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Long-Term Asset Prioritization to Support District Planning

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LONG-TERM ASSET PRIORITIZATION TO SUPPORT DISTRICT PLANNING

THESIS

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Abstract

The United States Air Force (USAF) relies on its installations to project military power across the globe. However, due to the deferred infrastructure maintenance and recapitalization backlog of $33 billion as of 2019 (Wilson & Goldfein, 2019), it is more critical than ever for base-level community planners to focus their attention to the projects that will achieve each installation's long-term goals. The recent incorporation of asset management principles into the USAF District Planning Process allows a unique opportunity to improve the existing scoring model for a holistic look at what matters to enterprise leaders and community planners making the plans at the installations. This thesis offers a new model combining asset management and community planning principles. I use Multi-Attribute Utility Theory (MAUT) and the Analytic Hierarchy Process (AHP) to define the scoring for the criteria through utility curves, and the weights for the criteria, through an expert elicitation study of pairwise comparisons. The model was tested in a case study of ten projects at Hill AFB, assessing the projects using the six criteria of building condition, building importance, interior capacity, exterior capacity, interior configuration, and exterior configuration. The results show that facilities in the ideal condition range for investment that are sited poorly as to increase infrastructure maintenance liabilities, rise higher in the scoring to alert the planner to consider action. The methodologies provided in this thesis are expected to help shape the next iteration of guidance in the USAF District Planning Process, enabling the enterprise to reduce the infrastructure maintenance and recapitalization backlog burden on its installations.

For my Parents, who walked this path before me, and provide unending love, support and guidance, and my Siblings for their friendship.

"With faith, perseverance, hope, and God, all things are possible if you are surrounded by good people."

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I. Introduction

Background

The United States Air Force (USAF) views its installations as power projection platforms to perform critical worldwide missions (LeMay Center for Doctrine). These bases require extensive long-term planning to sustain their capabilities for the future. 10 U.S. Code §2864 requires the Department of Defense (DoD) to create master plans for every military installation, and for the USAF, this is accomplished by the Installation Development Plan (IDP). IDPs used to be comprised of smaller Area Development Plans (ADP), but were replaced by District Plans in 2020 to ensure planning actions account for the entire land area of the base. Previously, ADPs focused on small areas of each installation, typically similar in facility type or mission set; these routinely left sections of the installations unplanned. According to the *District Planning Playbook* (AFCEC, 2022), "District Plans allow for detailed planning and ensures all investments further the long-range development goals of the installation." These district plans establish a systematic framework for informing decision-making on the physical development of military bases. A common problem, however, is inadequate funding to achieve the projects included in the plans.

As of 2019, per the USAF Infrastructure Investment Strategy (I2S) (Wilson & Goldfein, 2019), the Department of the Air Force (DAF) has a $33 billion backlog of deferred infrastructure maintenance and recapitalization across its $263 billion portfolio. The I2S also explains that "increasing funding for infrastructure will not work unless we also change how we are managing infrastructure investments," showing that lack of funds is only part of the problem. The strategies continue in noting "the Air Force leadership is committed to this data driven infrastructure investment strategy," so a focus in this research is using the data that is already being collected to benefit the long-term investments through planning. Deferred maintenance is not limited to the US military, or even government infrastructure portfolios; large-sized institutions such as college campuses also struggle with strategizing and prioritizing investments to minimize premature facility degradation (Yoon et al., 2021). This problem requires identifying a methodology for prioritizing long-term development requirements using asset management and community planning principles.

AFCEC developed the District Planning Process and a model (the objective function) to decide on courses of action (COAs) to have base-level community planners focus on further developing to include in these plans. This model was created using some components from the Navy's 2008 Project Scoring Model that was developed to decide which projects, Navy-wide, receive centralized funding. However, when adapted to the Air Force District Planning, problems with the model arose.

Problem Statement

The Air Force Civil Engineer Center (AFCEC) has created an objective mathematical function to produce project scores in order to decide district planning courses of action. The previously developed objective function did not return the expected results, however, and AFCEC's subject matter experts (SME) realized that the model "did not lend itself to applying the art of planning" (Vandeveer, 2023). This thesis aims to help solve the problems associated with the original model through a new model which determines a relative order of priority for known deficiencies and future projects.

