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A UNITED STATES AIR FORCE SITE SELECTION METHODOLOGY IN A CONTESTED AGILE COMBAT EMPLOYMENT ENVIRONMENT

THESIS

Zachary T. Moer, Captain, USAF

AFIT-ENV-MS-22-M-241

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty
Department of Engineering Management
Graduate School of Engineering and Management
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Air University
Air Education and Training Command
in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Engineering Management

Zachary T. Moer, BS
Captain, USAF

March 2022

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THESIS

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Abstract

The United States Air Force's (USAF) Agile Combat Employment (ACE) strategy relies on host country access and underlying local infrastructure to facilitate airpower. However, numerous factors, including peer-to-peer threats, complex geopolitics, and intricate supply chain management, often complicate site access and thwart site selection decisions. When shaping the battlespace for future conflict, strategists and planners face the difficult task of identifying optimal locations to conduct adaptive basing operations given these complicating factors. Multi-Criteria Decision Analysis (MCDA) can help strategists appropriately account for competing objectives and maintain a competitive advantage with theater adversaries. This thesis presents an MCDA model that evaluates ACE site selection alternatives within the Pacific Air Forces (PACAF) Area of Responsibility (AOR) using a geographic information system (GIS) enabled analytic hierarchy process (AHP) methodology and open-source data pertinent to the theater. The model analyzed 576 airports in 26 countries and compared alternative locations based on runway length, the Fragile States Index (FSI), distance to China, construction equipment dealers, and natural water resources. The results demonstrate the framework's efficacy and utility in identifying existing airports best suited for the deployment of USAF combat and support assets. The methodology is expected to provide invaluable support to Combatant Commanders as they optimize ACE infrastructure, preserve resources, and minimize risk to United States Armed Forces.

Dedicated to my Wife and Son.

Acknowledgments

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Zachary Moer

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A UNITED STATES AIR FORCE SITE SELECTION METHODOLOGY IN A CONTESTED AGILE COMBAT EMPLOYMENT ENVIRONMENT

I. Introduction

Background

Optimizing site selection is a complex and pressing issue in the construction industry. Developers and planners must select sites through a hybrid decision-making process during which planners optimize tradeoffs between competing objectives. Organizations that construct infrastructure internationally experience additional challenges, with foreign variables and state administrations shaping project success or failure. Conducting a comprehensive analysis of alternatives is crucial for these organizations to make data-driven risk management decisions and maximize their probability of a successful outcome. Many domains impact international construction projects, but economic, social, and political factors play a crucial role in their outcomes, particularly in developing countries governed by unstable officials (Yanwen 2012). Therefore, data-driven peace and fragility indices could be the key to evaluating a site's utility in this context.

The Department of Defense (DoD), as part of its extensive overseas footprint, frequently encounters these challenges. One of its unique challenges is adapting its ever-evolving, dynamic military strategies to changing conditions. This policy of continual evolution ensures that the DoD's strategic adaptation will remain dynamic, and it has led to a more mature reliance upon light and lean force distribution. Strategies driven by this requirement, such as Agile Combat Employment (ACE), require services like the United States Air Force (USAF) to shift from traditional basing strategies (Mills et al. 2020). For example, ACE's foundation is a concept of operations known as adaptive basing, which utilizes "alternate basing options to enable flying operations" and "calls for forces to disaggregate capabilities from a single base and disperse forces and capabilities to many locations for operational maneuver" (Mills et al. 2017, pp. 22). The ACE concept diverges dramatically from former basing strategies and demands a paradigm shift from the predominant posturing of assets at large main operating bases, which is detrimental and counterintuitive to the ACE strategy (Mills et al. 2020). To implement this new leaner, more agile ACE-centric approach, the USAF must use or construct strategic infrastructure in foreign countries to support the ACE imperative (Priebe et al. 2019).

In addition, global security conditions require the USAF to consider its infrastructure's strategic implications during peacetime and wartime. Pre-conflict preparations, known as left-of-boom planning, tend to dominate combatant command planning; planners can leverage diplomatic agreements, military construction avenues, and funding to boost the USAF's strategic advantages before conflict transpires. However, post-conflict preparations, known as right-of-boom planning, pose many more challenging obstacles to military planners. First, prospective ACE operating locations are abundant; deciding which sites provide an optimal ACE environment can be a formidable task for planners. Second, peer-to-peer competitors will have a say in where the USAF conducts ACE operations as they will, undoubtedly, engage in counteroffensives to reduce the DoD's strategic advantages. Prearranged ACE infrastructure will always be vulnerable to this threat, regardless of the enemy knowing their whereabouts. Lastly, suppose peer-to-peer competitors compromise predetermined ACE hubs and spokes. In that case, it will be paramount to establish new airfields expeditiously to enable airpower projection in the theater under the ACE strategy. This risk presents a significant challenge to the civil engineer community because supply chain and construction management are arduous. Additionally, the construction of new airfields in the theater is prospectively unrealistic. Therefore, ACE infrastructure analysis in a right-of-boom environment is better suited using existing airfield alternatives and data purposed to minimize organizational risk and maximize site utility to the USAF.

The purpose of this research is to develop a right-of-boom site selection methodology for USAF ACE operations that evaluates decision criteria and facilitates rapid decision-making by combatant command planners. Former site selection frameworks, expert advice, and ACE concept of operations guide the methodology's development. In addition, a literature review covers the approaches, optimization systems, and selection criteria advantageous to the site selection problem. Finally, Pacific Air Forces (PACAF) ACE serves as the case study for analysis and provides a framework for building right-of-boom ACE site selection decisions.

Problem Statement

How do combatant commanders or planners decide where to go for ACE when predetermined USAF hubs and spokes become compromised? Current site selection methodologies fail to account for inherent challenges in foreign countries, and investigation into this research question stands to benefit the DoD, USAF, and even the private sector. Moreover, the development of an ACE site selection tool could aid planners tremendously in generating supporting data and balancing strategic variables.

Significance

Several factors reinforce the legitimacy of this research to the USAF. First, failure to plan for the contingency of enemy action causing a collapse of existing infrastructure would jeopardize the ACE strategy. Second, untimely decisions could provide adversaries with a competitive advantage, resulting in unnecessary deaths, compromised assets, and failed military engagements. Third, suboptimal sites could increase construction time and costs, both of which can be scarce resources in peacetime and wartime environments. Fourth, when considering the country or countries best fit for ACE operations, imprudent consideration of a state's fragility could compromise site feasibility and lead to mission failure. Finally, the proximity of peer-to-peer competitors makes agile site selection paramount. Site selection decisions present varying risks and rewards in military strategy based on mission capabilities, adversarial threats, and other factors. Considering these tradeoffs is a delicate balancing act that planners cannot take lightly, given the lives and resources at stake in a wartime environment.

Research Objectives

The first research objective is to study previously conducted site selection methods—such as landfills, airports, and military bases—to determine the characteristics, constraints, and criteria needed to address the site selection problem. A literature review of frameworks and data sources is necessary to decide the priorities, best practices, and shortfalls to incorporate into the case study. Furthermore, investigating appropriate decision-making criteria is essential to solving the site selection problem.

The second research objective is to develop a site selection methodology that utilizes geographic information system (GIS) technology and advanced optimization techniques to determine the best sites based on competing selection criteria. The methodology requires collecting selection criteria, constraints, and data sources from previous research, PACAF experts, and the 800th RED HORSE Group. Data availability will influence what criteria and constraints are feasible to meet adaptive basing objectives.

The third research objective is to implement the methodology by utilizing PACAF Area of Responsibility (AOR) data and determine the optimal deployment sites using identified PACAF alternatives. This objective aims to demonstrate the framework's utility in hopes that it can be adapted using more accurate, sensitive, and timely data and intelligence. In addition, an assessment of candidate sites based on selection criteria and constraints would be an informative result for PACAF planners.

Scope and Approach

Site selection decisions for the DoD and USAF require special considerations, and this research develops a framework that accounts for these factors. Bureaucracy and regulatory requirements often hinder civilian solutions applied to government problems. Furthermore, primary datasets for USAF site alternatives, restrictions, and objective measures are typically classified SECRET, making them challenging to consider and incorporate into unclassified systems. This research explores existing site selection methodologies and describes their shortfalls and tradeoffs.

Site selection criteria steer optimization model outputs, and practitioners expend time and resources to design parameters thoughtfully and meet stakeholder objectives. While site selection constraints and criteria differ between methodologies, this research analyzes existing site selection approaches and their application to the case study. Furthermore, factors unique to the DoD require special consideration in this research.

The site selection problems necessitate optimization, and many approaches exist to meet this objective. This research leverages former research to determine the best-suited optimization techniques for site selection. A balance between accuracy and ease of use is crucial to applying the methodology operationally.

MCDA is the most practical approach to determine the optimal site for international construction projects. Since the literature suggests a GIS-enabled AHP is the most common and beneficial MCDA technique, the proposed methodology follows that suggestion. In addition, variables incorporated into this research encompass several domains on varying scales. Therefore, the methodology uses Utility Theory to rescale these variables and account for user preference appropriately.

Although subject matter expert input (e.g., Combatant Command staff) would significantly enhance the proposed framework, incorporating these inputs would limit this research's release. Alternatively, themes from ACE and other military strategies can facilitate the formation of hypothetical site selection criteria using unclassified data sources. For instance, minimum risk, minimum cost, and maximum resources are usually desired outcomes in pre-conflict and in-conflict environments and could provide value in an ACE site selection framework. Additionally, some performance indicators are difficult to quantify in an unclassified environment, such as covert and overt state agreements. Therefore, the proposed methodology employs surrogate datasets to combat these challenges and demonstrate the model's utility. For example, the framework utilizes the Fragile States Index (FSI) as a placeholder for state agreements because it quantifies a country's relative peace and fragility. If regional peace and state fragility truly affect project outcomes, the indices defined by The Fund For Peace could be quality indicators for adaptive basing strategy.

Key stakeholder input is valuable to optimization models because they guide decision variable selection and prioritization. However, this research aims to produce a field-deployable methodology, not to generate precise results. Therefore, no formal criteria, constraints, or priorities were solicited from PACAF experts for sensitivity purposes. Nevertheless, existing research, policy, and unclassified military strategy documents are an excellent starting place for geographic considerations and other decision criteria. Examples include the distance from theater adversary missile threats, manufactured and natural resource needs, and mission requirements. This research develops an initial model based on available open-source data.

II. Literature Review

Chapter Overview

The utilization of Multi-Criteria Decision Analysis (MCDA) to address construction issues is widespread. Studies indicate a notable increase in its application over the past two decades (Jato-Espino et al. 2014). The following literature review summarizes site selection findings using a categorical approach. First, a description of Geographic Information System (GIS)-based approaches conveys relevant methodologies in the MCDA domain. Second, a summary of airport site selection methodologies compares existing methodologies to help shape infrastructure considerations. Third, a review of military base site selection techniques and contributory criteria describes the factors and mechanisms best suited for siting military infrastructure. Finally, an assessment of site selection MCDA techniques identifies the advantages and disadvantages of different site optimization approaches.

GIS-Based Site Selection Methodologies

GISs can be an essential enabler for site selection methodologies. A 2018 MCDA site selection review highly recommended integrating GIS into site selection analysis because complex geographic constraints are a significant factor for this type of optimization (Li Yap et al. 2019). Site selection methods are primarily concerned with geospatial data, and GIS-based analysis provides a reliable and pragmatic tool for integrating constraints, analyzing data, and producing visualizations (Jato-Espino et al. 2014; Rikalovic et al. 2014). The prevalence of GIS-based MCDA varies across construction disciplines, with the majority applied to energy and logistics facility site selection (Li Yap et al. 2019).

Landfills are a common infrastructure type researched in site selection optimization. Landfill methodologies include analysis of large candidate areas with various environmental restrictions. Akbari et al. (2008) optimized a landfill siting in Iran by pairing GIS analysis with a fuzzy Analytic Hierarchy Process (AHP) technique. The authors established discriminatory criteria, such as distance from transportation networks and agricultural districts, to rule out unfeasible sites and optimize candidate locations based on five fuzzy decision criteria. The results yielded a ranking of four alternative sites, providing infrastructure planners with insight into the most suitable location for the landfill (Akbari et al. 2008). Sener et al. (2010) utilized a similar method in Turkey by employing traditional AHP and additional criteria. The authors believed the primary benefit of combing GIS and AHP was the method's ability to handle extensive, complicated data (Şener et al. 2010). The geographic requirements of adaptive basing infrastructure are similar to the analysis performed on these landfills. Furthermore, these site selection examples evaluate several criteria that could benefit ACE site selection solutions.

Recent studies enhance these landfill methodologies. Most leveraged AHP (Majid and Mir 2021), while others employed unique techniques in the field, such as MULTIMOORA (Rahimi et al. 2020). The primary improvement in current methodologies was the identification of more robust selection criteria. Rezaeisabzevar et al. (2020) defined an array of criteria that practitioners should evaluate when addressing landfill site selection that considered the adverse physical and environmental effects of a landfill alternative and the nearby population's social and economic impacts (Rezaeisabzevar et al. 2020). Balancing these factors was crucial to ensure the alternatives satisfied the project's objectives. While several landfill constraints fall outside the scope of this case study's requirements, many improved criteria, such as community buffers, distance from airports, and flooding, could provide the optimization function with constraints supporting and preserving adaptive basing infrastructure.

Renewable energy facilities are another common infrastructure type in research. While landfill methods focus more on avoiding geographic features, renewable energy methods aspire to optimize resource availability. Vasileiou et al. (2017) proposed a GIS-based AHP method to determine the best location for offshore wind and wave energy systems; similar to the landfill methodologies, constraints refined a larger candidate area before analysis occurred with evaluation criteria. Pairwise comparison of the eight categorized evaluation criteria guided the objective function to determine the most suitable location of 12 alternatives (Vasileiou et al. 2017). Maximizing resource availability is vital for adaptive basing optimization because it requires many resources to construct and sustain the infrastructure. Therefore, a resource-focused approach must be incorporated into the methodology, pending priority formulation and data availability.

Risk considerations are essential for infrastructure planners because construction projects require significant pre-planning, coordination, and funding. Shorabeh et al. (2019) developed a risk-based methodology by pairing GIS, AHP, and Ordered Weighted Averaging (OWA) to a solar-power plant site selection model. The technique paired geospatial analysis and AHP results with an OWA metric that accounts for the user's risk tolerance. Due to the model's flexibility, the results depicted a range of alternatives based on the risk factor, providing the user with a menu of options. A benefit of the methodology was its ability to compare results based on different risk profiles (Shorabeh et al. 2019). In the solar power plant study, all risk profiles pointed to the same alternative, which provided investors and planners confidence that the site was the best alternative under the best and worst-case scenarios. The USAF's risk thresholds regularly shift based on force posture and changing geopolitical threats. This research attempts to capture risk measures to support decision-makers in uncertain operations, and using a method analogous to OWA would support this end-state.

Other studies offer different solutions to the site selection problem. Jelokhani-Niaraki and Malczewski (2015) proposed a web-based GIS solution that uses participant input to determine the optimal site. The method converted user preferences of six criteria to OWA and generated consensus from a set of alternatives (Jelokhani-Niaraki and Malczewski 2015). A web-based model could provide the convenience and flexibility needed to satisfy fluctuating USAF requirements. Changes in military leadership and diplomatic agreements inevitably alter adaptive basing strategies and requirements, necessitating an adaptable system. Conversely, a web-based system requires management and coordination with users and could introduce vulnerabilities to the DoD. If a web-based system is desirable, benefit and risk analysis are imperative before implementation.

A review of GIS-based methodologies in construction disciplines revealed many criteria that the case study should consider. Nearly all solutions preemptively removed unsuitable sites from large regions before evaluating alternatives based on objective measures. Optimization techniques accounted for performance metrics, such as risk, in different ways, but decision-makers preferred AHP due to its simplicity and flexibility (Jozaghi et al. 2018). The adaptive basing site selection problem possesses complex geographic constraints accompanied by changing variables and large amounts of data. Therefore, GIS-based technology is an appealing element to acquire adaptive basing solutions.

Airport Site Selection Methodologies

ACE and adaptive basing aim to project air power from alternate locations, which necessitates a runway, taxiways, ramp areas, and supporting infrastructure. Airport site selection methodologies provide the case study with superior best practices and selection criteria due to the similarities between civilian airports and USAF bases. However, research in this review mainly focused on regional civilian airports; some studies recommended not identically applying their frameworks to military airports because defense-focused parameters tend to dominate military optimization (Alves et al. 2020). Despite this, numerous objective measures and constraints described in airport studies apply to the case study, more so than other construction disciplines previously outlined.

Erkan and Elsharida (2019) provided an overview of airport site selection methodologies dating back to 1969. Their study confirmed that AHP was the most frequently applied method of siting airport infrastructure. 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, cost, economic, and environmental considerations were the most commonly referenced criteria found in the literature (Erkan and Elsharida 2019). These findings support using a GIS-based AHP methodology, and the most common criteria align with several of the case study's expected outcomes.

Like most site selection frameworks, the number of alternatives, selection criteria, and constraints can burden the model's objective function and stifle computational efficiency. For airport site selection, it is advantageous to refine the alternatives—whether by intuition or other means—and carefully obtain expert input to guide constraints and establish the objective’s priorities (Saatcioglu 1982). Minor criteria variations can significantly alter optimization model solutions, and accurately establishing these factors is essential in the preliminary stages of framework development.

Alves et al. (2020) described a decision-making methodology for regional airport site selection. Like other techniques described, the methodology leveraged GIS and AHP in order to eliminate unfeasible territories and objectively rank feasible sites based on scoring criteria. Their methodology’s initial phase generated 24 significant selection criteria based on a thorough literature review, of which nine eliminatory criteria and six discriminatory criteria supported the final methodology. For example, distance from critical resources and infrastructure, as well as geographic restrictions, formed the methodology’s selection criteria and constraints. The authors described the principle of direct quantities, which utilized well-defined criteria available in GIS or reliable data sources and reduced parameter subjectivity. Finally, sensitivity analysis verified result objectivity (Alves et al. 2020). The method’s framework is comparable to former airport optimization methods (Ballis 2003), but its emphasis on modern considerations and data quality distinguishes it from other studies. The method illustrates that a balance of engineering, economic, societal, and environmental criteria are paramount to reveal the optimal airport site option. In addition to providing applicable decision criteria to the case study, the article highlights the importance of limiting prejudice among data and AHP weighting to simplify expert assessment and improve sensitivity analysis.

Some airport site selection methodologies use more straightforward MCDA techniques to weigh criteria. Erkan and Elsharida (2020) compared AHP and Rank Order Comparison (ROC) optimization methods using 23 sub-criteria to site an airport in Libya (Erkan and Elsharida 2020). The ROC method simplified the expert input process by equally distributing criteria weights based on the formed priorities and establishing a centroid of weights to reduce sensitivity. The results showed that 80.3% of the AHP and ROC outputs were identical, and the authors concluded the ROC method was "practical and effective" based on the correlation between methods (Erkan and Elsharida 2020, pp. 26). Since ease of use is desirable for decision frameworks, the ROC method may be advantageous for ACE site selection because future user MCDA awareness is unknown. In addition, simplified input from subject matter experts could enable a more agile model that integrates feedback over time.

A purely geographic approach to the case study could simplify the methodology if criteria such as cost and resource availability are less central. A 2020 study in India simplified airport site selection analysis by only considering seven criteria derived from remote sensing data sources (Ramu 2020). For example, the authors used water bodies, transportation networks, and geological characteristics, to name a few, to establish selection parameters for their methodology. This method limited user input but provided high-quality results due to data quality and availability. Most construction optimizations seek to maximize cost and minimize risk, making the method less useful for those outcomes. In a contingency environment, a simplified procedure based solely on geographic features might be applicable when country accessibility is known, basing network composition is paramount, and cost minimization is less critical.

Organizations that conduct projects in foreign countries execute multiple projects simultaneously, and considering existing sites or multiple alternative sites may be necessary to meet the organization's objectives. Some studies addressed this requirement using an average nearest neighbor technique (Erkan and Elsharida 2020). Organizations can use this technique to meet diverse objectives, such as optimizing the distance between numerous sites or ensuring redundancy of essential resources. For the adaptive basing methodology, an average nearest neighbor element could enhance a site selection framework because the network of distributed forces must be purposeful and strategic (Mills et al. 2017).

A review of airport site selection literature concludes that GIS-based AHP and ROC methodologies are the most common and proven methods in the field. Researchers used different criteria strategies to meet stakeholder objectives, but most methods incorporated benchmark criteria related to aviation and runway construction. A thorough analysis of geographic constraints and selection criteria is vital because overloading the model with poorly designed evaluation criteria will lead to poor results. Adaptive basing experts must weigh their advantages and disadvantages according to the latest policies and informed strategies. If an interconnected configuration of installations is desirable, the average nearest neighbor technique provides utility to methodologies. Many considerations complicate airport site selection, but the tools and processes described in this review can and should be used to meet these challenges and generate indispensable results.

Military Site Selection and Contributing Criteria

Military site selection frameworks are invaluable for this research because their mechanisms and considerations usually meet the DoD's requirements and expectations. Their main drawback is their scarcity in the MCDA field, as most research focuses on civilian site selection issues. The salient takeaways from this research category are the methods and criteria employed to fulfill defense priorities.

Due to military construction guidelines, defense projects usually require specific resources that meet quality standards. This requirement makes access to proper materials, such as gravel, cement, and wood, particularly important because shipment by air and sea is impractical due to cost. Al-Chaar et al. (2017) addressed this problem for United States Army contingency bases. Under several criteria and constraints, namely transportation networks and material types, the methodology identified the optimum location for a contingency base by avoiding regions susceptible to flood risk, maximizing access to transportation networks, and determining construction resource centers. The method involved a manual examination of material suppliers, which required extensive effort. However, the method yielded beneficial in situations where material use was flexible or when most construction could be satisfied by a single material (Al-Chaar et al. 2017). Indeed, the adaptive basing site selection methodology requires similar material or equipment accessibility criteria. Should planners desire novel contingency bases, runway construction alone would entail enormous resource requirements that the DoD cannot judiciously import to each base. Moreover, if cost and risk optimization are a chief concern, it cannot be mitigated simply by siting the infrastructure in areas isolated from the local population.

Other military-specific criteria, such as security risks, are important considerations for this research. The DoD takes great care in minimizing defense infrastructure vulnerabilities, and neglecting to account for these factors would compromise ACE and adaptive basing operations. A 2018 study developed a methodology that integrated these elements for a military airport in Turkey. The study used AHP to analyze nine criteria for an objective function, including military criteria, expansion potential, cost, environmental and social effects, climate conditions, infrastructure facilities, land, geographic features, and needs. Within the military criteria are five sub-criteria: the level of military necessity to the region, distance to military units, transportation to military units, military security risk, and the nearest military airport. Paired with Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods, the technique weighed, ranked, and analyzed alternatives to arrive at the most suitable decisions (Sennaroglu and Varlik Celebi 2018).

While the authors adequately described the military criteria, they did not discuss the benefits or implications of using military-specific parameters. This article was the only source that defined military-specific considerations of all the literature reviewed. Several factors contribute to this observation, but the most probable cause is that military organizations often solve operational issues in operational environments to reduce vulnerabilities and better support strategies. In contrast, civilian organizations more commonly address problems in academia. As such, the absence of military site selection frameworks in the literature is not surprising. Nevertheless, this research should consider the measures identified by Sennaroglu and Varlik Celebia (2018) as criteria development progresses.

