derive area cost factors for countries of interest.

As previously mentioned, performing an analysis in a classified environment would be a fruitful endeavor for ACE site selection. Planners could incorporate additional or higher-quality criteria not considered in this study, which would significantly improve the quality of the results. A host-nation agreement constraint could simplify analysis by removing unfeasible airports based on country accessibility. A more accurate missile threat constraint would give ACE planners confidence the model mitigates missile ranges appropriately.

A list of site requirements for ACE operations, including fuel availability, could add additional grading points for airfield alternatives and ensure optimal supply-chain management throughout adaptive basing. These examples and more are possible when an ACE site-selection framework integrates classified data sources; as ACE planners perform most of their planning on classified networks, this should be a viable course of action.

Conclusion

While ACE strategy matures, Air Force leaders, strategists, and planners must develop contingency plans that confront worst-case outcomes. The proposed ACE site selection framework, a geographic information system-based analytic hierarchy process methodology, can help mitigate right-of-boom operational risks by incorporating leadership preferences and balancing the risk and utility of prospective operating sites. This framework supports adaptive basing and allows for preplanning through data collection and initial site identification. The application demonstrates the framework is flexible, scalable, expedient, and reproducible, allowing planners to evaluate prospective sites and inform decisionmakers. Moreover, planners can include additional relevant factors when those are or become available.

As the US Air Force navigates ACE development, America's adversaries continue to make unprecedented advances in military strength. Further, these nations' involvement in disputed territories challenges global stability and could compel the United States to engage in armed conflict in the near future. If necessary, the service must adapt its strategies and leverage advanced decision-making methods to navigate complicated scenarios. The proposed ACE site-selection framework can provide these necessary tools to the warfighter and ensure the Air Force maintains strategic advantages throughout conflict.