This project will use the analytic hierarchy process (AHP) to develop weights for my six criteria, use multi-attribute utility theory (MAUT) to adapt the original AFCEC-developed criteria to new criteria, and use a sensitivity analysis to observe ordered project results at differing criteria weights. This will address the current issues with criteria existing on differing scales, and the current model results not meeting SME expectations. Finally, I use a case study to assess the output differences between the existing and proposed models.

Research Objectives

The first objective in this research is to investigate the current frameworks, guidelines, and processes that exist around the two academic disciplines of asset management and community planning. A literature review of these areas determined the elements that were missing in the original model from both the asset management and community planning perspectives. I ask the following research questions:

1. What are the appropriate criteria to use in the model's function?
2. Do the selected criteria quantify what needs to be measured?
3. Does the model produce acceptable outcomes?

II. Literature Review

Chapter Overview

This chapter provides a summary of the existing knowledge surrounding the two main fields where this research intersects: asset management and community planning. The first section, focusing on asset management, examines the USAF's current asset management practices and shortcomings, and discusses how the private sector views and aims to apply asset management to tackle and prevent the problems stemming from deferred maintenance. A subsection explores the *BUILDER Sustainment Management System* (SMS) that the DoD uses for facility assessments and projected degradation forecasting, and investigates the limitations with this system. The second section centers on community planning, focusing first on the principle of urban sprawl. I dive into the United States' sprawling development practices since the 1950s, the adoption of these sprawling patterns on military installations, and discuss the more recent principles of New Urbanism that are emerging in DoD and Air Force planning guidance.

Asset Management

The USAF has six Civil Engineering (CE) "Truths" that describe the fundamental purpose, organization, and practices of engineers. Of these, the second "truth" states that "asset management principles drive how we mitigate risk to installation health" (USAF Doctrine 33-4). The International Organization for Standardization (ISO) defines assets as "an item, thing or entity that has potential or actual value to an organization," and asset management as the process that "enables an organization to realize value from assets in the achievement of its organizational objectives" (International Organization for

Standardization, 2014). The USAF, as of 2019, has a $263 billion asset portfolio with a $33 billion backlog of deferred infrastructure maintenance and recapitalization (Wilson & Goldfein, 2019).

Yoon (2021) discusses the problem of deferred maintenance, showing that it is not limited to the federal government's vast infrastructure networks or the DoD portfolio of military bases; deferred maintenance also impacts large-sized institutions (public or private) that have struggled with investment strategies to minimize premature facility degradation. Yoon (2021) proposed a mitigation strategy for deferred maintenance for a campus-sized institution as a 5-step process: (1) building selection, (2) system evaluation, (3) deferred maintenance component evaluation, (4) deferred maintenance subsystem model evaluation, and (5) total subsystem evaluation. Step 1, Building selection, was accomplished using condition index targets, then step 2 converted the facility's condition value to a system reliability metric. This key performance factor in Yoon's research of reliability allows the facility condition to be evaluated at different system levels, which can drive investment decisions. Step 3 used life-cycle analysis to find the reliability of components with deferred maintenance, then step 4 combined the component reliabilities into a subsystem evaluation using a fault tree analysis. Finally, step 5 rolled up the analyses of the subsystems into a "total subsystem reliability assessment […] to estimate total subsystem reliability" (Yoon et al., 2021). When trying to catch up with deferred maintenance, the USAF and DoD focus less on the reliability of a facility, which is a time- and information-intensive analysis for just one facility, let alone the entire enterprise portfolio (Hammond, 2021), and not on getting ahead of a problem (beyond scheduled preventative maintenance), and focus more on a condition-based, fix-it-as-itfails attitude, which has facilitated the backlog along with aging infrastructure and lack of funding (Sloan et al., 2021). Tam (2008) also proposed a framework for optimizing maintenance investment decisions, where cost and reliability, as a function of cost, are the main factors in determining risk of a given maintenance plan. This is important to note, as a lot of the existing research exists around risk-based models, while the USAF has moved away from funding projects based on risk. My research, additionally, is not looking specifically at maintenance plans, but long-term construction objectives that aim to meet an installation's operational goals. This does need to be looked at with the maintenance backlog in mind, as the dollar value grows, and the annual funding for new projects remains unknown.