Several researchers incorporated criteria to address financial risk into site selection models (e.g., Sennaroglu and Varlik Celebia 2018 and Alves et al. 2020), and Ekran and Elsharida (2019) determined that cost and economic factors are two of the most recurrent criteria in airport site selection research. However, none considered the project's economic, social, and political implications in a foreign setting. Several organizations produce data on countries' peace, fragility, and economic stability that could account for these risks in the methodology. An example of this is the Fragile State Index (FSI) produced by The Fund For Peace. The objective of the FSI "is to create practical tools and approaches for conflict mitigation that are contextually relevant, timely, and useful to those who can help create greater stability." The FSI ranks 178 United Nations (UN) countries based on 12 indicators that equate to risks and vulnerabilities. The four categories that classify the FSI indicators are cohesion, economic, political, and social (The Fund For Peace 2021).

The FSI scoring methodology considers three evaluation criteria: content analysis, quantitative data, and qualitative review. The content analysis uses a Boolean search engine technique to aggregate data by querying global media sources and determining each indicator's prevalent issues. On average, the content analysis system examines forty to fifty million online sources annually and assigns each country a conditional score based on the results. A quantitative analysis synthesizes pre-existing data related to the indicators from several sources, including the United Nations, World Health Organization, and World Bank. The results are normalized and synthesized to generate another conditional score. Social scientists assess each country's major events in the qualitative review and provide a third conditional score. Lastly, a series of rules triangulate the three scores, and a panel of researchers reviews the results to ensure consistency and rule out biases and outliers (The Fund For Peace 2021). Organizations could use the FSI to guide the decision framework when data is unavailable or too massive to incorporate feasibly. For example, the qualitative measure of economic decline could supplement a lack of quantitative economic data to provide insight to project planners on the risks assumed in a particular country. The Fund For Peace publishes new data annually, which provides additional benefits to organizations that desire up-to-date information on fragility and peace risk levels.

Another country risk resource is the Global Peace Index produced by Vision of Humanity. The Global Peace Index's objective is to "provide measures of global peace powered by research, data, and analysis." Vision of Humanity—a subsidiary of the Institute for Economics Peace—is an independent and non-partisan organization focused on measuring human welfare and global reform. Their organization classifies these measures by positive and negative peace to develop peace indicators for their methodology. The Global Peace Index utilizes three peace domains: ongoing domestic and international conflict, societal safety and security, and militarization. These domains encompass 23 internal and external peace indicators tied to clearly defined quantitative or qualitative data sources. The final country peace index merges weighted indicator scores, which are further scaled based on internal or external peace orientation (Vision of Humanity 2020). An advantage of the Global Peace Index is the robustness of its results; however, a panel of experts employed by Vision of Humanity establishes weights for each indicator, which can introduce subjectivity and skew the results. Other sources—such as the International Country Risk Guide—prepare risk profiles for investors, but their cost makes them less proven than open sources like the FSI and Global Peace Index. While academic reviews of risk indices have been critical in the past, some recent studies contend that applying them to policy matters or developing countries has advantages (Glawion et al. 2019; Shimbar and Ebrahimi 2020).

Despite the scarcity of military-site selection methodologies, a few provide worthwhile insights on the methods and requirements best suited for the topic. The novelty of adaptive basing requires the case study to consider requirements and objective measures meticulously. However, albeit dissimilar in scope, past military research efforts can help guide the undertaking. Furthermore, regional peace and state fragility indices like the FSI provide a means to quantify country-specific risk profiles. Employment of this data type to an ACE site selection methodology could benefit the DoD because The Fund For Peace manages the data independently and updates it annually.

Multiple-Criteria Decision Analysis Options

The evolution of MCDA provides modern researchers with many optimization choices. Most methods create similar results, but sensitivity analysis is a primary concern when considering which model to select. The literature suggests several trends for MCDA choices for site selection problems.

AHP involves scoring and weighting parameters based on a criterion's relative significance compared to another; this method is known as pairwise comparison. Studies reference AHP as the most applied MCDA method for construction disciplines (Jato-Espino et al. 2014) and the study of site selection optimization (Li Yap et al. 2019).

Furthermore, sources attribute its prevalence to its simplicity and flexibility (Jozaghi et al. 2018), and military site-selection frameworks have proven effective (Sennaroglu and Varlik Celebi 2018). Thus, the technique is attractive for the adaptive basing site selection methodology.

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), ELimination Et Choix Traduisant la Realité (ELECTRE), and PROMETHEE are also proven methods in the site selection optimization domain (Kiker et al. 2005; Malczewski 2006; Zavadskas et al. 2016). Utilization of TOPSIS is best when the distance from the best and worst solution is the desired study output (Jozaghi et al. 2018). ELECTRE leverages an outranking system that can reduce ambiguity and variance in results but is complicated in nature, which can be problematic for the methodology's operational deployment (Li Yap et al. 2019). PROMETHEE is an appropriate framework when criteria conflicts exist (Kiker et al. 2005), but it "does not provide a clear way to assign the weights and values to the criteria," and fewer studies exist to address its application to site selection problems (Li Yap et al. 2019, pp. 556).

The MCDA techniques described in the literature offer distinct advantages and disadvantages to site selection optimization. Based on literature surveys and the methodologies described in the previous sections, AHP appears to be the best course of action for this research. Its reliability, simplicity, and flexibility make it the best choice for adaptive basing site selection, which requires all three characteristics to guarantee the methodology withstands DoD formalities and challenges.

Summary

Despite the significance of the aforementioned site selection methodologies, there are several limitations to the approaches described in the literature review. First, no approach addresses the site selection problem in conjunction with regional peace and state fragility, which studies indicate contribute to an international project's success (Yanwen 2012). Although projects in international settings are less common than domestic, academia and global organizations could gain new insight to support decisions and steer future research. Integration of the FSI into a site selection framework would be an innovative first step in addressing this shortcoming.

The availability of required resources is another issue for the case study. Although studies demonstrated methods to optimize resource access (Al-Chaar et al. 2017), the data-collection process required to gather supplier information is unviable when performing analysis across multiple countries and sites. If resources are a feature requirement of the optimization function, exploring new data acquisition techniques would be necessary for an adaptive basing site selection framework.

The nature of ACE and adaptive basing necessitates the integration of DoD and USAF-specific criteria. A few studies provided sample criteria to meet military goals (Al-Chaar et al. 2017; Sennaroglu and Varlik Celebi 2018), but none concentrated on USAF needs and DoD objectives. Therefore, contemporary adaptive basing requirements and considerations would be necessary to elucidate the best solutions.

Site selection poses many challenges to planners and strategists. It consists of dynamic variables, competing interests, varying risks, and at times limited data to support decision-making. Optimization practitioners must leverage technology to evaluate alternatives, maximize positive outcomes, and minimize adverse consequences. Careful consideration of selection parameters is essential in all applications, but even more so for construction projects in foreign countries.

MCDA and site selection literature report many trends in the field. AHP is the most commonly used approach to construction and site selection problems due to its simplicity and flexibility. Researchers often apply ELECTRE, PROMETHEE, and TOPSIS when AHP models fall victim to sensitivity or conflicting criteria. GIS technology can be a powerful enabler of MCDA results since most site selection factors are geographic. Site selection methodologies consider a breadth of criteria and constraints that contain some similarities, but airport and military base site selection provide the most applicable parameters for this case study. Undoubtedly, new strategies accompanied by new challenges require this research to cultivate new decision variables to meet the USAF's needs.

International construction projects have consequences on both the builder and the local community, and adaptive basing site selection decisions will shape worldwide security and DoD posture. If the proposed method is successful, the results could also positively impact international construction companies; in terms of the case study, the framework will ensure that the main priority—be it risk, cost, or sustainability—is met. Optimization of adaptive basing site selection will assure mission longevity and secure airpower projection capabilities in the Pacific theater.

III. Where To Go When Plan A Fails: A United States Air Force Site Selection Methodology in a Contested Agile Combat Employment Environment

The United States Air Force's Agile Combat Employment strategy relies on foreign country access and infrastructure to generate airpower. However, numerous factors complicate site selection decisions, including peer-to-peer threats, complex geopolitics, and resource requirements. Multi-Criteria Decision Analysis can help strategists appropriately account for competing objectives and maintain a competitive advantage with theater adversaries. This paper presents a Multi-Criteria Decision Analysis model that evaluates Agile Combat Employment site selection alternatives using a Geographic Information System enabled Analytic Hierarchy Process methodology built on unclassified, publically available data. The model analyzed 576 airports in 26 countries and compared alternatives based on runway length, the Fragile States Index, a randomly selected point in China, construction equipment dealers, and natural water resources. The results demonstrate the framework's utility by identifying existing airports best suited for strategic end-states. The methodology could support Combatant Commands as they optimize Agile Combat Employment infrastructure while preserving resources and minimizing mission risks.

Introduction

In 1945, English author H.G. Wells famously said, "Adapt or perish, now as ever, is nature's inexorable imperative" (Wells 1945, pp. 19). Throughout history, humankind's survival has hinged on our capacity to innovate and evolve amidst difficult circumstances. Today, the sentiment rings true for the United States Air Force (USAF) and its pacing adversaries. The People's Republic of China (PRC) continues to develop its military capabilities considerably, driving the USAF to "accelerate change or lose" (Brown 2020). In view of complex geopolitical landscapes, financial stressors, resource limitations, and other competing objectives, the USAF must adapt its strategy, policy, and forces to deter factions threatening global peace and prepare for future global conflict.

Accordingly, the USAF developed a modernized power-projection strategy, Agile Combat Employment (ACE). ACE's foundation, adaptive basing, utilizes "alternate basing options to enable flying operations" and "calls for forces to disaggregate capabilities from a single base and disperse forces and capabilities to many locations for operational maneuver" (Mills et al. 2017, pp. 22). However, the United States Armed Forces are predominately postured at large main operating bases, which is detrimental to ACE strategy (Mills et al. 2020). Therefore, the USAF must leverage strategic infrastructure in foreign countries to support ACE (Priebe et al. 2019).

Efforts to establish strategic ACE operating sites are underway in the Pacific Air Forces (PACAF) and the United States Air Forces in Europe (USAFE) (Everstine 2020). However, what happens if these operating sites become compromised at the onset of conflict? The People's Liberation Army (PLA) recognizes foreign country access, resource logistics, and limited defensibility as vulnerabilities to the ACE concept (Solen

2021). Consequently, the PRC will likely aim to undermine the strategy by denying USAF access to these locations, thereby reducing the survivability of air operations. This probability begs the question, how can the USAF adapt ACE if its access to predetermined hubs and spokes become compromised?

This paper proposes ACE-SSF, a right-of-boom site selection methodology that utilizes existing airport infrastructure, evaluates decision criteria, and facilitates rapid decision-making for ACE site selection. ACE-SSF combines Geographic Information Systems (GIS) Analysis and Multi-Criteria Decision Analysis (MCDA) and provides a flexible, scalable, expedient, and reproducible framework to evaluate prospective sites and inform decision-makers. Former site selection frameworks, expert advice, and ACE concept of operations guide the methodology's development. The ACE-SSF methodology uses the PACAF Area of Responsibility to demonstrate the framework's utility.

Background

The DoD, USAF, and ACE Doctrine.

Great Power Competition, a principal priority of the National Defense Strategy, has been a catalyst for modern-day military doctrine and strategy (Department of Defense 2018). The Department of Defense recognizes the PRC's ambition to fulfill "great rejuvenation of the Chinese nation," including the unprecedented expansion and modernization of the PLA (Department of Defense 2021, pp. 1). The PRC's military development spans numerous domains, but the rapid growth of its nuclear forces and long-range precision strike capabilities raise particular concern to the USAF. These advancements pose a significant threat to the USAF's conventional basing strategy reliant on large main operating bases to sustain airpower in contested, degraded, and operationally limited environments. Accordingly, the 2018 NDS 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" (Mattis 2018, pp. 6).

These realities prompted the USAF to adopt ACE. PLARF missiles, and to a lesser extent, People's Liberation Army Air Force (PLAAF) aircraft, represent the most significant risk to USAF installations, particularly in the Pacific theater (Priebe et al. 2019). An unclassified 2021 DoD report to Congress estimated the PLARF maintains 300 Ground Launched Cruise Missiles (GLCM), 1,000 Short-Range Ballistic Missiles (SRBM), 600 Medium-Range Ballistic Missiles (MRBM), 300 Intermediate-Range Ballistic Missiles (IRBM), and 150 Intercontinental Ballistic Missiles (ICBM) (Department of Defense 2021). ACE helps mitigate these threats by dispersing aircraft throughout the theater using a hub and spoke basing configurations; this strategy offers the USAF unpredictability and requires the PLARF to expend more missiles to reduce USAF airpower effects (Mills et al. 2020).

Several significant challenges accompany the ACE concept and site selection. First, it requires numerous operating sites to form the hub and spoke networks; dispersed operations will inevitably increase operational costs and complicate agile combat support activities (Priebe et al. 2019). 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's realization (Priebe et al. 2019). 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 capriciousness and posture contingency plans. Finally, the current ACE concept relies on prepositioned assets to support the strategy ("AFDP 3-99: Department of the Air Force Role In Joint All-Domain Operations (JADO)" 2020). Should the PRC conduct anti-access area denial (A2AD) at these locations, ACE operations would require repositioning to under-resourced operating sites. This condition would necessitate planners obtaining assets from the host nation because airlift capabilities will be preoccupied, and traditional combat support will be unpredictable ("AFDP 3-99: Department of the Air Force Role In Joint All-Domain Operations (JADO)" 2020).

Should this right-of-boom A2AD transpire, ACE planners must consider site alternatives that maximize airfield utility, survivability, and resources while minimizing risks to forces and strategic outcomes. This prospect presents a formidable task to ACE planners because airfield options and decision variables are abundant. ACE-SSF simplifies the decision-making process and supplies leaders with a flexible, scalable, expedient, and reproducible framework to support data-driven site selection decisions.

Multi-Criteria Decision Analysis.

MCDA is a technique that can simplify complicated decisions. Generally speaking, MCDA combines user preferences with decision alternatives, criteria, and constraints to meet a defined objective. The technique is inherently flexible, and its ability to balance competing objectives and compare tradeoffs present advantages to site selection problems.

Analytic Hierarchy Process (AHP) is a prevalent MCDA technique in literature. AHP involves scoring and weighting parameters based on a criterion's relative significance compared to another; this method is known as a pairwise comparison. Studies reference AHP as the most applied MCDA method to construction disciplines (Jato-Espino et al. 2014) and the study of site selection optimization (Li Yap et al. 2019). In addition, sources attribute AHP's popularity to its simplicity and flexibility (Jozaghi et al. 2018), and military site-selection frameworks have proven their effectiveness (Sennaroglu and Varlik Celebi 2018). These features make AHP an ideal component for the ACE-SSF methodology.

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), ELimination Et Choix Traduisant la Realité (ELECTRE), and PROMETHEE are also proven methods in the site selection optimization domain (Kiker et al. 2005; Malczewski 2006; Zavadskas et al. 2016). Utilization of TOPSIS is best when the distance from the best and worst solution is the desired study output (Jozaghi et al. 2018). ELECTRE leverages an outranking system that can reduce ambiguity and variance in results but is complicated in nature, which can be problematic for the methodology's operational deployment (Li Yap et al. 2019). PROMETHEE is an appropriate framework when criteria conflicts exist (Kiker et al. 2005), but it "does not provide a clear way to assign the weights and values to the criteria," and fewer studies exist to address its application to site selection problems (Li Yap et al. 2019, pp. 556).

The MCDA techniques described in the literature offer distinct advantages and disadvantages to site selection optimization. Based on literature surveys and the methodologies described in the previous sections, AHP appears to be the best course of action for ACE-SSF. Its reliability, simplicity, and flexibility make it the best choice for ACE site selection, which requires all three characteristics to guarantee the methodology withstands DoD formalities and challenges.

Geographic Information Systems.

GISs can be an essential enabler for site selection methodologies. A 2018 MCDA site selection review highly recommended integrating GIS in site selection analysis because complex geographic constraints are a significant factor for this type of optimization (Li Yap et al. 2019). Site selection methods are primarily concerned with geospatial data, and GIS-based methods provide are a reliable and pragmatic tool for integrating constraints, analyzing data, and producing visualizations (Jato-Espino et al. 2014; Rikalovic et al. 2014). The prevalence of GIS-based MCDA varies across construction disciplines, with the majority applied to energy and logistics facility site selection (Li Yap et al. 2019).

ACE and adaptive basing aim to project air power from alternate locations, which requires a runway, taxiways, apron space, and supporting infrastructure. Airport site selection methodologies provide the case study superior best practices and selection criteria due to the similarities between airports and USAF bases. Erkan and Elsharida (2019) provided an overview of airport site selection since 1969. The study confirmed that AHP was the most frequently applied method of siting airport infrastructure. 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, cost, economic, and environmental considerations were the most common among the literature (Erkan and Elsharida 2019).

Like most site selection frameworks, the number of alternatives, selection criteria, and constraints can burden the objective function and stifle computational efficiency. For airport site selection, it is advantageous to refine the alternatives, whether by intuition or other means, and carefully obtain expert input to guide constraints and establish the objective's priorities (Saatcioglu 1982). Minor criteria variations can significantly alter optimization model solutions; accurately establishing these factors is essential in the preliminary stages of framework development.

Alves et al. (2020) described a decision-making methodology for regional airport site selection. The methodology leveraged GIS and AHP to eliminate unfeasible territories and rank feasible sites based on scoring criteria. Their method evaluated 24 significant selection criteria based on a thorough literature review, of which nine eliminatory criteria and six discriminatory criteria support the final methodology (Alves et al. 2020). The method's framework is comparable to former airport optimization methods (Ballis 2003), but its emphasis on modern considerations and data quality distinguished it from other studies. Alves et al. illustrated that a balance of engineering, economic, societal, and environmental criteria are paramount to reveal the optimal airport site option. Furthermore, the article highlighted the importance of limiting prejudice among data and AHP weighting to simplify expert assessment and reduce model sensitivity.

Erkan and Elsharida (2020) compared AHP and Rank Order Comparison (ROC) optimization methods using 23 sub-criteria to site an airport in Libya (Erkan and Elsharida 2020). The ROC method simplified the expert input process by equally distributing criteria weights based on the formed priorities and establishing a centroid of weights to reduce sensitivity. The results showed that 80.3% of the AHP and ROC outputs were identical, and the authors concluded the ROC method is "practical and effective" based on the correlation between methods (Erkan and Elsharida 2020, pp. 26).

A purely geographic approach to the case study could simplify the methodology if criteria such as cost and resource availability are less central. A 2020 study in India simplified airport site selection analysis by only considering seven criteria derived from remote sensing data sources (Ramu 2020). This method limited user input but provided high-quality results due to data quality and availability. Most construction optimizations seek to maximize cost and minimize risk, making the method less useful for those outcomes. In a contingency environment, a simplified procedure based solely on geographic features could be applicable when country accessibility is known, basing network composition is paramount, and cost minimization is less critical.

Literature suggests GIS-based AHP methodologies are the most common and proven methods in the field. Researchers use different criteria strategies to meet stakeholder objectives, but most methods incorporate benchmark criteria related to aviation and runway construction. A thorough analysis of geographic constraints and selection criteria is vital because overloading the model can produce poor results; adaptive basing experts must weigh their advantages and disadvantages according to the latest policies and informed strategy. Many considerations complicate airport site selection, but the tools and processes described can meet these challenges and generate indispensable results.

Military Site Selection.

Military site selection frameworks are invaluable for ACE-SSF because their mechanisms and considerations usually meet the DoD's requirements and expectations. Their main drawback is their scarcity in the MCDA field, as most research focuses on civilian site selection issues. The salient takeaways from this literature are the methods and criteria employed to fulfill defense priorities.

The DoD takes great care in minimizing defense infrastructure vulnerabilities, and neglecting to account for these factors could compromise ACE operations. A 2018 study developed a methodology that integrated these elements for a military airport in Turkey. The study used AHP to analyze nine criteria for an objective function, including "military criteria, expansion potential, cost, environmental and social effects, climate conditions, infrastructure facilities, land, geographic features, and needs." Five sub-criteria were within the military criteria, including "level of military necessity to the region, distance to military units, transportation to military units, military security risk, and the nearest military airport." Paired with Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods, the technique weighed, ranked, and analyzed alternatives to arrive at the most suitable decisions (Sennaroglu and Varlik Celebi 2018).

Kelly (2019) developed a model that evaluated several aircrafts' utilities in adaptive basing environments. The tool used Value Focused Thinking to assess the utility of four aircraft systems in a distributed basing environment. Notably, it used runway characteristics, such as "runway parameters, parking, munitions, fuel, and warehouse storage" to quantify aircraft efficacy at military and civilian airfields (Kelly

2019). Kelly's research studied the most useful aircraft for a distributed basing network, while this research concentrates on sites most useful for a given aircraft. However, Kelly incorporated vital criteria for ACE concepts that ACE site selection could or should consider.

While fewer military site selection studies exist in the literature, they suggest the inclusion of risk metrics, aviation requirements, proximities to critical resources, and distances from objective locations. Like most site selection solutions, the methods, criteria, and constraints must be tailored to the endeavors overarching objective, which will change from scenario to scenario. For instance, PACAF and USAFE ACE operations will inevitably involve unique data and selection criteria due to varying aircraft, threats, and geographic constraints. Nevertheless, these studies provide a few salient takeaways that build upon the ACE-SSF methodology.

Research Takeaways.

Despite the significance of the aforementioned site selection methodologies, no studies address ACE site selection processes when A2AD prevents access to established ACE operating sites. Furthermore, former site selection approaches do not include regional peace and state fragility in their calculus, which studies indicate contributes to mission success in foreign locations (Yanwen 2012). Additionally, the nature of ACE and adaptive basing necessitates the integration of DoD and USAF-specific criteria. A few studies provide sample criteria to meet military goals (Al-Chaar et al. 2017; Kelly 2019; Sennaroglu and Varlik Celebi 2018), but none concentrate on USAF needs and DoD objectives. Contemporary adaptive basing requirements and considerations are necessary to elucidate the best solutions.

Site selection consists of dynamic variables, competing interests, varying risks, and at times limited data to support decision-making. Optimization practitioners must leverage technology to evaluate alternatives, maximize positive outcomes, and minimize adverse consequences. Accordingly, ACE-SSF applies GIS and AHP to analyze airport alternatives and inform decision-makers based on risk and utility metrics. Site selection methodologies consider a breadth of criteria and constraints that contain some similarities, but airport and military base site selection provide the most applicable parameters for this case study. ACE site selection decisions will shape worldwide security and DoD posture, and optimizing it will assure mission longevity and secure airpower projection capabilities.

Data

GIS-based AHP models require various 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. In contrast, accurate data on peer-to-peer missile threats, state agreements, theater posture plans (TTPs), and operational plans (OPLANs) are stored in classified environments, requiring analysis in controlled areas. ACE-SSF uses solely open-source data to simplify the analysis, simulate inaccessible variables, and demonstrate the methodology's utility. Military site selection is complex and could include various variables to form optimal solutions. The ACE-SSF uses six data sources to produce geospatial indicators. Research, intuition, and committee input are the basis of their inclusion.

World Airports Dataset.

The method's principal data source is a global airport dataset (ESRI Deutschland 2020). The dataset contains information about medium and large airports, including, but not limited to, geospatial coordinate, 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 environment. Furthermore, each airport offers varying risk and utility tradeoffs based on miscellaneous factors, such as the aircraft utilized, runway length, apron space, and fuel availability.