Weck (2011) expanded on practices that should be considered when implementing asset management, in something he calls "the -ilities." His research shows that there is value beyond focusing on only risk or reliability when implementing asset management strategies; quality, maintainability, safety, flexibility impact all systems in a facility beyond whether it works or has failed. These are some objectives that should be implemented in planning decisions, especially when noting that most facilities are kept past their intended life cycle (quality, maintainability, safety), and it's likely facilities will have several uses and missions throughout their lifetime (flexibility toward space use).

A large part of how funding for future projects used to be decided was based on risk; this was in at least the last five years until the new FY24-27 Business Rules direction change in 2022. In the Air Force Comprehensive Asset Management Plan (AFCAMP) centralized civil engineer disbursement, funding was decided mostly on a combination of the facility's condition index (BCI), denoted by the probability of failure

(PoF), and the facility's relative importance, denoted by the consequence of failure (CoF), which is based on the facility's Mission Dependency Index (MDI). While this method aims to enable the 'most important' facilities to receive funding, it leaves out several important factors, and may be better used in another type of risk-based method. Rowe (2011) discusses several possible scoring models, and tests them on a water pipeline system, which could be extrapolated to several other network infrastructure systems on a military installation. His sensitivity analysis tested the risk scoring results based on the ranges of the individual asset scores and how the scoring integration process affects asset prioritization. Rowe showed the benefits of using a multi-attribute model, and although they used a proprietary system, MAUT and AHP demonstrated promise as a method to rank project importance through more than just BCI and MDI.

Schraven (2011), discusses several challenges public agencies face when trying to implement asset management principles, including effective decision-making when deciding infrastructure objectives, and managing priorities with several stakeholders all having differing interests. This is especially relevant to USAF installations, as these struggles are faced consistently, even with the MDI system, and now Tactical MDI in place assigning relative importance of a facility or infrastructure system to that base.

The Navy Shore Infrastructure Investment Support Strategy (Streicher, 2008) was the basis for AFCEC's initial objective function, which this research aims to improve, and the report proposed many criteria to create a model to decide which projects would be funded on a yearly basis. While the model created by AFCEC is not intended to produce an ordered ranking of which projects should be funded Air-Force wide, the methodology and results show which criterion have a potential to be utilized in the AHP as criteria needing weights. The initial AFCEC model only used MDI, configuration, capacity, and condition. My research proposes two additional criteria of exterior configuration and exterior capacity, which brings the number of criteria into the "magic number" range of 5 +/- 2 (Lee, 2015) for models utilizing the MAUT.

Condition-based assessments using BUILDER SMS.

Goals and Capabilities.

The *SMS Playbook* (AFCEC, 2021) lists sustainment management systems like BUILDER as a way to provide enterprise-wide asset visibility of condition and geographic data, enabling higher levels of CE leadership to project long-term built infrastructure requirements. These systems aim to enable proactive approaches to asset management with a degradation model of each component to model future scenarios using a combination of current condition and component age. These models should "help leadership, civil engineers, technicians, and Activity Management Plan (AMP) Managers and Sub-AMP Managers influence when, where, and how to best maintain the AF's built infrastructure" (AFCEC, 2021). According to the US Army Corps of Engineers,

> The process starts with the automated download of real property data, and then more detailed system inventory is modeled and/or collected which identifies components and their key life cycle attributes such as the age and material. From this inventory, Condition Index (CI) measures for each component are predicted based on its expected stage in the life cycle. Objective and repeatable inspections can then be performed on various components to verify their condition with respect to the expected life-cycle deterioration. The level of detail and frequency of these inspections are not fixed like other processes; they are dependent on knowledge of component criticality, the expected and measured condition and rate of deterioration, and remaining maintenance and service life. This 'knowledge-based' inspection focuses attention to the most critical components at the time. In addition to these condition assessments, functionality assessments can be performed to evaluate user requirement changes, compliance and obsolescence issues (*BUILDER™ Sustainment Management System*).