ESRI's World Airport dataset includes 45 data entries per airport, but this research applies two to the decision framework: airport geographic coordinate and runway length. Opportunity exists to add additional decision variables from this dataset, such as runway width, surface type, and lighting. Presumably, USAF planners maintain access to comparable data with more precise information that ACE planners could include, if necessary. For this research, runway length is a primary consideration because it dictates which aircraft can operate at that location and how much risk aviators assume during takeoff and landing.

The World Airport dataset includes 3,187 airports from 232 countries. However, ACE-SSF in the Pacific theater subsets the data to 577 airports from 26 countries to support PACAF-level analysis. Table 1 illustrates the number of airports per country in this site selection framework, and Figure 1 depicts the airports in the Pacific Theater.

Table 1: Airport Alternatives by Country

Country	Airports	Country	Airports
Australia	115	Maldives	6
Bangladesh	8	Myanmar	17
Bhutan	1	Nepal	7
Brunei	1	New Zealand	27
Cambodia	4	Papua New Guinea	21
East Timor	1	Philippines	44
Federated States of Micronesia	4	Samoa	1
Fiji	3	Singapore	2
India	77	Solomon Islands	2
Indonesia	51	South Korea	16
Japan	81	Sri Lanka	7
Laos	3	Thailand	32
Malaysia	24	Vietnam	21

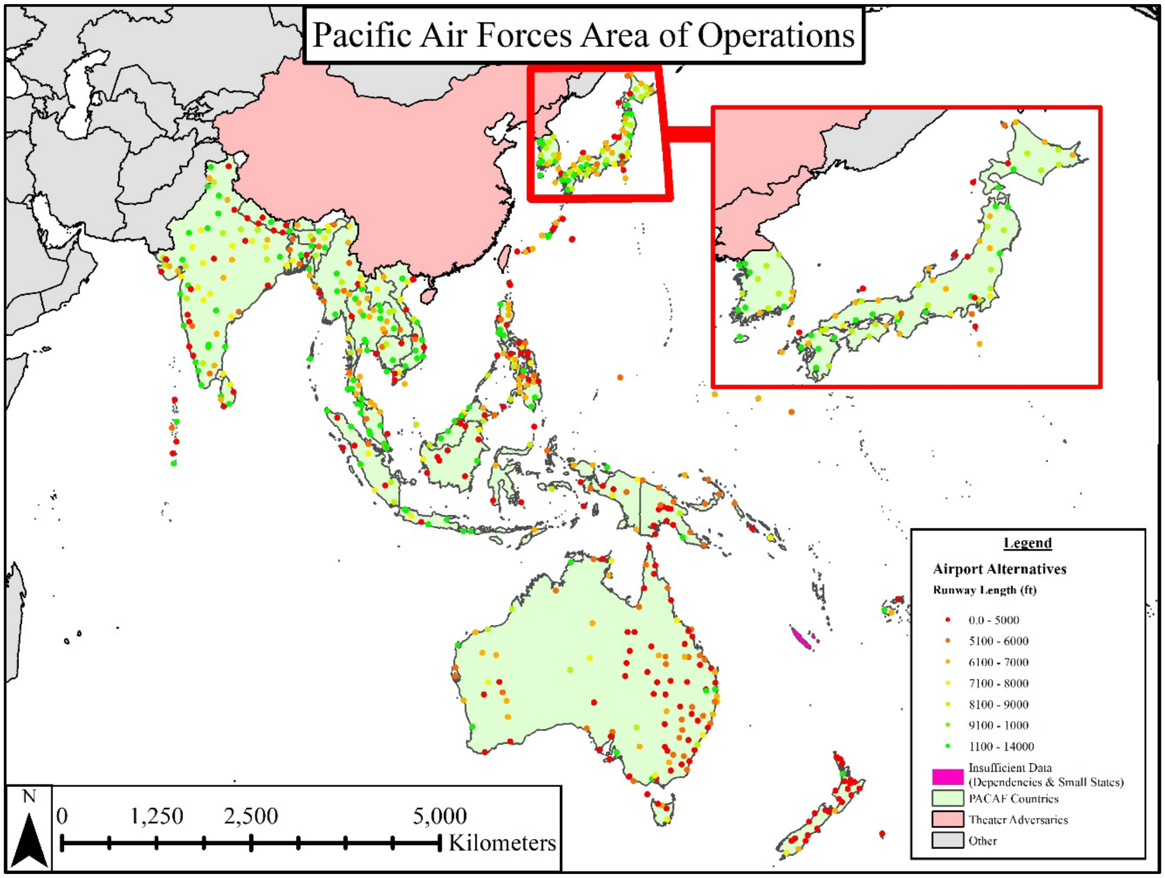


Figure 1: Geospatial Data Source – PACAF Airport Alternatives (Runway Length)

Fragile States Index.

Host country attributes are an integral factor to ACE effectiveness. Historically, the USAF 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. Details surrounding these agreements are sometimes public, but the USAF often obscures these arrangements; some agreements are unpredictable, and others are best kept secret to maintain strategic advantages. Consequently, it is challenging to incorporate and scale this variable for a decision-making framework due to its uncertainty and confidentiality.

Alternatively, ACE-SSF applies the Fragile States Index to simulate accessibility and quantify country-level utility (The Fund For Peace 2021). The Fragile States Index scores and ranks 178 countries based on 12 indicators. These indicators support the Fund For Peace's peace and fragility framework, the Conflict Assessment System Tool, which quantifies state risk based on cohesive, economic, political, and social conditions (The Fund For Peace 2021). Although country access intelligence, such as defense agreements, would be best for site selection optimization, the Fragile State Index offers an alternate risk metric valuable to ACE-SSF. Figure 1 depicts the Fragile States Index data in 2021.

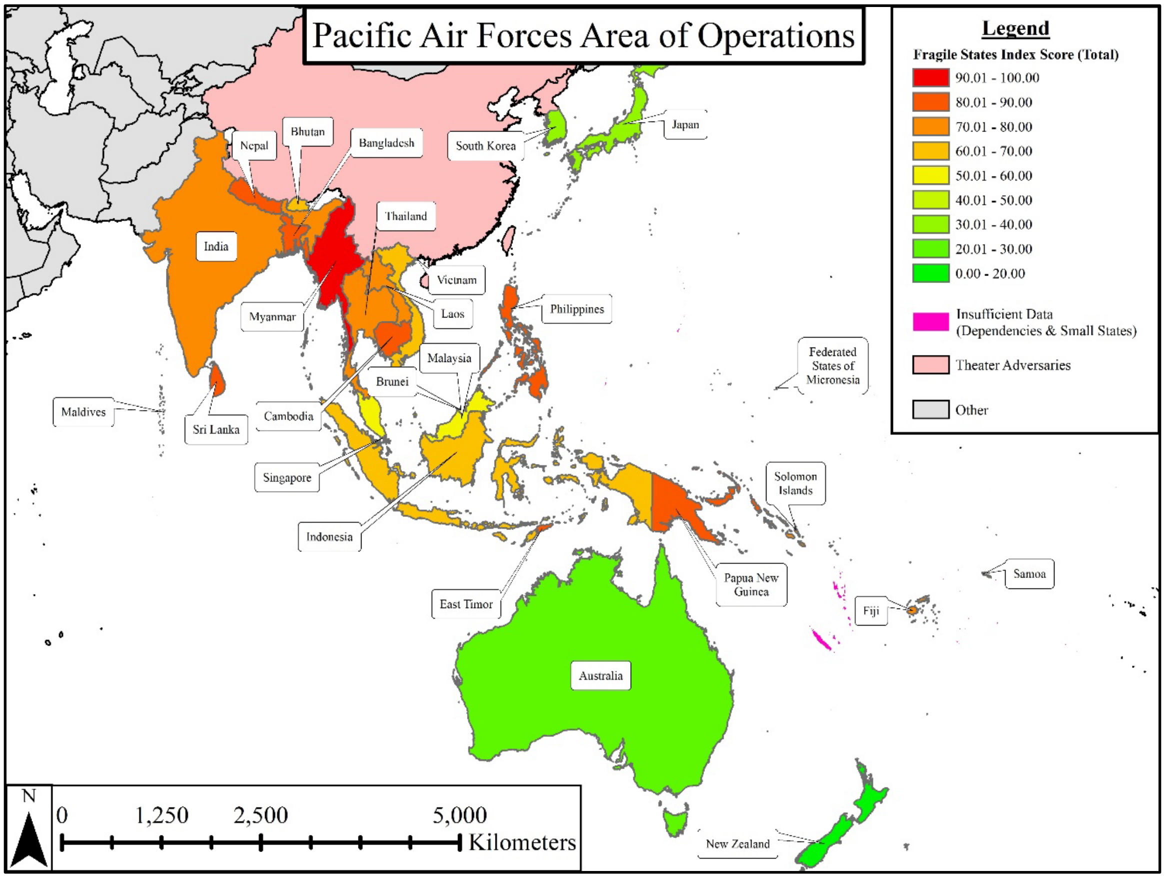


Figure 2: Geospatial Data Source – PACAF Airport Alternatives (Runway Length)

The Fragile States Index includes comparative data on most PACAF countries. However, 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 their analysis (The Fund For Peace 2021). Consequently, the ACE site selection framework disregards 11 dependencies and seven developing countries from the analysis. The framework also disregards select territories with presumed inaccessibility, such as China, North Korea, Russian, and Taiwan. The final data subgroup includes 26 Pacific countries with their respective index score and contributing indicators.

Distance to China.

A variable integral to ACE operations is the distance an aircraft will need to fly to accomplish its mission. ACE sited further from threats is exposed to less risk but could require refueling support and allows adversaries additional time to prepare and respond when aircraft scramble. Conversely, ACE sited closer to adversaries enables a swifter and less predictable strategy but has more exposure to various risks, such as SRBMs. Therefore, a sortie distance decision variable must strike a delicate balance between risk and utility.

Where to go for ACE also poses the question "where to?" Although the answer may be found in TTPs and OPLANs, right-of-boom ACE will require sortie flexibility because the theater will be set, and planned targets will change. ACE-SSF facilitates adaptability by including an expected sortie distance variable, allowing planners to customize results based on known or probable mission requirements. To remain in the unclassified realm, the ACE-SSF analysis was conducted using a randomly selected point in China to calculate distance. The sortie distance variable aims to optimize sortie distance by comparing each alternative's aptitude to meet the same objective. When paired with the missile threat variable, the two decision components help balance risk and utility for ACE sorties.

Principal Construction Equipment Dealers.

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 construct would be impractical. Therefore, ACE-SSF includes access to construction equipment as a decision-making component.

When a contingency requires heavy equipment in the PACAF theater, crisis managers often use unit 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, ACE-SSF uses dealer and rental locations for Caterpillar, Komatsu, Hitachi, and Volvo to quantify construction equipment proximity and availability.

Unlike the other data sources, the construction equipment dealer locations required an extensive data collection process. ACE-SSF uses Caterpillar, Komatsu, Hitachi, and Volvo as equipment sources because they (1) are brands the USAF civil engineers have experience using, (2) are not headquartered in China, North Korea, and Russia, (3) are the top construction equipment producers in the world, and (4) each maintain a vast global network of dealers (Caterpillar 2021; Hitachi 2021; Komatsu 2021; Volvo 2021). The following describes the data collection process, which yielded 565 construction equipment deals in the 26 countries of interest:

1. Identify principal construction equipment producers;
2. Find the dealer and rental store locator features on each corporation's web page;
3. Search for dealers and rental stores for each country (and, if applicable, subregion) in the analysis;
4. Record country, name, and address for each dealer identified;
5. Search each address on Google Maps (modify address when required); and

6. Record dealer’s geographic coordinates using Google Maps geocoding tool.

While several programs could simplify this process, each website had layouts and search qualities that complicated data-mining efforts. Furthermore, the addresses provided on each corporation’s websites varied in language and format, complicating the geocoding process. As a result, the hands-on data collection process proved most effective and efficient. Figure 4 depicts the construction equipment dealer data collected in this research.

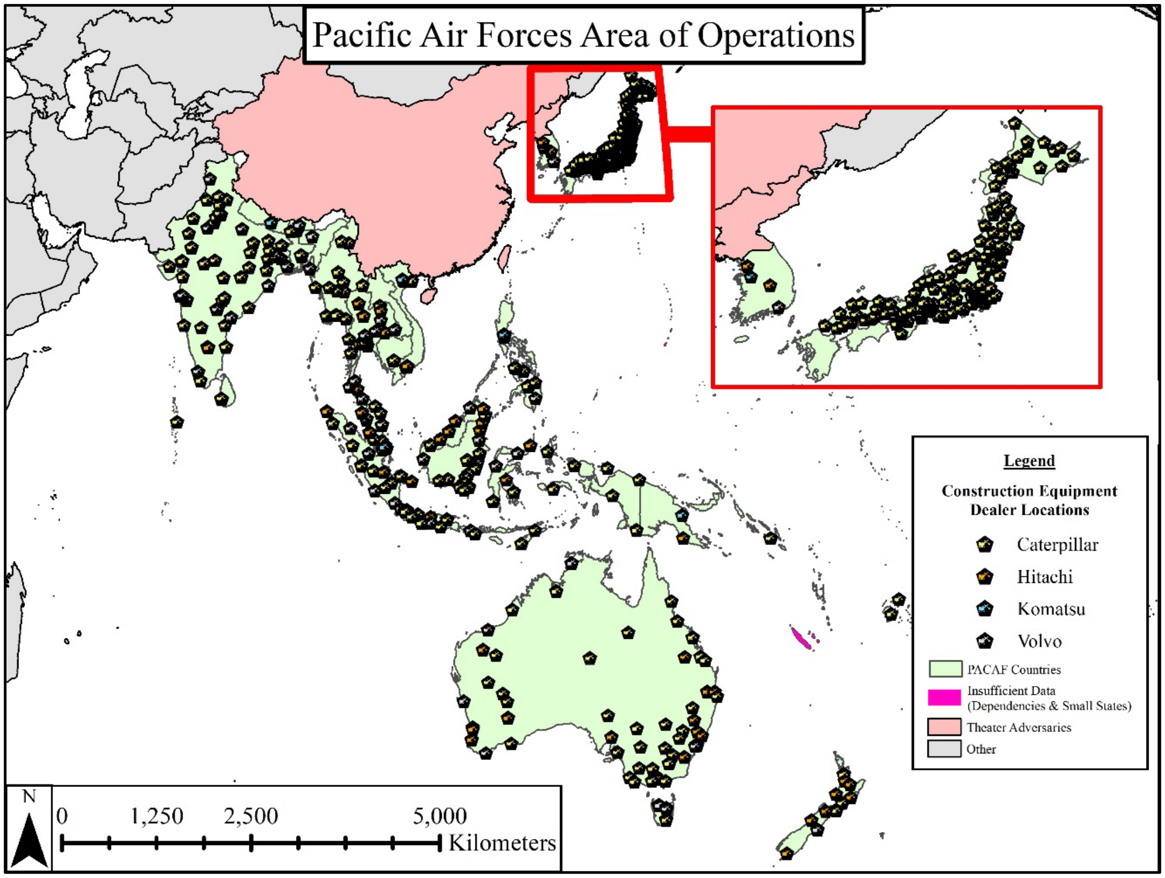


Figure 3: Geospatial Data Source – PACAF Construction Equipment Dealers

World Water Bodies.

ACE-SSF includes water access into 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 (ROWPU) 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 (ESRI 2021). The data classifies water sources into five categories: open water rivers, lakes, dry salt flats, seas, and oceans. Since ROWPU units can filter freshwater and seawater (AFCESA/CEXX 2012), the methodology uses each water resource subset to the 26 countries included in the analysis. Figure 5 depicts this research's water source selection parameter.

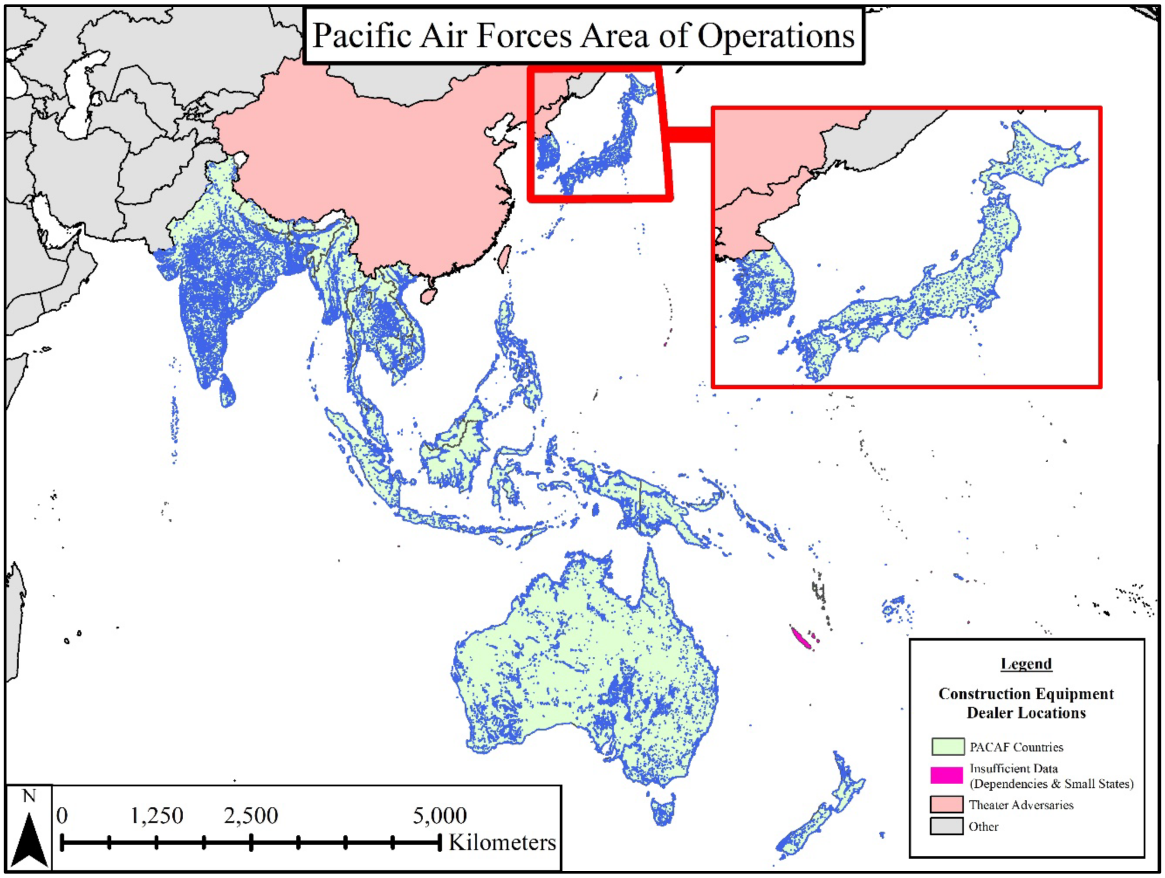


Figure 4: Geospatial Data Source – PACAF Water Sources

PRC Missile Threats.

Peer military capabilities represent a strategic risk for ACE because proximity to these threats can limit the USAF's ability to counteract and jeopardize mission execution. PRC missile capabilities are particularly concerning in the PACAF theater because they control one of the world's largest, most far-reaching missile arsenals. Therefore, ACE site selection must consider appropriate, flexible, and thoughtful missile risk thresholds.

Since the research is limited to unclassified sources, the methodology uses a generalized missile threat variable in its approach. Everelth (2020) developed a Google Earth representation of the PLARF based on declassified central intelligence agency documentation, DoD reports, and various research publications (Eveleth 2020). This data source acts as a surrogate data set to more accurate, classified intelligence. Rather than speculating missile capabilities at each locality, the framework utilizes three missile risk profiles assuming each launch site has either SRBMs, MRBMs, or IRBMs (Missile Defense Project 2021). Should the USAF adopt ACE-SSF operationally, ACE planners could improve the missile threat decision variable by incorporating more accurate coordinates, armament types, and estimated ranges. Figure 6 depcits the threat rings and contributing PLARF brigade locations.

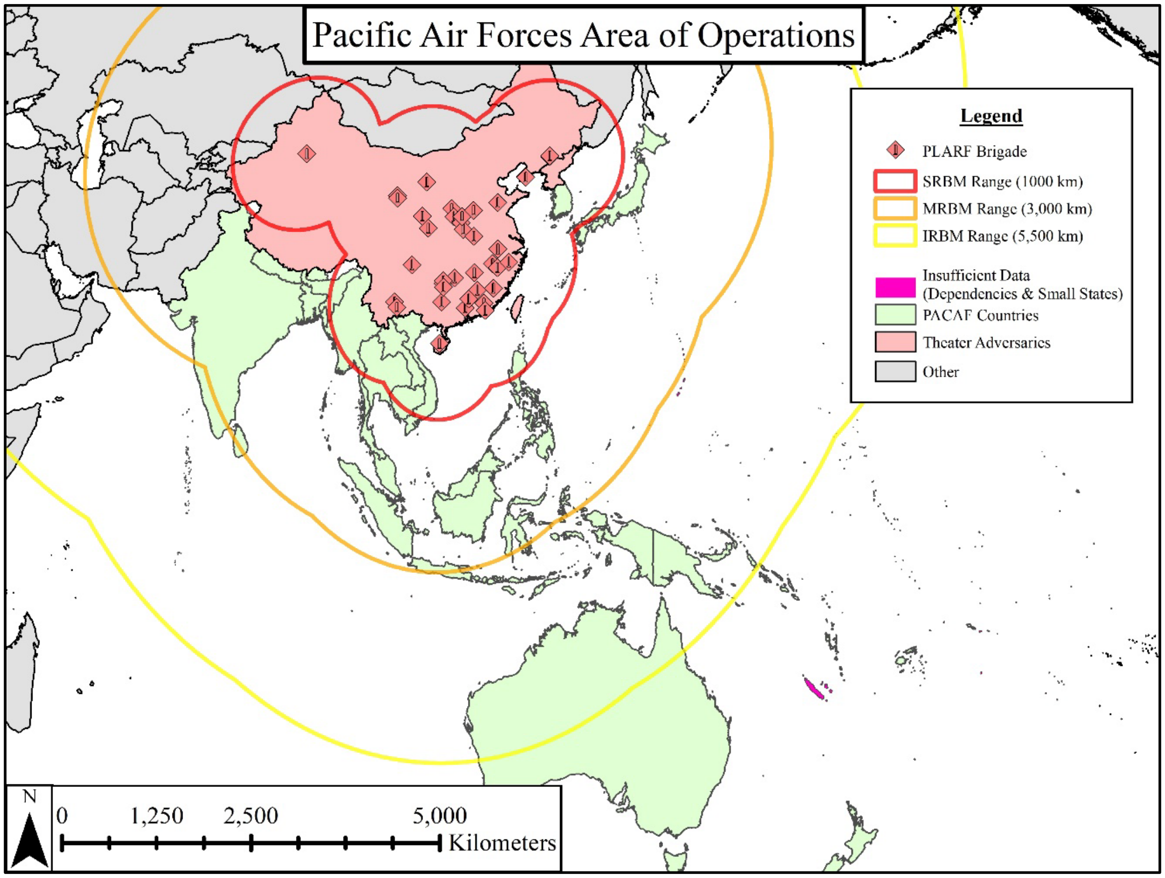


Figure 5: Geospatial Data Source – PACAF Missile Threats

Methods

Geospatial Analysis.

The USAF uses ArcMap and other Environmental Systems Research Institute (ESRI) programs as a base software for many GIS technologies (Baumann 2019). Accordingly, ACE-SSF utilizes ArcMap 10.7.1 to perform geospatial analysis. The USINDOPACOM AOR comprises 36 nations, of which 26 met the analysis criteria (USINDOPACOM 2021). The methodology requires subgrouping landmasses to establish an evaluation environment prior to analysis. The subgroup process results in three landmass categories: PACAF Nations, PACAF Theater Adversaries, and an “other” group encompassing other Combatant Command responsibilities.

Since several data sources surpass the evaluation environment, the method applies the ArcMap clip tool, which subsets data to the 26 nations in the PACAF AOR. Two ArcMap tools calculate proximities to generate utility metrics: Near and Point Distance. For example, to find the distance between A and the nearest B, the Near tool calculates the distance between a point in shapefile A (the Airports) and the closest point in shapefile B (e.g., the Construction Equipment Dealers). In this case, the tool identifies the nearest dealer to each airport and its associated distance in kilometers. Alternatively, to find the distance between point A and all points B, the Point Distance tool determines the distance from point A (randomly chosen point in China) and all points in B (the Airports). In this case, the tool identifies each airport’s distance from a point in China that represents a sortie distance estimate. Ultimately, Near and Point Distance implementation yield three geospatial decision variables for each airport: distance from water sources, distance from construction equipment sources, and sortie distance. Each result is deterministic but could be variable based on changes in resource availability and the geographic target ACE planners establish to simulate sortie distance.

ACE-SSF formulates missile threat profiles using Eveleth's (2020) PLARF datafiles. The data includes various PLARF unit characteristics, but this framework primarily uses coordinate approximations to generate missile range capability estimates. Two ArcMap tools facilitate the process: Buffer and Dissolve. First, the Buffer tool produces a polygon buffer around a shapefile's points (e.g., PLARF arsenal coordinates) based on a prescribed radius (e.g., 1,000 kilometers). The Buffer tool yields a circular polygon conglomeration representing the missile range capabilities at each site. Then, the dissolve tool aggregates each circular polygon, representing inclusive PLARF arsenal capabilities based on the threat profile (e.g., 1,000 kilometers). The method repeats the buffer and dissolve process three times to create SRBM, MRBM, and IRBM missile threat rings (1,500, 3,000, and 5,500 kilometers, respectively) (Missile Defense Project 2021).

The final geospatial analysis pertains to each airport's proximity to missile threats. ArcMap's Erase tool, which removes points (e.g., the Airports) that intersect with a defined polygon (e.g., SRBM threat ring), identifies the alternatives that remain outside a designated missile threat range. The method repeats the erase process three times to determine the airports available under each risk profile and assigns dummy variables based on their susceptibility to SRBM, MRBM, and IRBM arsenals.

The runway length and FSI variables require no geospatial analysis. The World Airport dataset provides runway characteristics, and each PACAF AOR country retains its FSI score within its ArcMap attributes. With the geospatial indicators acquired, the method requires data exportation to Microsoft Excel to consolidate the data. As a result, the consolidated Excel dataset includes, but is not limited to, the following for each airport alternative: runway length (feet), FSI score, estimated sortie distance (kilometers), distance to the nearest construction equipment dealer (kilometers), and distance to the nearest water source (kilometers).

Utility Value Formulation.

Each decision variable has contrasting units or scales. Utility functions provide 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 zero and one; higher scores represent qualities beneficial or desirable for the objective, and lower scores represent qualities unfavorable or undesirable for the objective.

Utility values are beneficial to ACE-SSF because USAF 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.

This research develops the utility functions based on background information, research committee input, and general intuition. The following Table 2 depicts the functions that scale each decision variable.

Table 2: Decision Variable Utility Functions (ACE-SSF)

Variable	Utility Function
Runway Length	$x_1 = runway\ length\ (feet) \xrightarrow{yields} u_1 = runway\ length\ (utile)$ $If\ x_1 \geq 10{,}000', u_1 = 1$ $If\ 5{,}000' \geq x_1 > 10{,}000', u_1 = 0.0002l - 1$ $If\ x_1 < 5{,}000', u_1 = 0$
Fragile States Index Score	$x_2 = Fragile\ States\ Index\ Score \xrightarrow{yields} u_2 = Fragile\ States\ Index\ Score\ (utile)$ $u_2 = 1 - \frac{x_2}{100}$
Distance from China	$x_3 = Sortie\ Distance\ (kilometers) \xrightarrow{yields} u_3 = sortie\ distance\ (utile)$ $If\ x_3 \geq 6{,}000km, u_3 = 1$ $If\ 2{,}000km \geq x_3 > 6{,}000km, u_3 = 1$ $If\ x_3 < 2{,}000km, u_3 = 0$
Distance to Construction Equipment Dealer	$x_4 = Construction\ Equipment\ Dealer\ (kilometers) \xrightarrow{yields} u_4 = Construction\ Equipment\ Dealer\ (utile)$ $If\ x_4 \geq 500km, u_4 = 0$ $If\ 400km \geq x_4 > 500km, u_4 = 0.1$ $If\ 300km \geq x_4 > 400km, u_4 = 0.2$ $If\ 200km \geq x_4 > 300km, u_4 = 0.3$ $If\ 100km \geq x_4 > 200km, u_4 = 0.4$ $If\ 50km \geq x_4 > 100km, u_4 = 0.5$ $If\ 30km \geq x_4 > 50km, u_4 = 0.6$ $If\ 20km \geq x_4 > 30km, u_4 = 0.7$ $If\ 10km \geq x_4 > 20km, u_4 = 0.8$ $If\ 5km \geq x_4 > 10km, u_4 = 0.9$ $If\ x_4 < 5km, u_4 = 1$
Distance to Water Source	$x_5 = Water\ Source\ (kilometers) \xrightarrow{yields} u_5 = Water\ Source\ (utile)$ $If\ x_5 \geq 15km, u_5 = 0$ $If\ 10km \geq x_5 > 15km, u_5 = 0.1$ $If\ 7.5km \geq x_5 > 10km, u_5 = 0.2$ $If\ 5km \geq x_5 > 7.5km, u_5 = 0.3$ $If\ 4km \geq x_5 > 5km, u_5 = 0.4$ $If\ 3km \geq x_5 > 4km, u_5 = 0.5$ $If\ 2km \geq x_5 > 3km, u_5 = 0.6$ $If\ 1.5km \geq x_5 > 2km, u_5 = 0.7$ $If\ 1km \geq x_5 > 1.5km, u_5 = 0.8$ $If\ 0.5km \geq x_5 > 1km, u_5 = 0.9$ $If\ x_5 < 0.5km, u_5 = 1$

Analytic Hierarchy Process.

Not all ACE site selection factors are equal in importance. For instance, although water accessibility is vital for troop sustainability, an inadequate runway will completely undermine ACE site operability. AHP enables the model to form a hierarchy among the decision criteria by performing a pairwise comparison of each variable. In practice, it is best to conduct AHP pairwise comparison as an organization because it usually moderates selection bias. Group brainstorm sessions or surveys involving subject matter experts are both excellent means to gather these inputs.

This methodology forms pairwise comparison inputs from the research's primary stakeholders, including Air Force Institute of Technology (AFIT) civil engineer experts and the 800th RED HORSE Group. Runway length is most critical, followed by the Fragile States Index, sortie distance, distance from construction equipment dealers, and distance from water sources. A few pairwise comparisons deviate from this trend, but the results produce a 0.098 consistency ratio (CR). The model's weights are appropriate because research suggests a CR less than 0.1 is consistent. The following summarizes the formulated AHP weights for the ACE site selection framework. Additionally, Tables 3 – 5 portray the AHP results in greater detail.

(1) Runway Length: 40%

(2) Fragile States Index: 25%

(3) Distance from China (sortie distance): 16%

(4) Distance from Construction Equipment Dealers: 10%

(5) Distance from Water Sources: 10%

Table 3: Pairwise Comparison Matrix

	Runway Length	**Fragile States Index**	**Sortie Distance**	**Construction Equipment**	**Water Sources**	Vector [V]	Weight [W]
Runway Length	1	2	3	4	4	2.49	0.40 **(40%)**
Fragile States Index	$\frac{1}{2}$	1	2	3	3	1.55	0.25 **(25%)**
Sortie Distance	$\frac{1}{3}$	$\frac{2}{3}$	1	2	2	0.98	0.16 **(16%)**
Construction Equipment	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	1	0.62	0.10 **(10%)**
Water Sources	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	1	0.62	0.10 **(10%)**
						Total 6.26	Total 1

Table 4: Eigenvalue Calculation

	Runway Length	**Fragile States Index**	**Sortie Distance**	**Construction Equipment**	**Water Sources**	[W]	[W]’	[W]”
Runway Length	1	2	3	4	4	0.40	2.16	5.42
Fragile States Index	$\frac{1}{2}$	1	2	3	3	0.25	1.35	5.47
Sortie Distance	$\frac{1}{3}$	$\frac{2}{3}$	1	2	2	0.16	0.85	5.46
Construction Equipment	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	1	0.10	0.54	5.42
Water Sources	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	1	0.10	0.54	5.42
						Total 1		Total (λ) 27.20

Table 5: Consistency Ratio Calculations

Number of Criteria (n)	5
Maximum Eigenvalue (λ)	27.20
Random Consistency Index (RI)	1.12
Consistency Ratio	0.098

The final step in the AHP process is to apply the AHP weights to each airport alternative’s utility values. For instance, Yokota Air Base’s runway has a utility value of

1.0, and the AHP weight scales this value to 0.4. This procedure scales the utility values based on established preferences and then aggregates weighted decision criteria to generate utility scores for each airport. Table 6 articulates the aggregation equation for the model's AHP scores. Sorting the data by this metric illustrates a one to n list of airport alternatives ranked by the risk and utility they offer ACE operations.

Table 6: Airport AHP Score Formula

Criteria	$A_x = Airport\ AHP\ Score$
	$u_1 = runway\ length\ (utile)$
	$u_2 = Fragile\ States\ Index\ Score\ (utile)$
	$u_3 = Sortie\ Distance\ (utile)$
	$u_4 = Construction\ Equipment\ Distance\ (utile)$
	$u_5 = Water\ Resource\ Distance\ (utile)$
	$w_n = AHP\ Weight$
Airport AHP Score Equation	$A_x = (u_1 \times w_1) + (u_2 \times w_2) + (u_3 \times w_3) + (u_4 \times w_4) + (u_5 \times w_5)$

Results

ACE-SSF results can be assessed using various mediums. For example, the scores produced in Microsoft Excel could facilitate site selection decisions by sorting the data in descending order of score and comparing selection criteria to define decision making. Alternatively, this research recommends using ArcMap and R-Studio to analyze the results. ArcMap utilization allows users to generate geospatial inferences, and R-Studio helps produce useful visualizations and perform a more thorough analysis.

Spatial Results.

One way to interpret ARC-SSF results is to manipulate each airport's symbology in ArcMap to reflect its AHP score. Figure 7 illustrates this approach by breaking airport scores into quartiles of 144 airports each. The most suitable airports are green, while the most unfit airports are red. This method highlights the airports, countries, and regions that present the utmost 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.

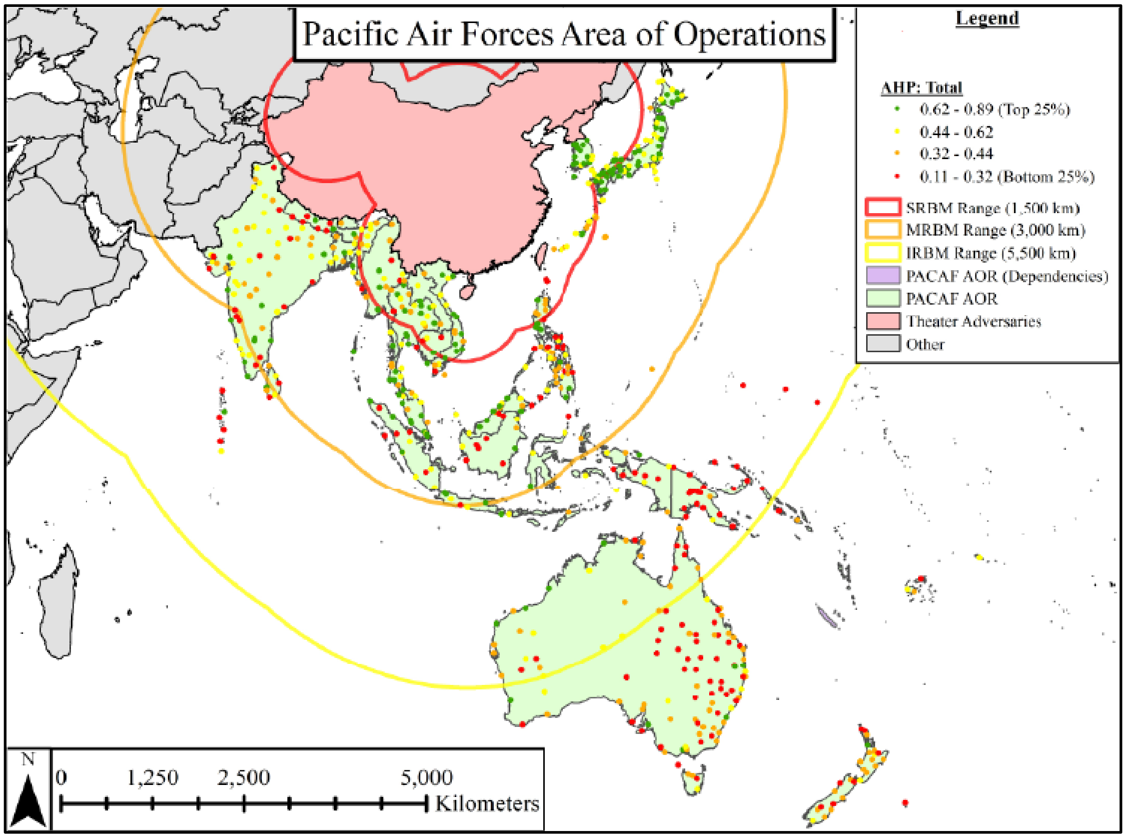


Figure 6: ACE-SSF AHP Results (PACAF AOR)

Additionally, geospatial presentation of the results lends additional inferences, such as countries the USAF would not otherwise consider. For example, based on intuition, the Philippines seems like a candidate country that would present advantages to USAF ACE operations. However, 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 SRBM range possess airports with surprising high utility, such as India, Indonesia, and Malaysia. The map indicates that 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, decision-makers could combine airport symbology and missile threat rings to guide decisions. For instance, if ACE planners intend to avoid SRBM threats yet are willing to accept MRBM 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 MRBM 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 in ArcMap can allow 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 draw a circle representing the maximum desired base cluster radius if leaders desire proximate base clusters. This method would ensure site selection decisions properly account for spoke quantity and separation requirements.

GIS representation of ACE-SSF results furthers the methodology by allowing users to perceive ideal alternatives. Furthermore, AHP results can be challenging to assimilate, and 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.

Statistical Analysis and Ranking.

Statistical tools can further refine results and provide ACE planners with informative data. ACE-SSF uses R-Studio (an R programming language interface) to evaluate airport AHP score trends, understand the relationship between AHP score and missile threats, and determine which countries possess the most high-scoring airport alternatives. Like other programming languages, R-Studio was chosen based on preference; Microsoft Excel or a similar programming software could similarly perform these processes. The primary outputs are graphical representations of the results.

Figure 8 depicts the graphic visualizations. The illustration aims to demonstrate the influence missile constraints 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 quarter of the results.

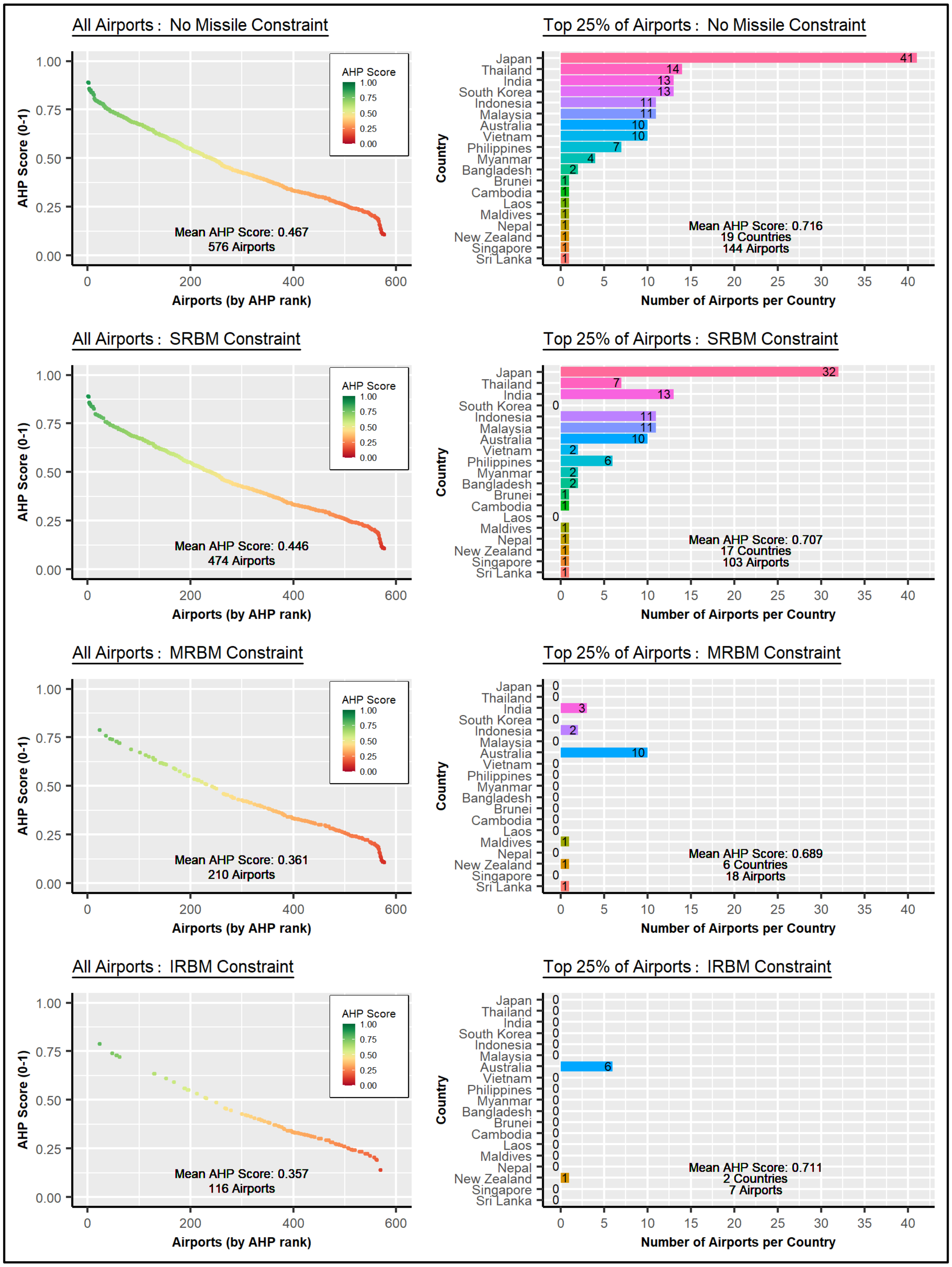


Figure 7: PACAF ACE Site Selection Analysis (Missile Threat Constraint)

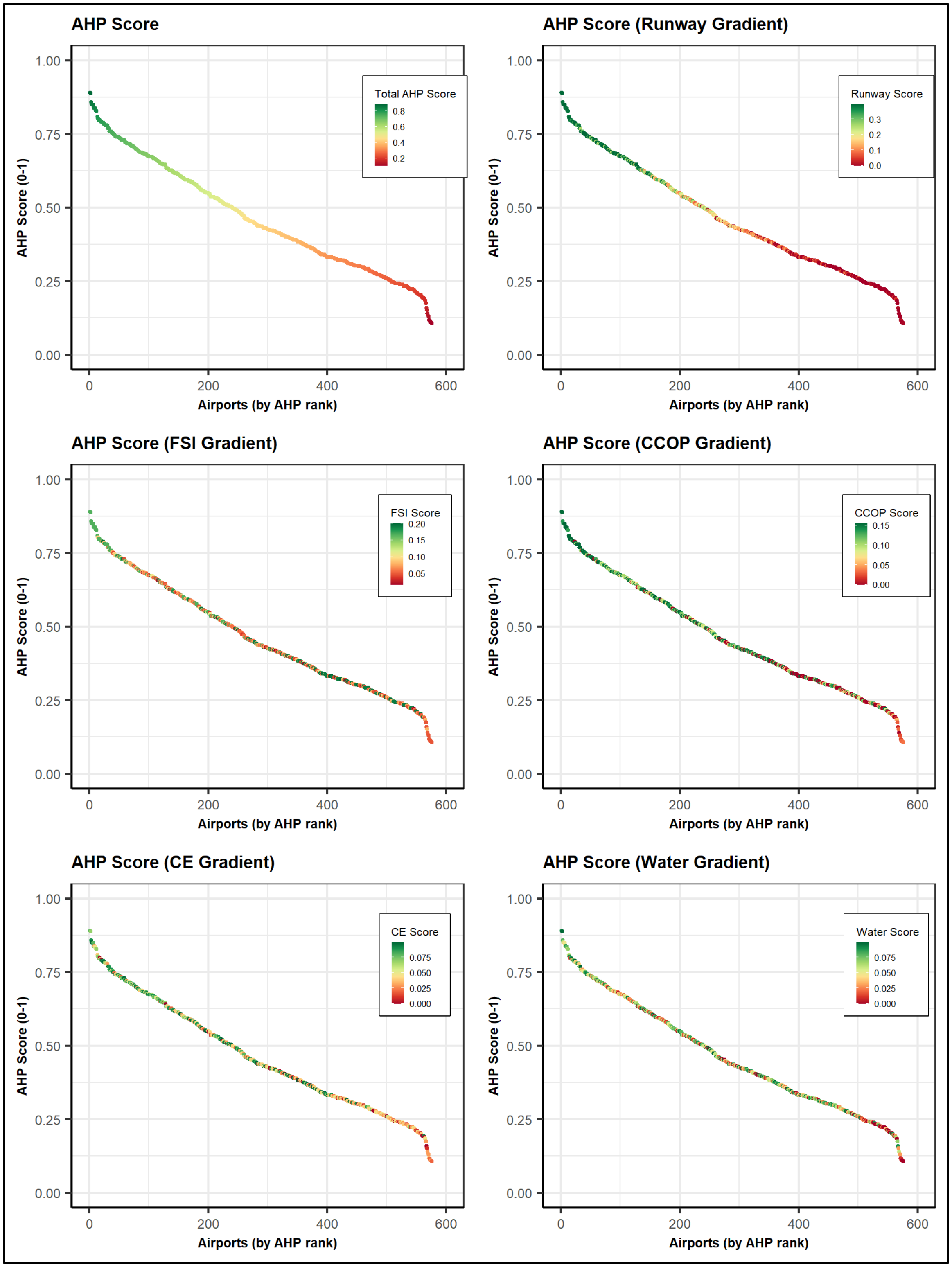
Unsurprisingly, these results show fewer airport alternatives remain as the model is constrained to longer-range missile threats. Moreover, the figure implies that the highest-scoring airports begin to noticeably disappear from the model under the MRBM and IRBM constraints. At these ranges, only six countries have airports that scored higher than 0.62, which indicates a significant loss of quality alternatives.

Statistics surrounding the airports and missile constraints are insightful to the site selection problem. The SRBM constraint retains 82.3% of the analyzed airports with a comparable mean AHP to the overall dataset (0.446 versus 0.467). On the other hand, the MRBM and IRBM constraints significantly reduce the quantity and quality of the airports; the MRBM and IRBM constraints retain 36.5% and 20.1% of the alternatives, respectively, and the mean AHP score drops down to 0.361 and 0.357, respectively. These observations suggest that using the SRBM range as a model constraint could help ACE planners reduce risk without losing too many ideal alternatives.

Additionally, the bar charts depicting top-quartile airports per country are insightful for ACE site selection. For example, ACE planners can use the airport distributions to determine which countries provide the best environment (airport quantity and quality) for operational effectiveness if they identify a desired missile risk threshold. Figure 3 indicates that Japan, India, Indonesia, and Malaysia have the most high-scoring airports under the SRBM constraint. However, these alternatives reduce significantly under the MRBM 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 the PRC (e.g., Australia). Should ACE planners assume a risk-averse strategy to avoid missile threats, several viable options remain based on the selection criteria.

Finally, Figure 9 portrays the AHP results and the influence of each contributing criteria. The illustration can assist planners in interpreting the results and forming decisions. First, the upper and lower tails of the primary plot (top-left) suggest the extreme results drop off more than the majority of the results. This observation suggests that the change in airport scores is more remarkable for the best and worst airports and that the change in remaining airports is relatively uniform. Second, formatting the primary data points based on the contributing criteria helps show each parameter's influence on the final score and indicates which criteria tend to align with the final score. For instance, the criteria with the largest weight, runway length, closely resembles the overall AHP score. Similarly, the criteria with the smallest weight, water source, is generally dissimilar to the overall AHP score. However, the FSI parameter does not follow an intuitive trend, which could be a signal to planners that the scoring mechanism is less predictable or that other geographic criteria or constraints are skewing the influence of that criteria.



AHP Score

AHP Score (Runway Gradient)

AHP Score (FSI Gradient)

AHP Score (CCOP Gradient)

AHP Score (CE Gradient)

AHP Score (Water Gradient)

Figure 8: Airport Feasibility Score and Selection Criteria Performance

Discussion

ACE-SSF and ACE Operations.

The ACE-SSF methodology could benefit strategists and planners significantly in an A2AD environment. These decision-makers 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. ACE-SSF could be an effective tool to lean on and support site selection decisions because the framework is scalable, flexible, expedient, and generates informative results and visualizations.

Several features make ACE-SSF a scalable framework. First, the framework could be applied to any AOR, despite the research concentrating on the PACAF AOR. Besides the PLARF and Construction Equipment decision variables, each data source extends the globe and could be incorporated into other AOR-specific analyses. So long as data is available concerning the alternatives, criteria, and constraints, ACE-SSF can be applied based on the needs of the USAF. 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. However, these categories could be broken down further into sub-categories 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 of the criteria categories will require further effort from users due to the additional pairwise comparisons.

However, these efforts would provide users more certainty that the airports will meet ACE requirements and maximize suitability to operations.

ACE-SSF's use of AHP and GIS provides significant flexibility for ACE planners. On the one hand, ACE planners may disagree with the criteria chosen for this research and wish to analyze other criteria. The framework can adapt to these considerations by adding, subtracting, or substituting criteria or constraints as needed. On the other hand, ACE planners may want to adjust utility functions and AHP criteria weights based on emerging knowledge or changes in resource availability. The framework can undoubtedly facilitate this 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, ACE planners could prepare criteria, weights, and scores pre-conflict 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, ACE-SSF 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 an ACE-SSF 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 in those countries. Alternatively, Combatant Commanders or planners could use the results to inform just-in-time decisions. ACE planners will better understand which countries will allow USAF operations when conflict begins. This knowledge could be used to constrain ACE-SSF results and select ACE operating sites that optimally support ACE requirements and strategic outcomes.

Right-of-boom ACE site selection will require significant coordination to establish and support operating sites that best facilitate ACE strategy. ACE-SSF leverages GIS and AHP to ensure ACE decision-makers properly account for and balance critical considerations for mission effectiveness. Should the USAF lose access to predetermined ACE operating sites, ACE-SSF could quickly support the strategy alteration process and give USAF leaders confidence that their decisions are backed by strategic priorities, preferences, and data.

ACE-SSF Improvements and Limitations.

This paper's purpose is not to identify "where to go" for ACE after A2AD. 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 ACE-SSF's potential and accuracy

First, a fully enabled ACE-SSF should analyze alternatives on a classified network to incorporate classified criteria, constraints, and site alternatives. While this paper demonstrates ACE-SSF'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 methodology significantly. Implementing classified features ensures ACE-SSF 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. Additionally, suppose ACE-SSF included the location of cached mission resources as a decision variable, such as maintenance equipment, temporary facilities, and munitions. In that case, the parameter could support decision-making by analyzing the point distance from the resource's geographic coordinate. The thought process could be applied to many data sources, including the airports 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-SSF does not include a cost component in its selection criteria. A cost parameter would be advantageous for ACE site selection because the USAF is subject to budget constraints and aspires to implement fiscally responsible strategies. However, this research could not produce this variable due to time and resource constraints. Traditionally, the USAF 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 USAF could implement a similar metric to quantify the cost. The United States Army Corp of Engineers produces area cost factor data, but the data is not comprehensive enough to provide metrics for the 26 countries analyzed in the case study. Should cost be a parameter the USAF desires for A2AD ACE site selection analysis, the USAF must generate or invest in data sources that derive area cost factors across the countries it intends to consider.

Finally, data on fuel availability at each airport would be instrumental in shaping right-of-boom site selection decisions. Unfortunately, this research could not locate any data sources that quantified real-time fuel levels for the analyzed alternatives. However, if ACE planners had access to or created a global fuel data source, ACE-SSF could use the data as a site utility indicator. A fuel availability criteria would be essential for certain ACE operations, such as refueling aircraft. While the feasibility of integrating fuel data is unknown, it would undoubtedly be a valuable metric to consider since fuel is an essential enabler of aircraft operations. If ACE-SSF does not include a fuel parameter, planners assume a degree of risk if the airport cannot support the aircraft with their fuel requirements.

Future Work.

As previously mentioned, performing ACE-SSF 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 reliability 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 that the model mitigates missile ranges appropriately. A list of site requirements for ACE operations could add additional grading points for airfield alternatives and ensure optimal supply chain management throughout adaptive basing. These examples and more are possible when ACE-SSF integrates classified data sources; as ACE planners perform most of their planning on classified networks, this should be a viable course of action.

Integrating cost and resource variables (e.g., fuel, munitions, site equipment) are the two most recommended criteria for future ACE-SSF analysis. Unfortunately, these parameters are not feasible in the current research environment. However, effort or investments to aggregate this data would prove rewarding for ACE-SSF and determining the sites that maximize ACE operability.

Lastly, this paper describes methods for scoring and hierarchizing individual airports in the Pacific theater. Additional ArcMap tools could analyze base clusters and provide recommended hub and spoke courses of action. Additional research is needed to determine the utility of these tools for ACE site selection. Theoretically, the program could evaluate airport AHP scores and determine which options should be selected based on search parameters (e.g., hub and spoke radius).

Conclusion

While ACE strategy matures, USAF leaders, strategists, and planners must develop contingency plans that confront worst-case outcomes. ACE-SSF, a GIS-based AHP 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 the spirit of adaptive basing surrounded by insurmountable requirements and many unknowns.

The case study analyzed 576 existing airport alternatives in the PACAF AOR based on five selection criteria and various constraints. The methodology evaluated the airports based on utility values and AHP weights and ranked the alternatives based on their resulting scores. The analysis demonstrates the utility of the ACE-SSF to hierarchize alternatives, generate visualizations to illustrate the results, and produce a repeatable framework to help leaders and planners make complex site selection decisions for ACE. Most importantly, the application demonstrates that ACE-SSF is a flexible, scalable, expedient, and reproducible framework to evaluate prospective sites and inform decision-makers.

As the USAF navigates ACE development, its pacing 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. Should this nightmare become a reality, the USAF must adapt its strategies and leverage advanced decision-making methods to navigate complicated scenarios. ACE-SSF can provide these necessary tools to the warfighter and ensure the USAF maintains strategic advantages throughout conflict.

IV. Discussion

ACE-SSF Sensitivity

A critical aspect of MCDA methods is model sensitivity. Practitioners intend to design models that produce noticeable variation when variables are modified, but not in an extreme manner. For example, if ACE-SSF reduces the distance thresholds for the water source decision variable, one would expect the framework to value alternatives with water sources near its geographic coordinate. However, having the best sites switch to the worst (and vice-versa) from simply changing one variable would be undesirable.

AHP models are inherently sensitive. For instance, ACE-SSF ranks runway length as the most important, and construction equipment and water sources are the least important. If the model swaps these relationships, the results will change significantly because the resource metrics will be the predominant score influencer. This type of extreme change is understandable because preferential inputs changed significantly. Presumably, ACE-SSF parameters, preferences, and priorities will not change significantly over time, which is conducive to the proposed methodology.

This research uses an alternate scenario to assess ACE-SSF's sensitivity. The alternate analysis set uses adjusted UVs and AHP weights to demonstrate how the parameters change ACE-SSF results. Table 7 depicts the UV function changes, including adjustments to the construction equipment and water source step functions. Tables 8 through 10 depict the AHP weight changes; these weights distribute the criteria systematically (e.g., 1, 3, 5, 7, 9) and result in a more consistent pairwise comparison than the original analysis (CR = 0.053 versus CR = 0.098). The scoring process in Chapter 3 was repeated to generate results for all 576 alternatives.

Table 7: Summary of ACE-SSF Simulation Changes

Analysis Component	Primary Scenario	Alternative Scenario
Construction Equipment Utility Values	Range: 0km – 500km	Range: 0km – 1,000km
Water Source Utility Values	Range: 0km – 15km	Range: 0km – 100km
Runway AHP Weight	0.4	0.51
FSI AHP Weight	0.25	0.26
Sortie Distance AHP Weight	0.16	0.13
Construction Equipment AHP Weight	0.1	0.06
Water Source AHP Weight	0.1	0.03

The first sensitivity evaluation method subsets the top 10% (58 airports) from the original and alternate results and determines the change in rank for each airport. Table 8 depicts the results of this process. The analysis indicates most alternatives change between one and five rankings between analysis, and over 77% of these top airports moved 15 positions or less between weighting scenarios. Only 12% received a rank that bumped them outside the top 10%. These observations suggest the model produces variable results based on the inputs while avoiding extreme swings in the results.

Appendix A includes a variety of figures that assess the model's sensitivity characteristics. First, by conditionally formatting the data points by each AHP component, the chart depicts how much a particular variable is influencing the models' output. Unsurprisingly, the runway, FSI, and distance to China criteria appear to influence the model more consistently. At the same time, the construction equipment and water source variables exert a minor degree of influence. Second, subsetting the data to individual countries can explain how much the results change. This analysis breaks out the results for the top 10 countries in the initial analysis and compares the initial and alternate analysis outcomes. The graphs suggest that changing the UV and AHP characteristics do produce variability in the results, but not so extreme as to cause concern in the framework. Finally, Figure 10 compares the primary and alternative analysis by highlighting the changes in top-scoring airports per country.

Table 8: Airport Analysis Results Comparison (Top 10%, n = 58)

Change in Rank (Δ)	Count (Frequency)
< -25	0
-21 to -25	0
-16 to -20	2
-11 to -15	4
-6 to -10	6
-1 to -5	10
0	4
1 to 5	14
6 to 10	2
11 to 15	5
16 to 20	1
21 to 25	1
> 25	2
Outside Top 10%	7

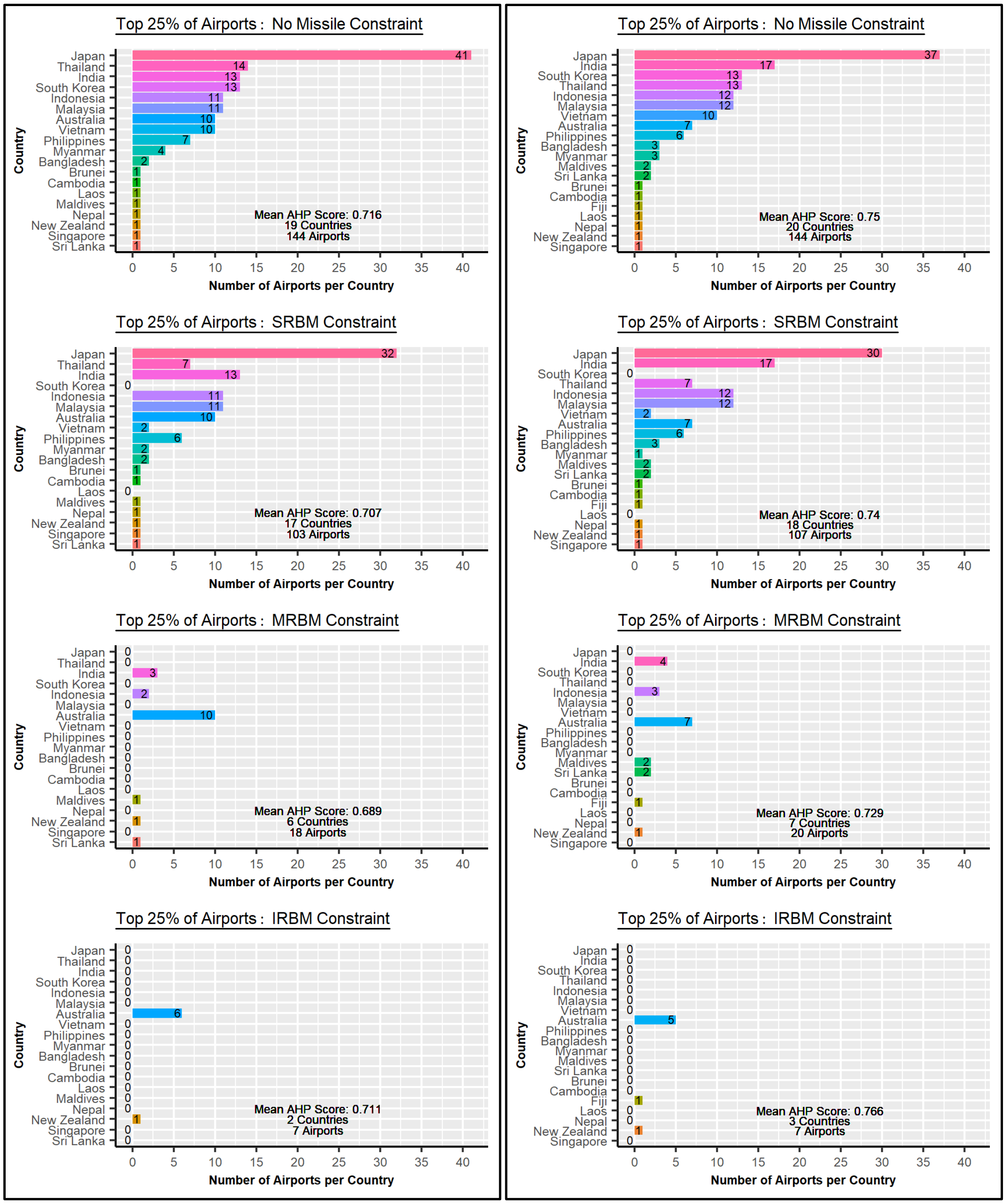


Figure 9: Primary (left) and Alternative (right) ACE-SSF Results

The sensitivity analysis exercise indicates that ACE-SSF is reasonably insensitive for ACE site selection. As discussed, MCDA models like AHP are inherently sensitive because users decide preferential weighting. While two groups of subject matter experts could value parameters inversely, the possibility is less likely for ACE site selection decision-making. Nevertheless, if ACE-SSF is implemented at Combatant Commands, planners and strategists must be conscious of inherent MCDA sensitivities and understand variability sources if they change priorities and preferences significantly.

V. Conclusions

This research addressed the question, “how should combatant commanders or planners decide where to go for ACE when predetermined USAF hubs and spokes become compromised,” by developing the MCDA site selection framework ACE-SSF. This methodology pairs modern optimization techniques with strategic military variables to simplify decision-making for ACE planners. Three takeaways stemming from this research support the operational implementation of ACE-SSF.

First, the case study described in Chapter 3 demonstrates ACE-SSF is robust, repeatable, scalable, simple, and flexible. Since ACE site selection decisions are complex and pressing, the proposed framework could pay dividends to combatant commanders and ensure USAF operations endure unabated throughout contested, A2AD, right-of-boom environments. Second, the research demonstrates the strategic and tactical benefits of combining GIS and AHP for site selection optimization. These modern techniques enable planners to develop solutions that are visualizable and understandable. These features are valuable to leaders who will undoubtedly be preoccupied with other complicated decisions. By implementing a GIS-enabled AHP framework, combatant command leaders can feel confident they are making data-driven decisions based on the risk and utility of the airport alternatives. As familiarity with the methodology increases, quicker decision-making by leadership is an expected outcome. Finally, the framework produces results that can be applied in many ways, locations, and decision applications. This research demonstrates the benefits of pairing GIS and AHP to form ACE site selection decisions. These same principles could improve decision-making in many other domains of USAF operations. MCDA methodologies like ACE-SSF allow decision-makers to incorporate priorities and preferences to meet, exceed, or optimize the desired outcome. The framework developed in this research could be adapted for various site selection decisions to ensure competing objectives are balanced and that leaders arrive at the best solution for their organization.

While ACE strategy matures, USAF leaders, strategists, and planners must develop contingency plans that confront worst-case outcomes. ACE-SSF, a GIS-based AHP 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 the spirit of adaptive basing surrounded by insurmountable requirements and many unknowns.

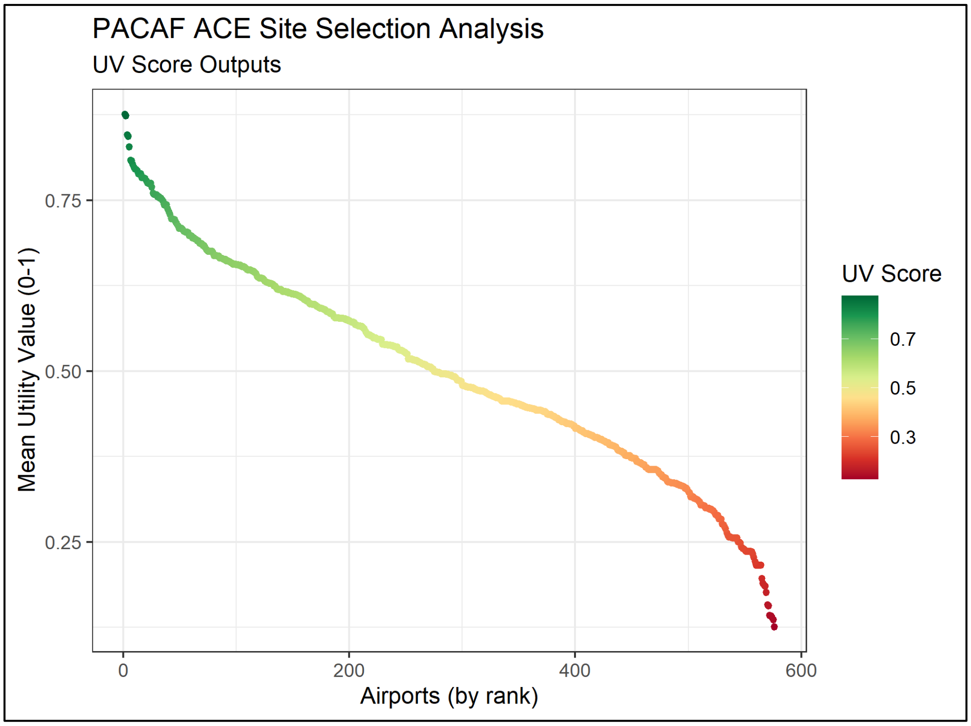
The case study analyzed 576 existing airport alternatives in the PACAF AOR based on five selection criteria and various constraints. The methodology evaluated the airports based on utility values and AHP weights and ranked the alternatives based on their resulting scores. The analysis demonstrates the utility of the ACE-SSF to hierarchize alternatives, generate visualizations to illustrate the results, and produce a repeatable framework to help leaders and planners make complex site selection decisions for ACE. Most importantly, the application demonstrates that ACE-SSF is a flexible, scalable, expedient, and reproducible framework to evaluate prospective sites and inform decision-makers.

As the USAF navigates ACE development, its pacing 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. Should this nightmare become a reality, the

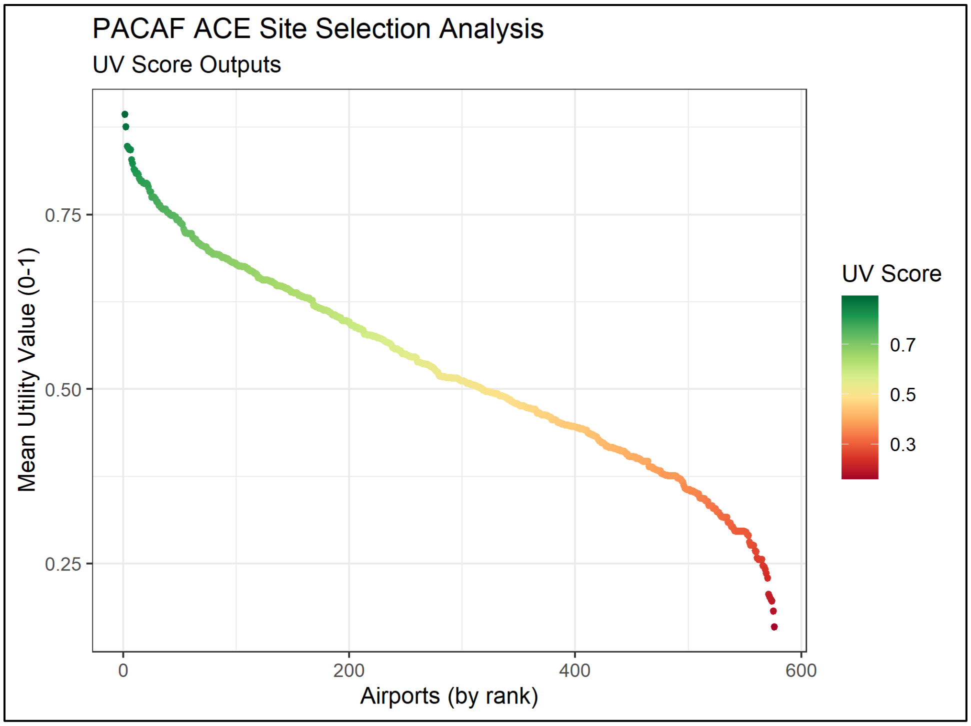
USAF must adapt its strategies and leverage advanced decision-making methods to navigate complicated scenarios. ACE-SSF can provide these necessary tools to the warfighter and ensure the USAF maintains strategic advantages throughout conflict.

Appendix A. Additional Analytical Figures

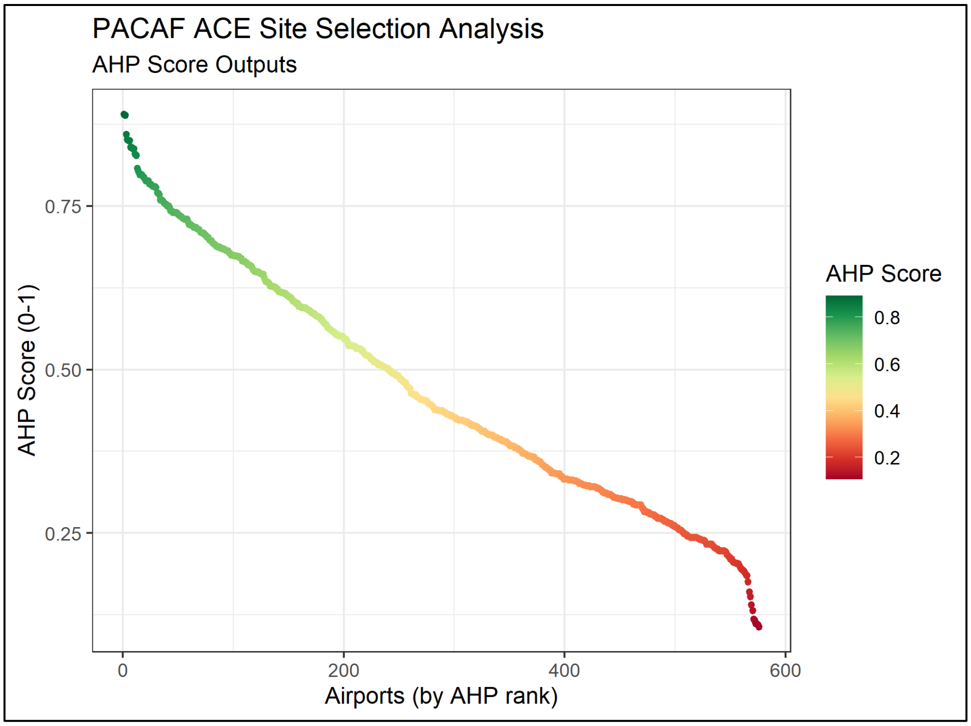
Appendix A provides additional context to this research's results and discussion. First, several figures portray all airports' UV scores, AHP scores, and selection criteria variables. These figures were vital in developing inferences on the framework's performance. Second, figures depicting the results for the most relevant countries (Japan, Thailand, India, South Korea, Indonesia, Malaysia, Australia, Vietnam, Philippines, and Myanmar) illustrate each country's portfolio of airports and their corresponding scores. These figures underscore country-specific metrics, including the total number of airports per country, where the airports fall on the waterfall chart, a country-specific mean cutline, and the overall mean AHP score for the country.



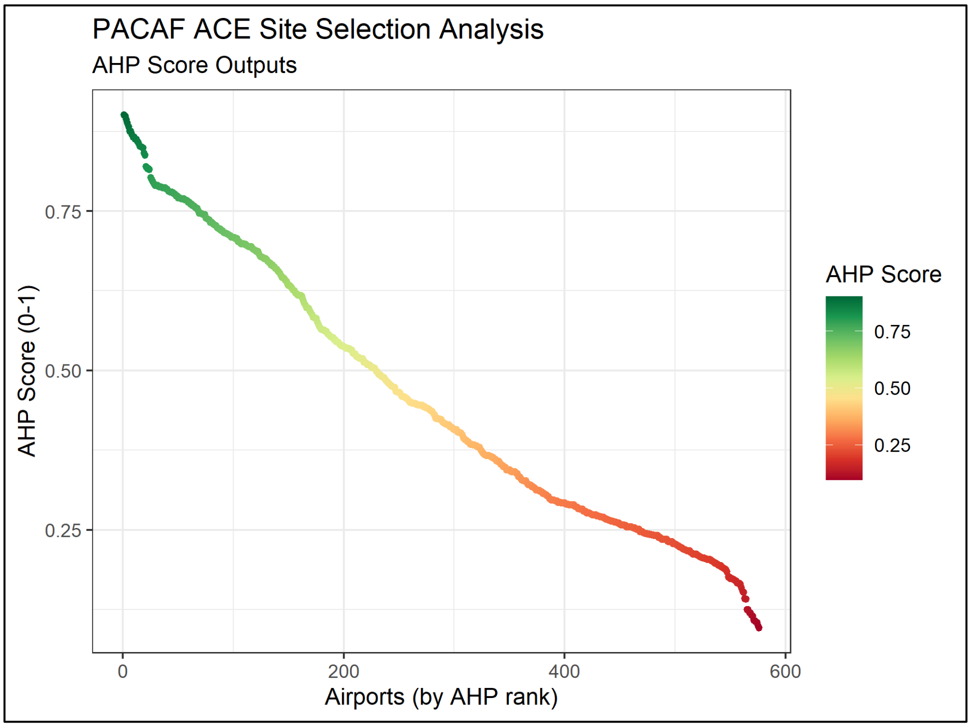
Primary UV Weight Results



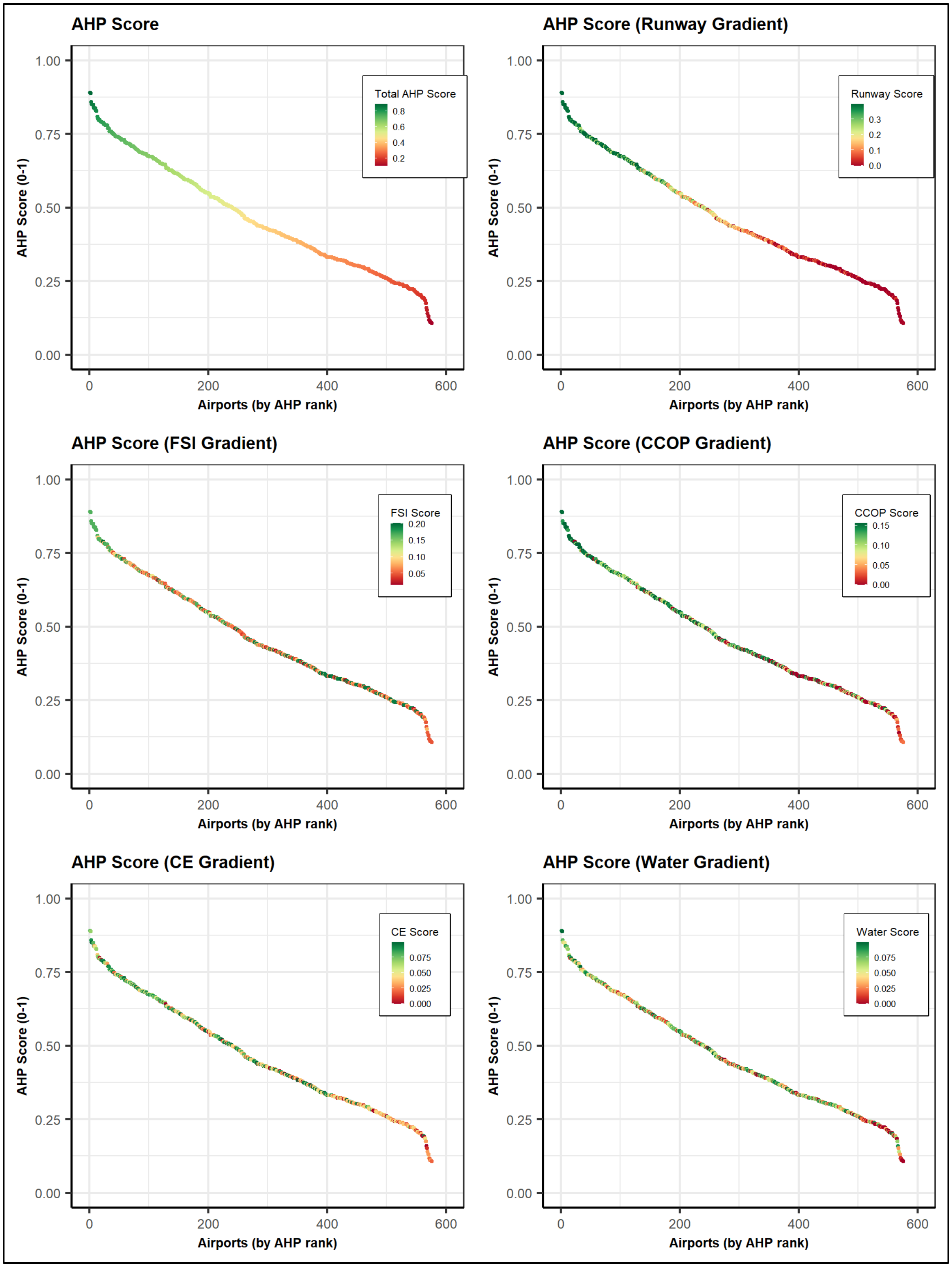
Alternate UV Weight Results



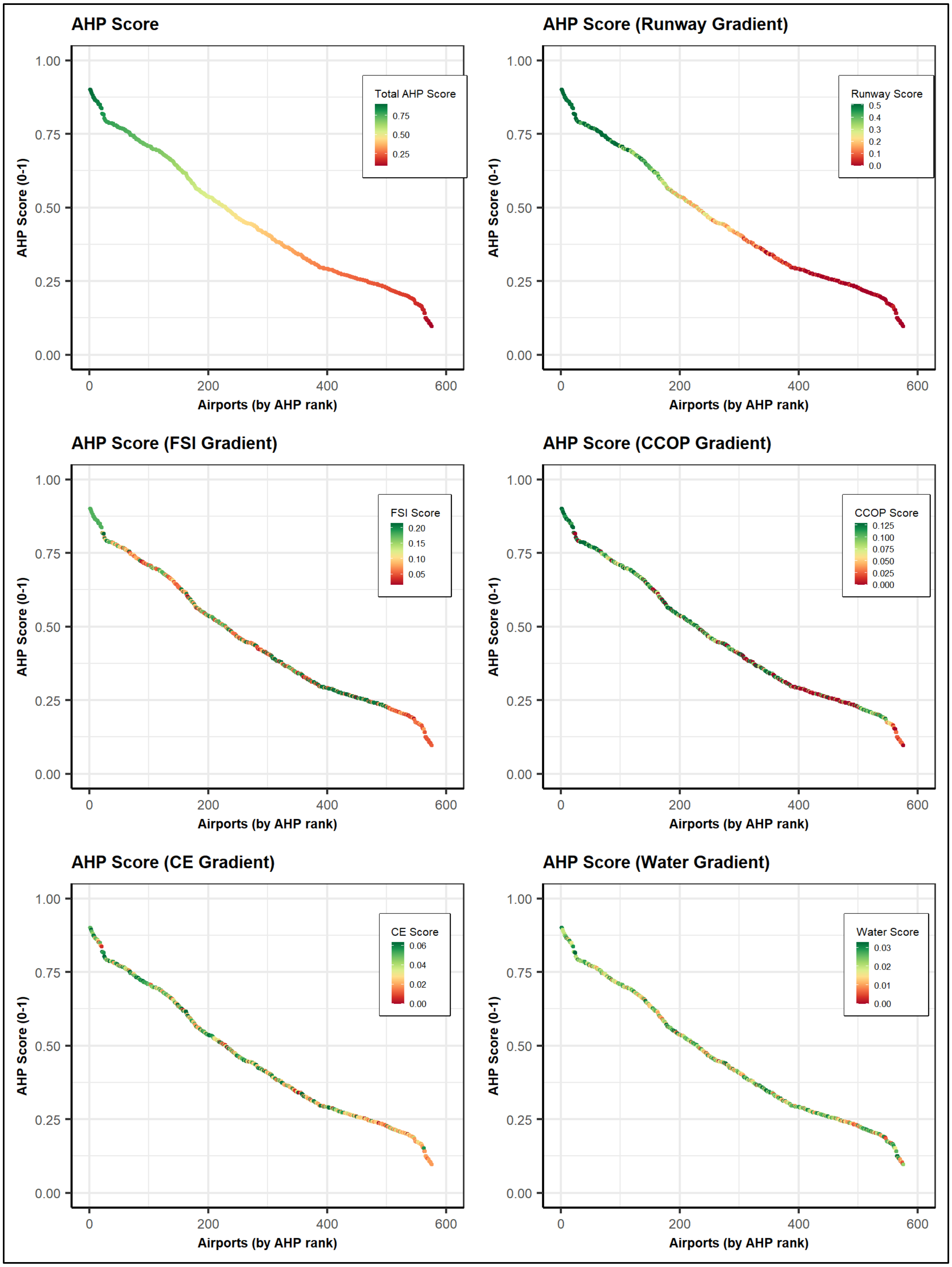
Primary UV and AHP Weight Results



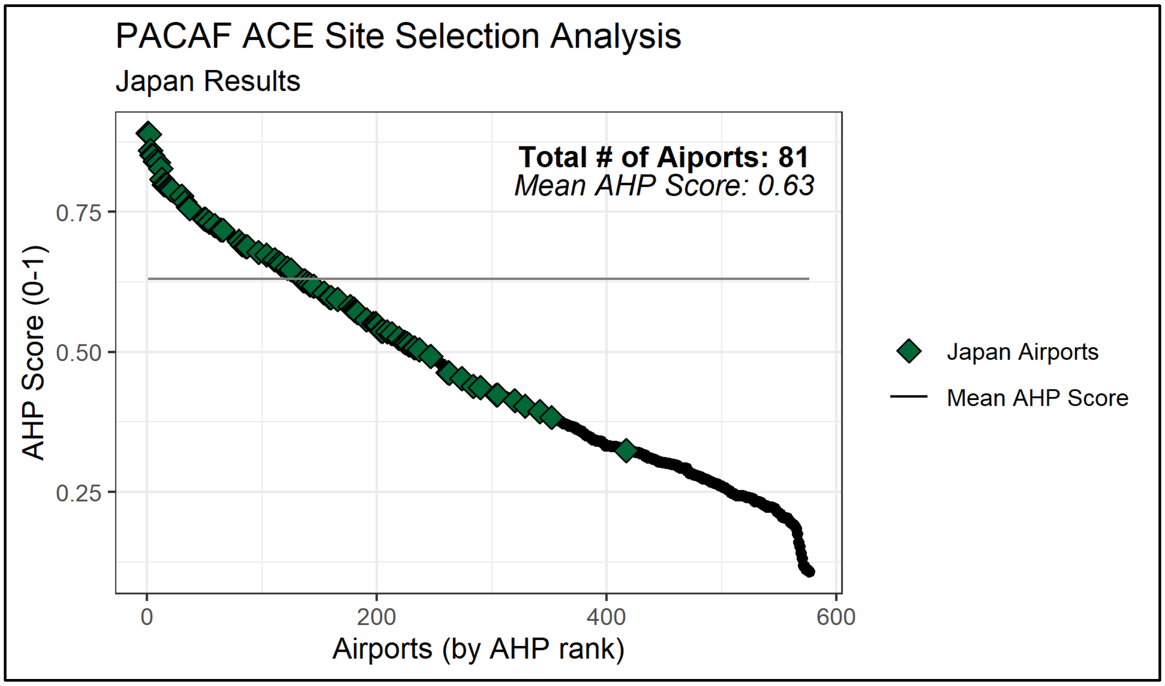
Alternate UV and AHP Weight Results



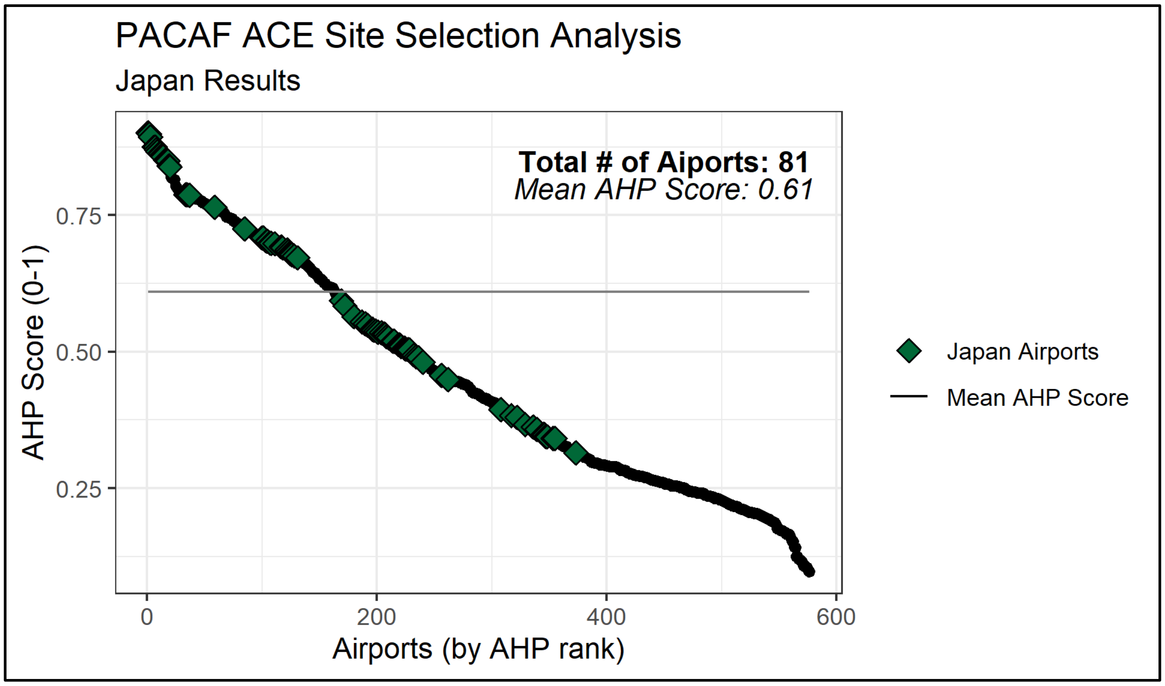
Variable Sensitivity – Primary UV and AHP Weights



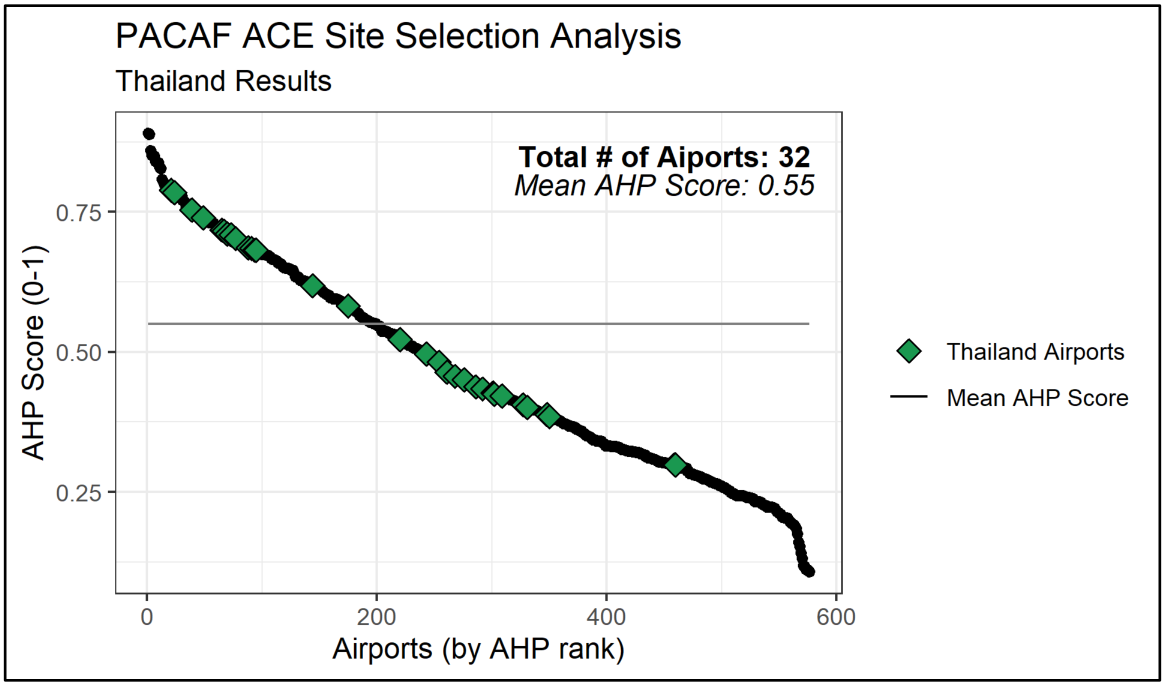
Variable Sensitivity – Alternate UV and AHP Weights



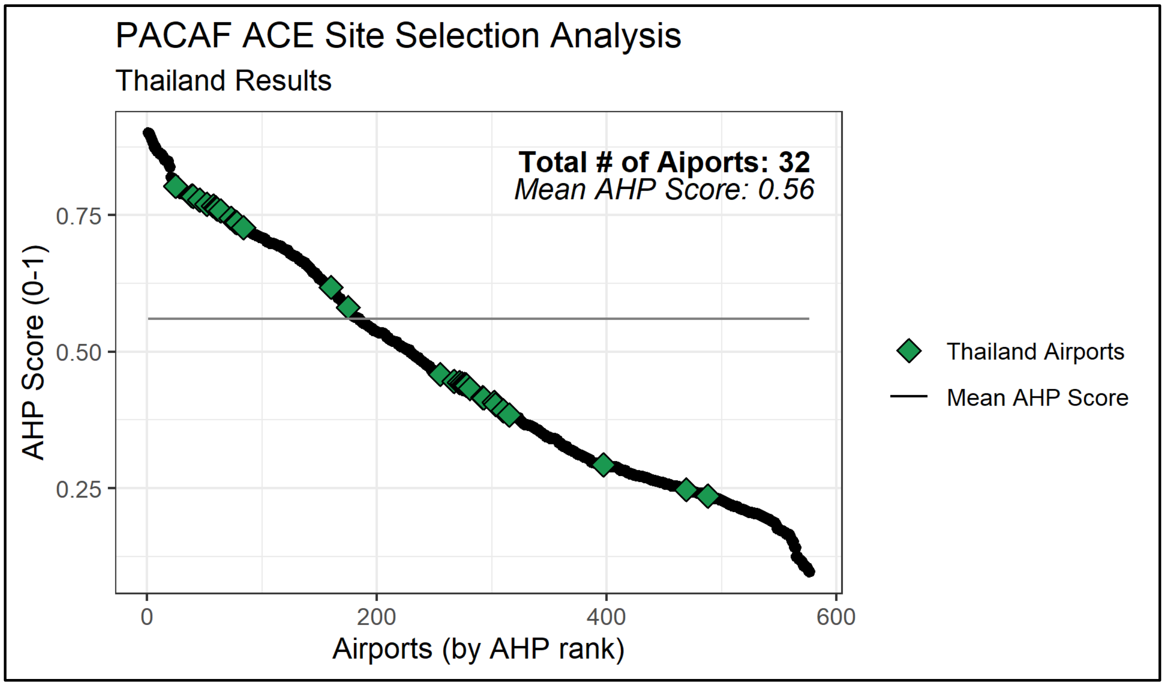
Japan Results – Primary UV and AHP Weights



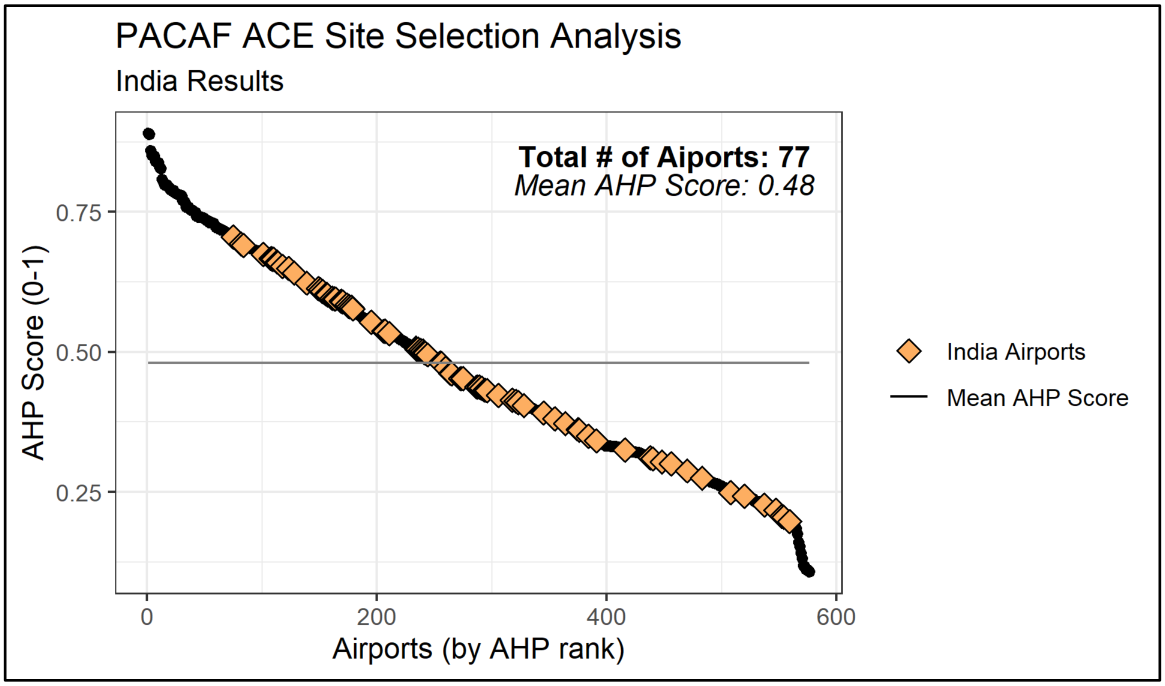
Japan Results – Alternate UV and AHP Weights



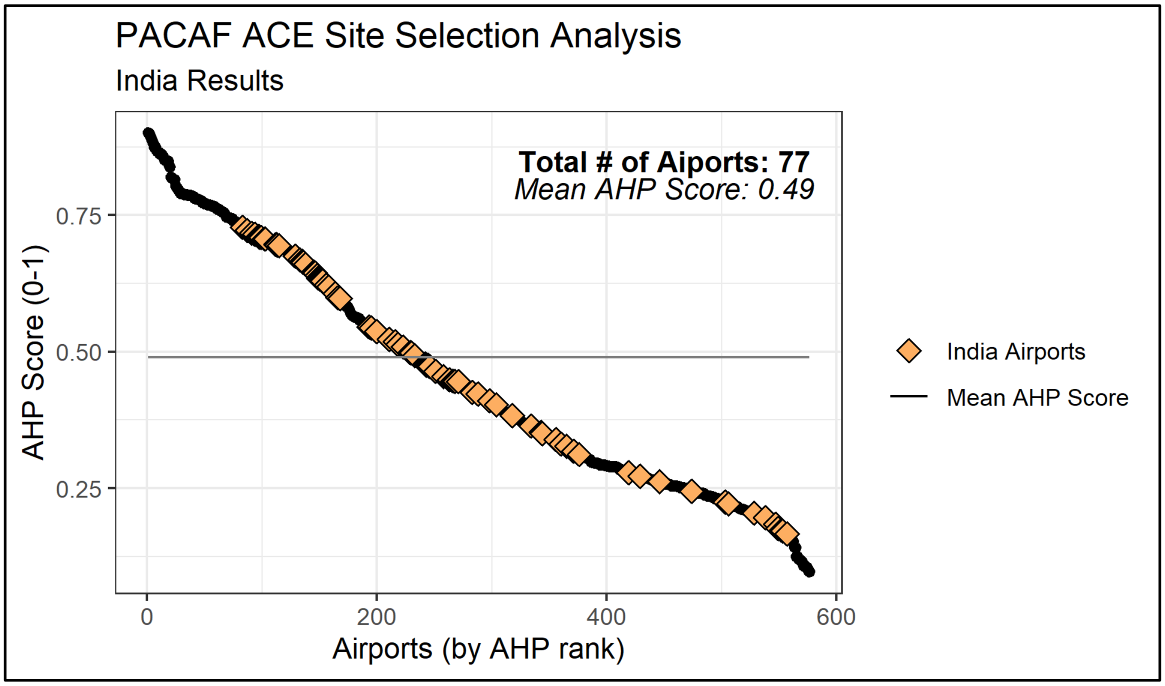
Thailand Results – Primary UV and AHP Weights



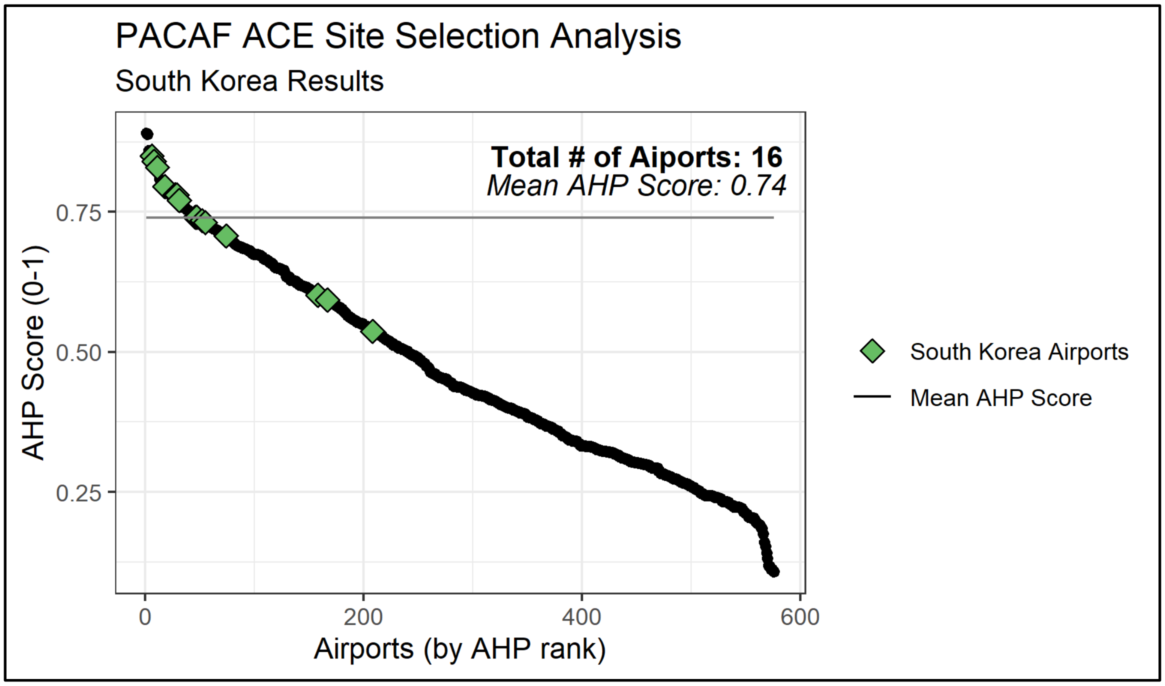
Thailand Results – Alternate UV and AHP Weights



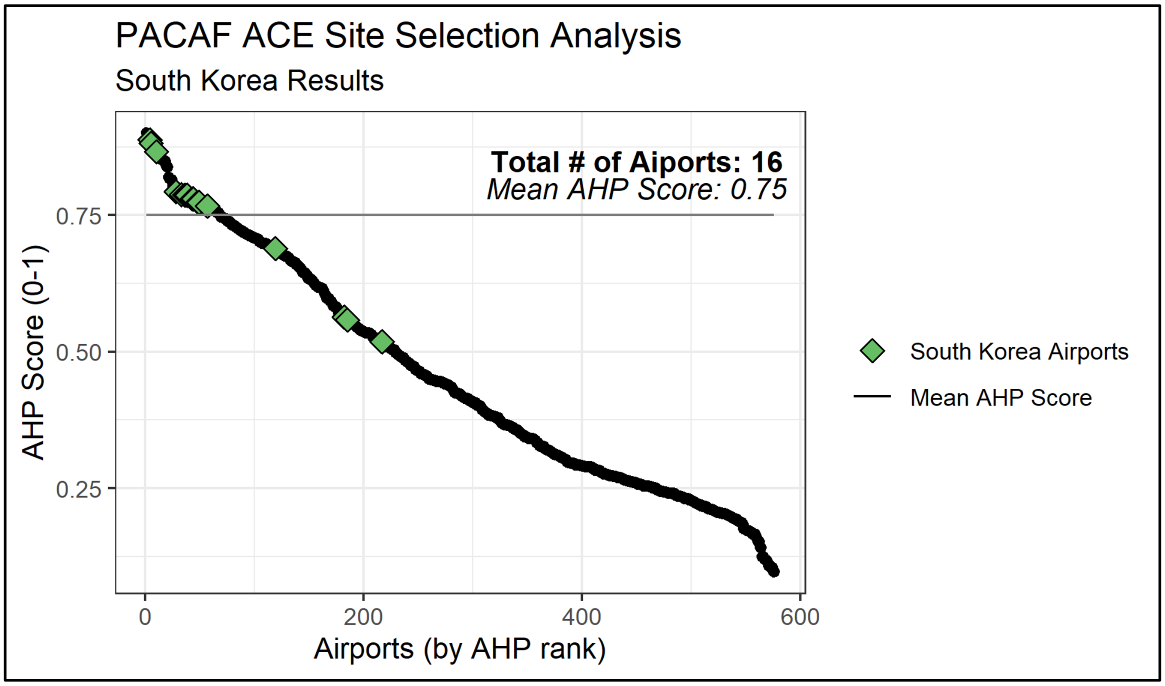
India Results – Primary UV and AHP Weights



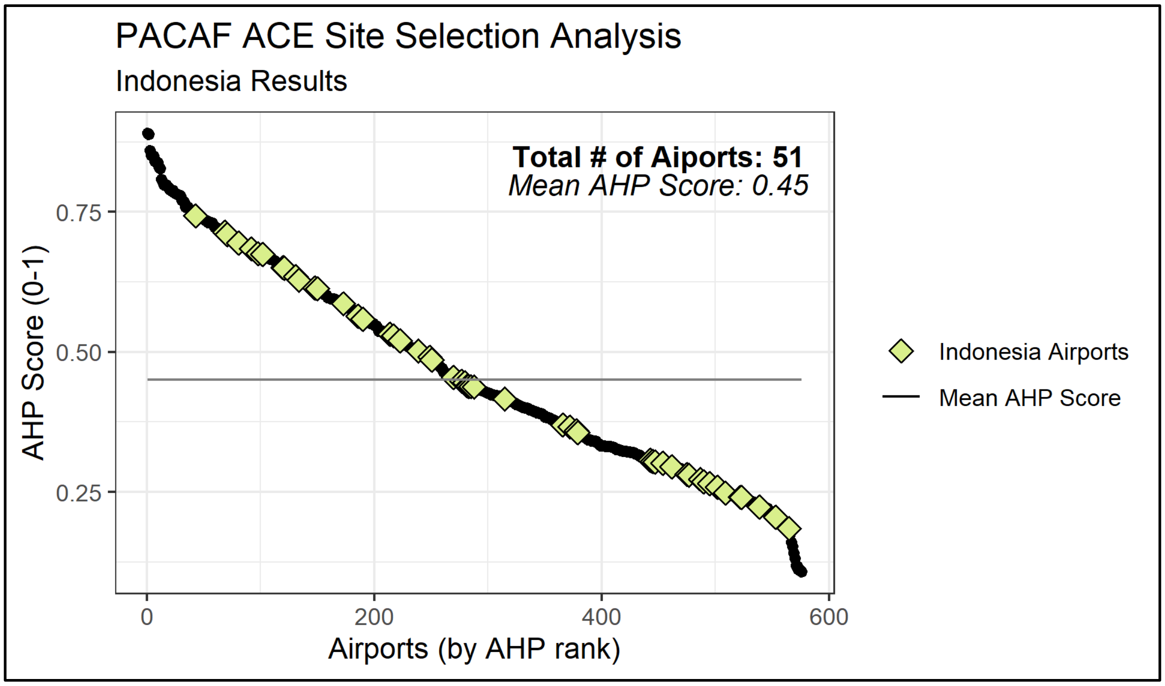
India Results – Alternate UV and AHP Weights



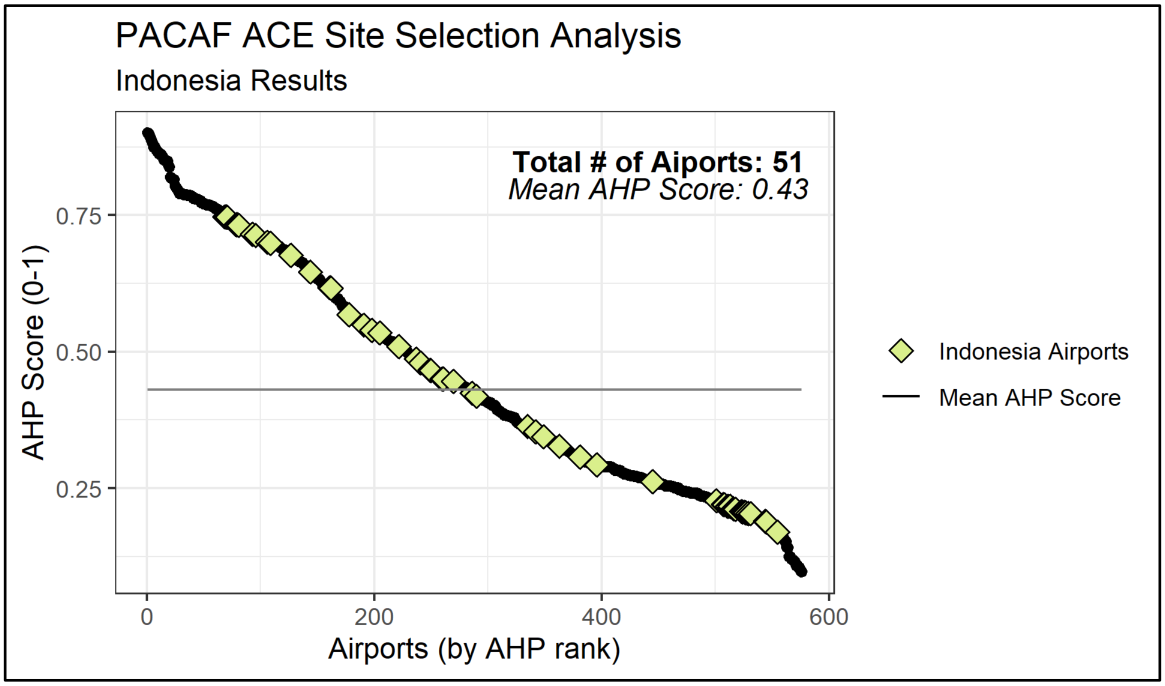
South Korea Results – Primary UV and AHP Weights



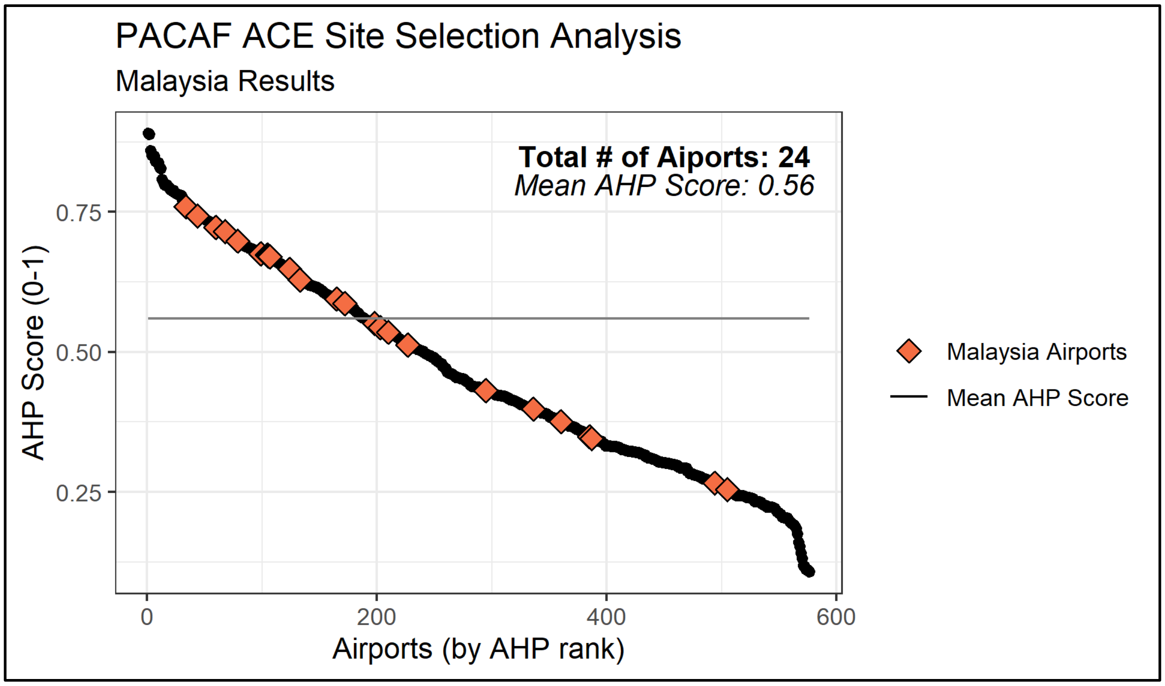
South Korea Results – Alternate UV and AHP Weights



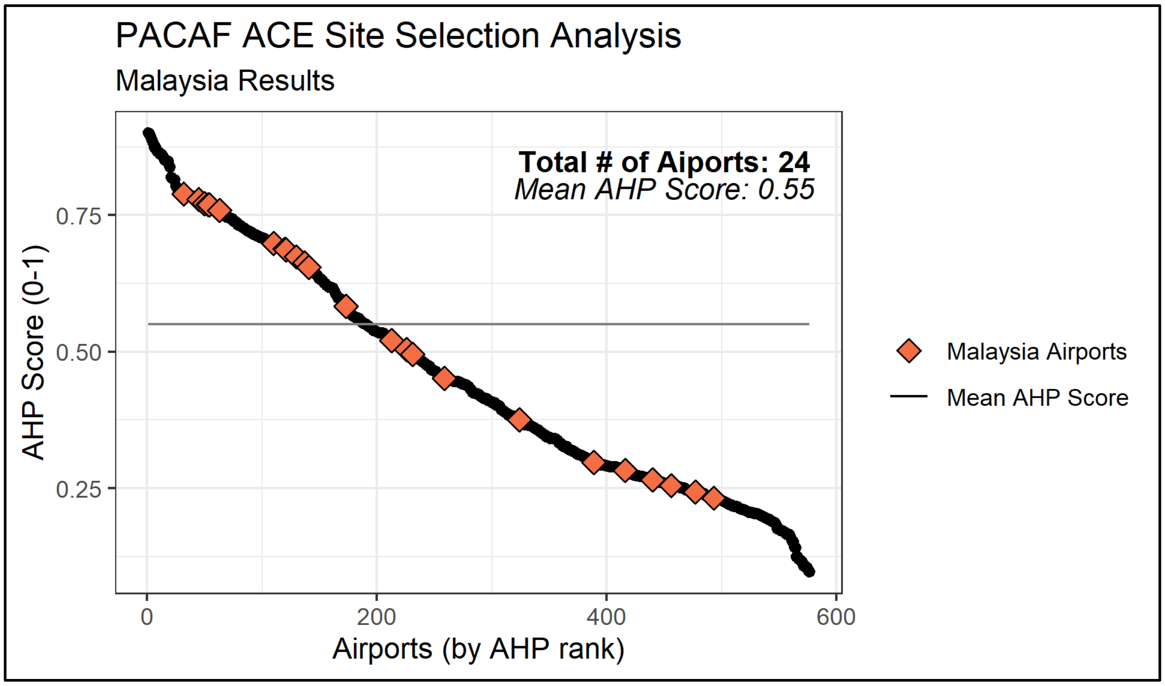
Indonesia Results – Primary UV and AHP Weights



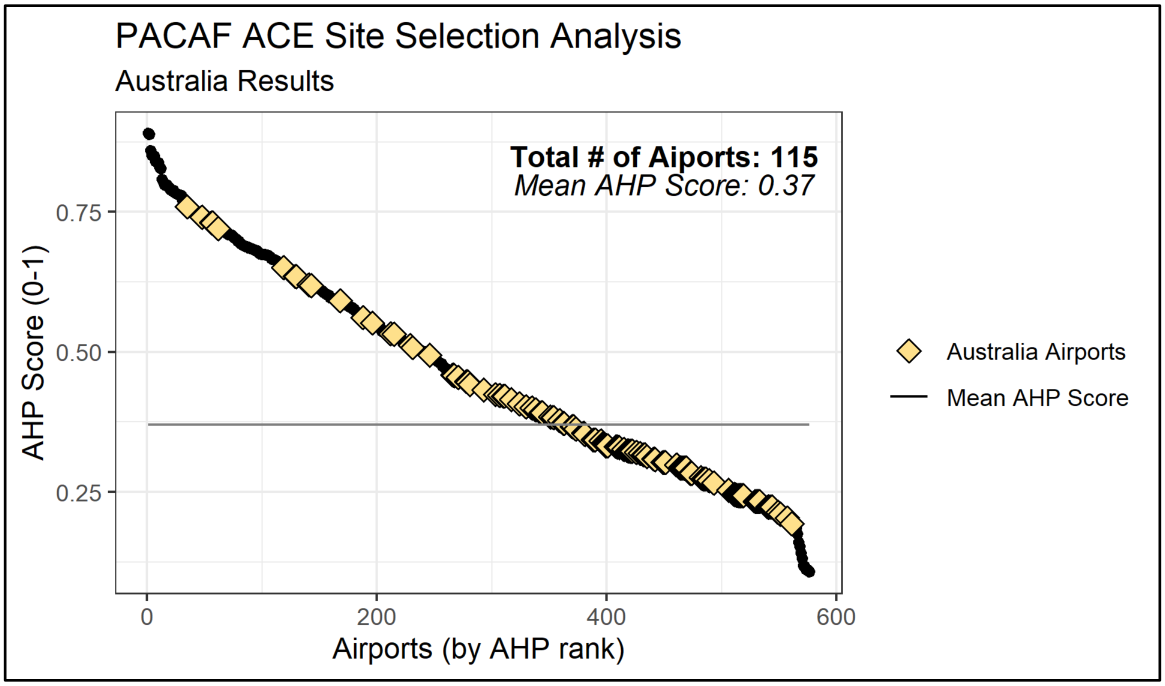
Indonesia Results – Alternate UV and AHP Weights



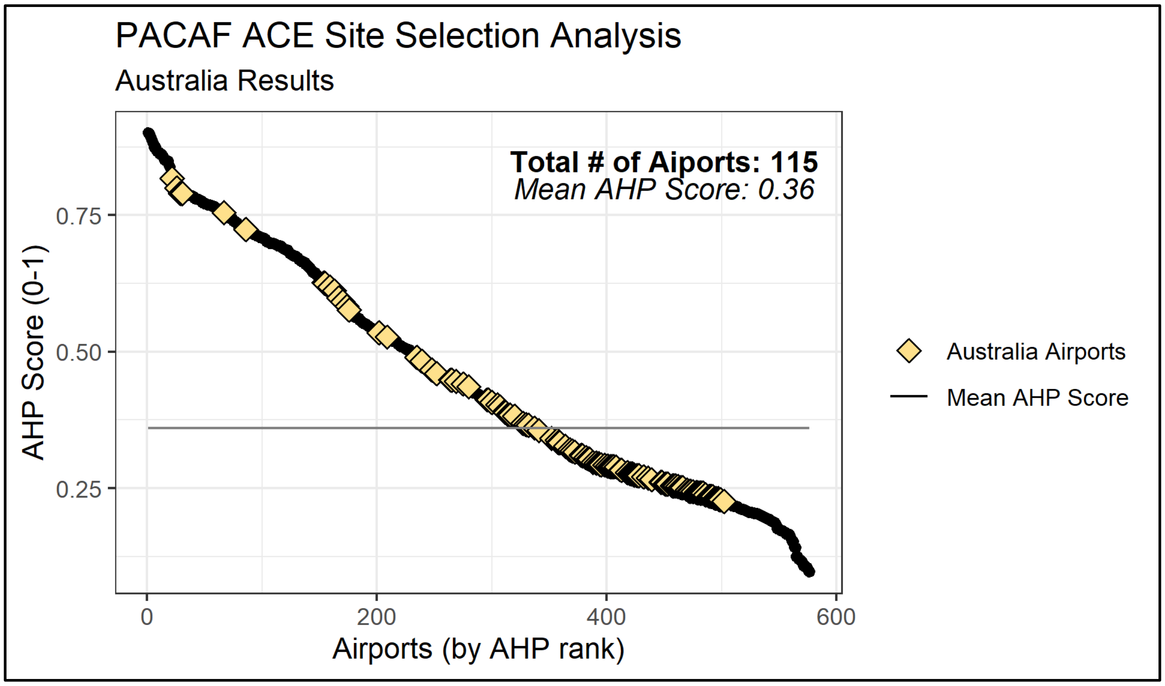
Malaysia Results – Primary UV and AHP Weights



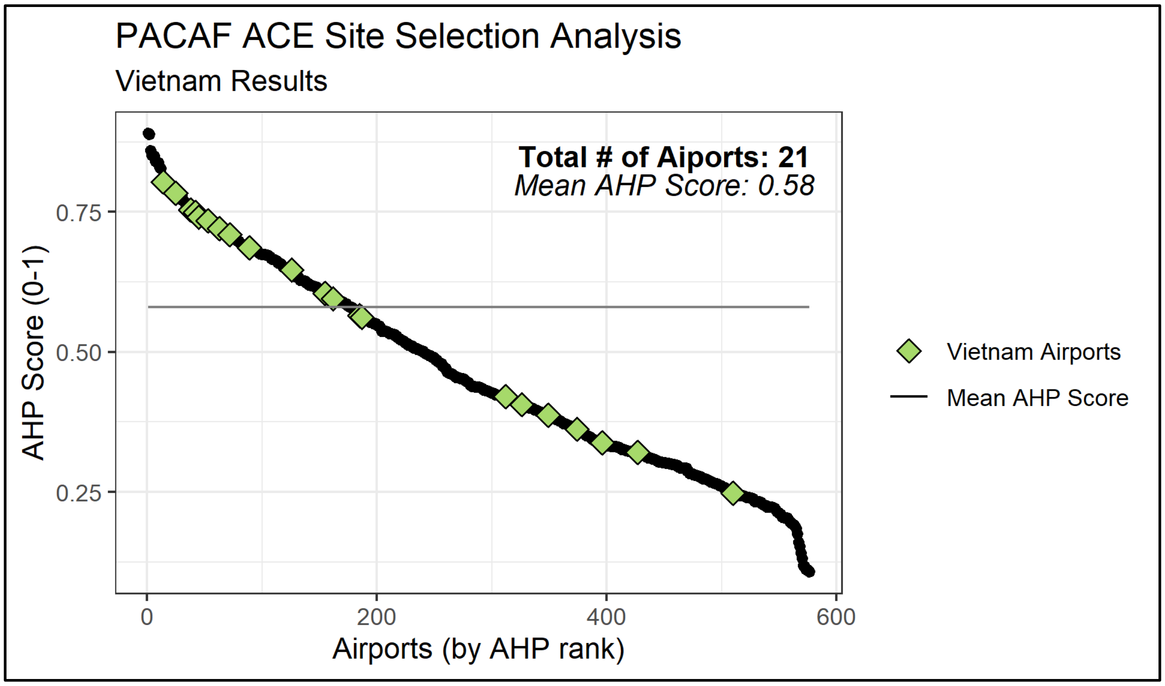
Malaysia Results – Alternate UV and AHP Weights



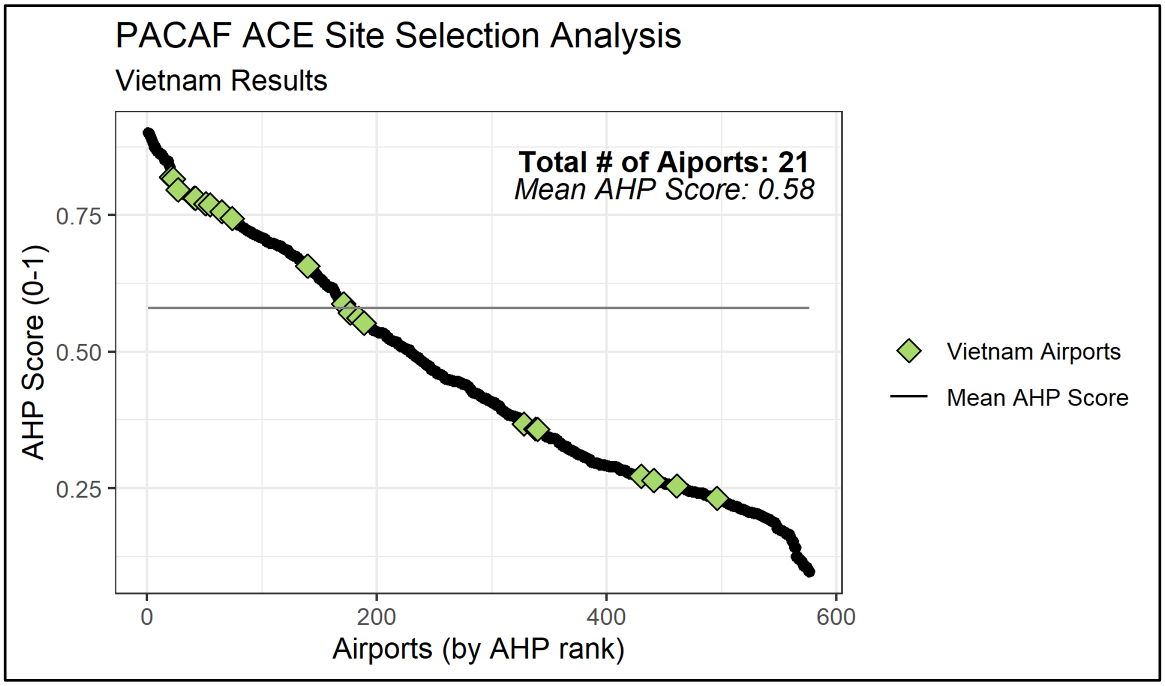
Australia Results – Primary UV and AHP Weights



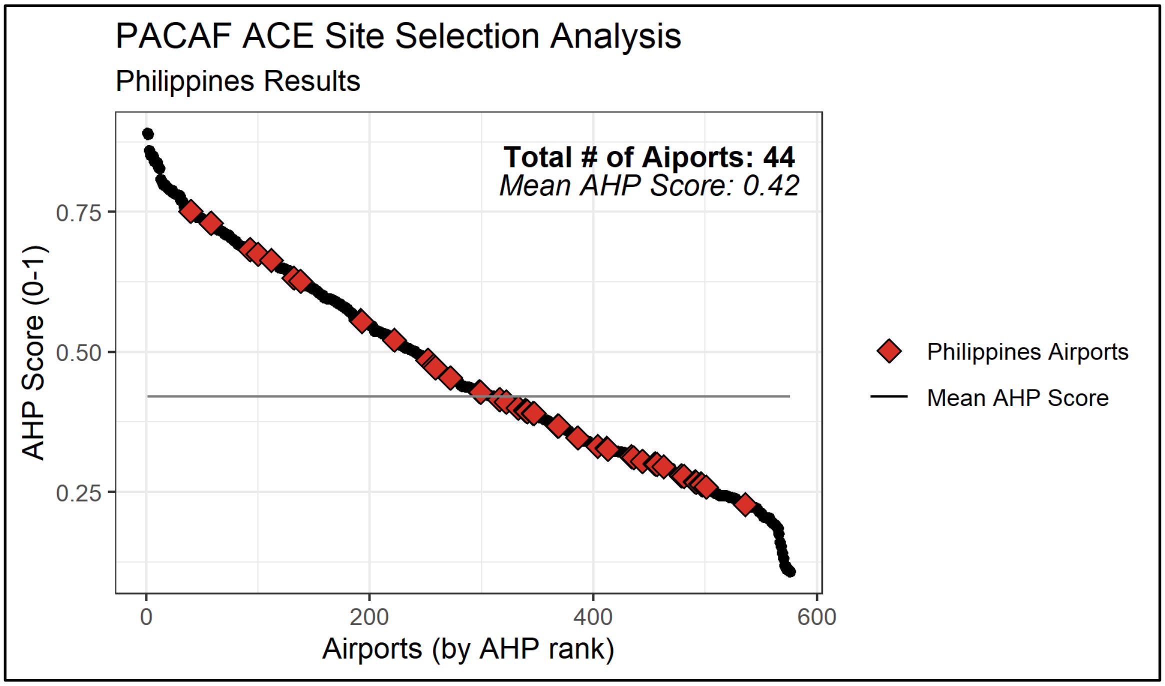
Australia Results – Alternate UV and AHP Weights



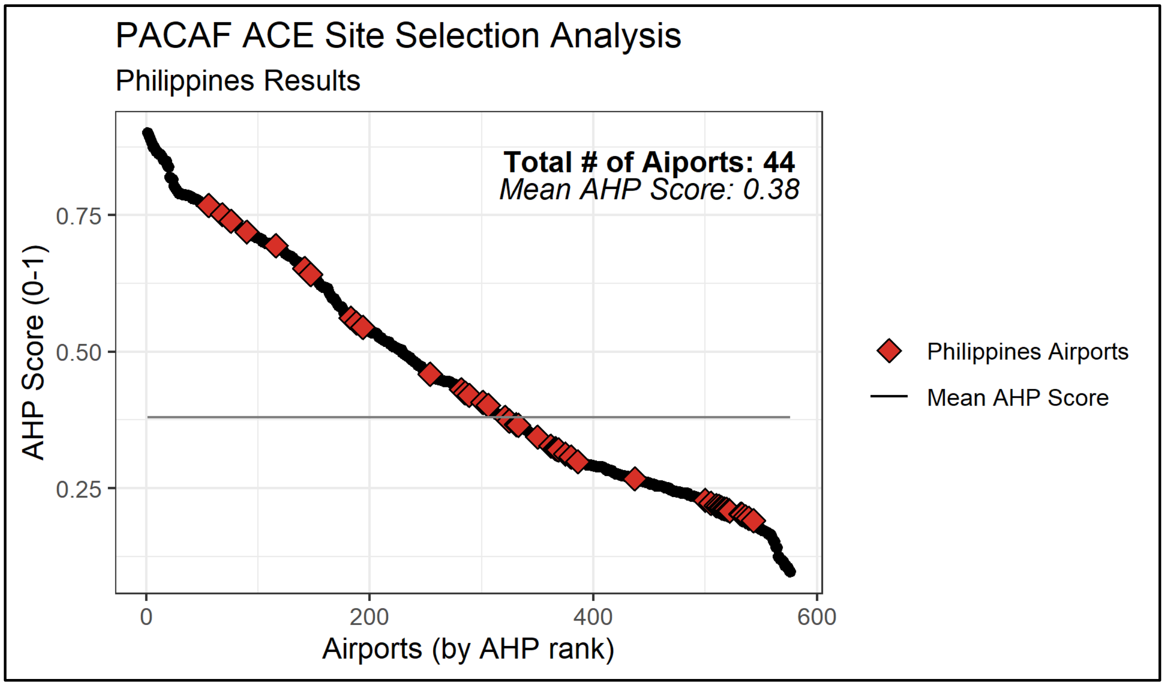
Vietnam Results – Primary UV and AHP Weights



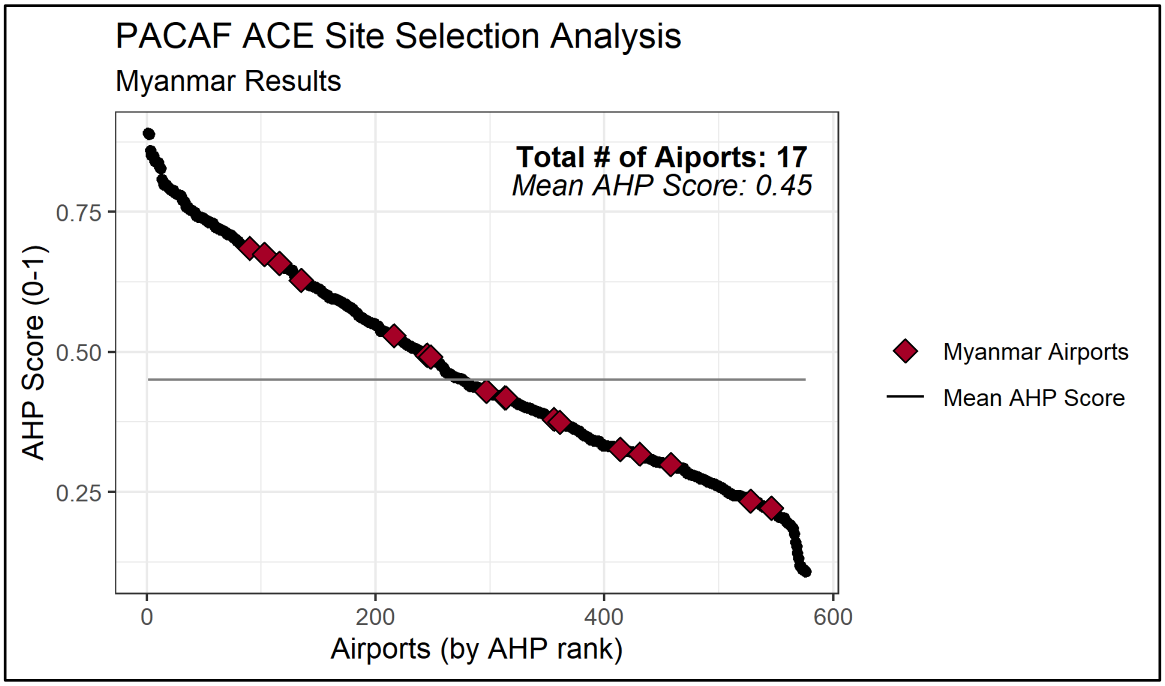
Vietnam Results – Alternate UV and AHP Weights



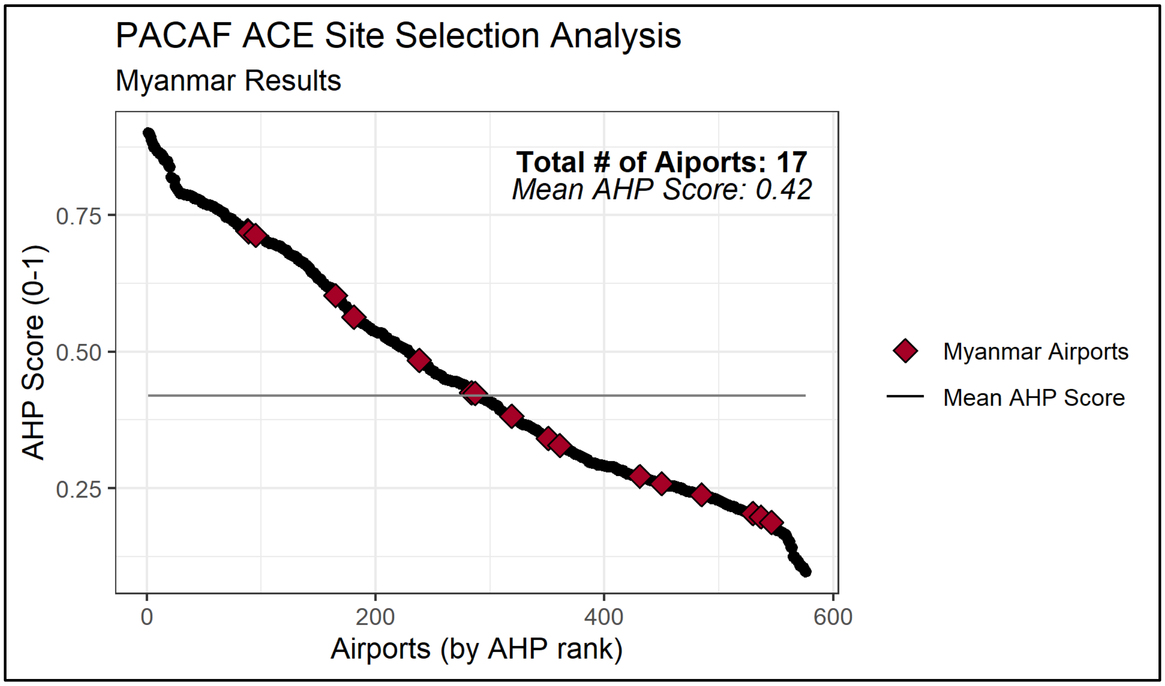
Philippines Results – Primary UV and AHP Weights



Philippines Results – Alternate UV and AHP Weights



Myanmar Results – Primary UV and AHP Weights



Myanmar Results – Alternate UV and AHP Weights

Appendix B. Sensitivity Analysis

Appendix B includes background information on the UV's, AHP weights, and AHP calculations used to evaluate ACE-SSF's performance and sensitivity. When compared to the corresponding tables in Chapter III, the following tables illustrate the changes made between the primary and alternate analysis scenarios. Despite these targeted changes, it is crucial to note that the framework enables planners to specify these input parameters, which can vary from one decision-maker to another. Furthermore, these elements allow planners to prioritize decisions variables based on their criticality to the mission.

Variable	Utility Function
Runway Length	$x_1 = runway\ length\ (feet) \xrightarrow{yields} u_1 = runway\ length\ (utile)$ $If\ x_1 \geq 10{,}000', u_1 = 1$ $If\ 5{,}000' \geq x_1 > 10{,}000', u_1 = 0.0002l - 1$ $If\ x_1 < 5{,}000', u_1 = 0$
Fragile States Index Score	$x_2 = Fragile\ States\ Index\ Score \xrightarrow{yields} u_2 = Fragile\ States\ Index\ Score\ (utile)$ $u_2 = 1 - \frac{x_2}{100}$
Distance from China	$x_3 = Sortie\ Distance\ (kilometers) \xrightarrow{yields} u_3 = sortie\ distance\ (utile)$ $If\ x_3 \geq 6{,}000km, u_3 = 1$ $If\ 2{,}000km \geq x_3 > 6{,}000km, u_3 = 1$ $If\ x_3 < 2{,}000km, u_3 = 0$
Distance to Construction Equipment Dealer	$x_4 = Construction\ Equipment\ Dealer\ (kilometers) \xrightarrow{yields} u_4 = Construction\ Equipment\ Dealer\ (utile)$ $If\ x_4 \geq 1{,}000km, u_4 = 0$ $If\ 700km \geq x_4 > 1{,}000km, u_4 = 0.1$ $If\ 400km \geq x_4 > 700km, u_4 = 0.2$ $If\ 200km \geq x_4 > 400km, u_4 = 0.3$ $If\ 100km \geq x_4 > 200km, u_4 = 0.4$ $If\ 75km \geq x_4 > 100km, u_4 = 0.5$ $If\ 50km \geq x_4 > 75km, u_4 = 0.6$ $If\ 25km \geq x_4 > 50km, u_4 = 0.7$ $If\ 10km \geq x_4 > 25km, u_4 = 0.8$ $If\ 5km \geq x_4 > 10km, u_4 = 0.9$ $If\ x_4 < 5km, u_4 = 1$
Distance to Water Source	$x_5 = Water\ Source\ (kilometers) \xrightarrow{yields} u_5 = Water\ Source\ (utile)$ $If\ x_5 \geq 100km, u_5 = 0$ $If\ 50km \geq x_5 > 100km, u_5 = 0.1$ $If\ 25km \geq x_5 > 50km, u_5 = 0.2$ $If\ 10km \geq x_5 > 25km, u_5 = 0.3$ $If\ 7.5km \geq x_5 > 10km, u_5 = 0.4$ $If\ 5.0km \geq x_5 > 7.5km, u_5 = 0.5$ $If\ 3.0km \geq x_5 > 5.0km, u_5 = 0.6$ $If\ 2.0km \geq x_5 > 3.0km, u_5 = 0.7$ $If\ 1.0km \geq x_5 > 2.0km, u_5 = 0.8$ $If\ 0.5km \geq x_5 > 1.0km, u_5 = 0.9$ $If\ x_5 < 0.5km, u_5 = 1$

Decision Variable Utility Functions (Alternate Analysis)

	Runway Length	Fragile States Index	Sortie Distance	Construction Equipment	Water Sources	Vector [V]	Weight [W]
Runway Length	1	3	5	7	9	3.94	0.51 **(51%)**
Fragile States Index	$\frac{1}{3}$	1	3	5	7	2.04	0.26 **(26%)**
Sortie Distance	$\frac{1}{5}$	$\frac{1}{3}$	1	3	5	1.00	0.13 **(13%)**
Construction Equipment	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	1	3	0.49	0.06 **(6%)**
Water Sources	$\frac{1}{9}$	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	1	0.25	0.03 **(3%)**
						Total 7.72	Total 1

Pairwise Comparison Matrix (Alternate Analysis)

	Runway Length	Fragile States Index	Sortie Distance	Construction Equipment	Water Sources	[W]	[W]’	[W]”
Runway Length	1	3	5	7	9	0.51	2.96	5.27
Fragile States Index	$\frac{1}{3}$	1	3	5	7	0.26	1.37	5.20
Sortie Distance	$\frac{1}{5}$	$\frac{1}{3}$	1	3	5	0.13	0.68	5.21
Construction Equipment	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	1	3	0.06	0.33	5.21
Water Sources	$\frac{1}{9}$	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$	1	0.03	0.17	5.30
						Total 1		Total (λ) 26.19

Eigenvalue Calculation (Alternate Analysis)

Number of Criteria (n)	5
Maximum Eigenvalue (λ)	26.19
Random Consistency Index (RI)	1.12
Consistency Ratio	0.053

Consistency Ratio Calculation (Alternate Analysis)

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14. ABSTRACT

The United States Air Force's (USAF) Agile Combat Employment (ACE) strategy relies on host country access and underlying local infrastructure to facilitate airpower. However, numerous factors, including peer-to-peer threats, complex geopolitics, and intricate supply chain management, often complicate site access and thwart site selection decisions. When shaping the battlespace for future conflict, strategists and planners face the difficult task of identifying optimal locations to conduct adaptive basing operations given these complicating factors. Multi-Criteria Decision Analysis (MCDA) can help strategists appropriately account for competing objectives and maintain a competitive advantage with theater adversaries. This thesis presents an MCDA model that evaluates ACE site selection alternatives within the Pacific Air Forces (PACAF) Area of Responsibility (AOR) using a geographic information system (GIS) enabled analytic hierarchy process (AHP) methodology and open-source data pertinent to the theater. The model analyzed 576 airports in 26 countries and compared alternative locations based on runway length, the Fragile States Index (FSI), distance to the People's Republic of China, construction equipment dealers, and natural water resources. The results demonstrate the framework's efficacy and utility in identifying existing airports best suited for the deployment of USAF combat and support assets. The methodology is expected to provide invaluable support to Combatant Commanders as they optimize ACE infrastructure, preserve resources, and minimize risk to United States Armed Forces.

15. SUBJECT TERMS
Agile Combat Employment, Site Selection, Multi-Criteria Decision Analysis, Analytic Hierarchy Process, Geographic Information System, Geospatial Analysis

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