Most initial data in BUILDER was input to the system using a contractor to get an initial baseline of component, system, and overall building condition. This data includes the installation date, manufacturer and part number/type, and other details of the component (cost, size, etc.). Further data is input and validated using condition assessment teams (CAT) on a semi-regular basis. Data must be updated at a minimum every five years and would typically be validated if the component/system/facility is submitted in a project competing for centralized funds. These projects require scoring worksheets, which contain a snapshot in time of BUILDER data to provide the condition score. Condition is assessed using a direct rating method, on a Green/Amber/Red scale, which BUILDER in turn gives a numeric value (0-100) in that color's range associated with the +/- rating with the color, which degrades with age between assessments. Distress surveys can also be used, which give a direct value of 0-100 to an asset and are more accurate, but they are more intensive and time consuming. AFCEC recommends the direct rating, which is typically used. The data is structured using ASTM International UNIFORMAT II classification system, and there are seven required inventory systems:

- B20: Exterior
- B30: Roofing
- C10: Interior Construction
- D20: Plumbing
- D30: Heating, Ventilation, and Air Conditioning (HVAC)
- D40: Fire
- D50: Electrical

The installation assets are broken into buildings (BUILDER) comprised of systems, such as the seven required listed above. Systems are further broken down into components, and components consist of sections. This can be seen in Figure 1, with the metric type that's used for that level. This structure allows condition data to be entered and associated with each component which has an associated cost, and rolls those values up for a cost-weighted average condition for each level above – system, building, etc.

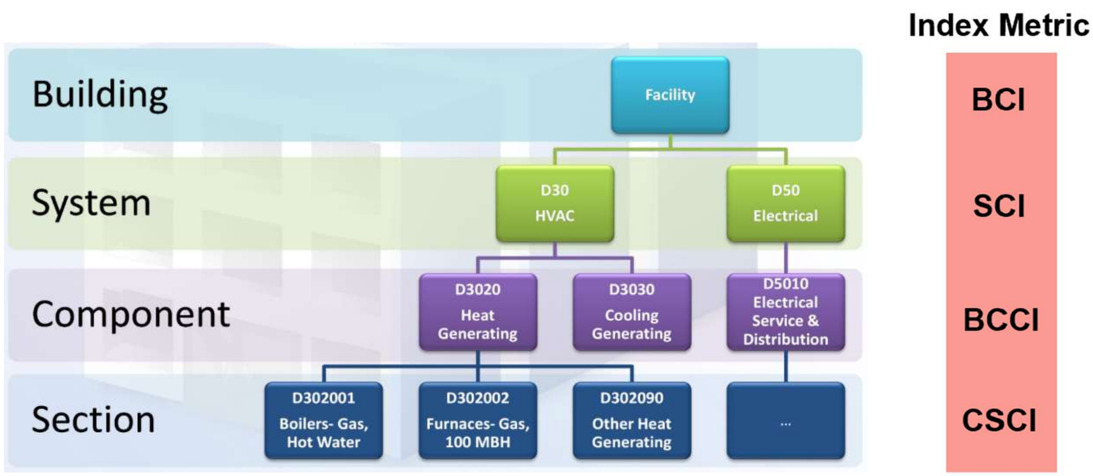

Figure 1: BUILDER structure breakdown example (SMS Playbook, 2021)

Benefits of BUILDER SMS.

BUILDER allows the condition data and costs to give an estimated value of a component, system, or building, which gives a good rough order of magnitude estimate when a forecasting projects or giving quick answers to decision-makers. The type of assessments required are also straightforward and generally easy to conduct, maintaining relatively consistent scoring across many individuals.

Part of what BUIDLER aims to do (with uncertain accuracy) is model predicted outcomes based on different budget scenarios and associated work types (do nothing, stop-gap repair, repair, replace) to identify the most cost-effective options, showing the benefits of repair versus replacement as well as the consequences of deferring work for a given item (SMS Playbook, 2021). AFCEC refers to these as scenario, trend, and cost analysis capabilities. Figure 2 shows probability distributions for the time to failure for a hypothetical component-section (Grussing, 2012).

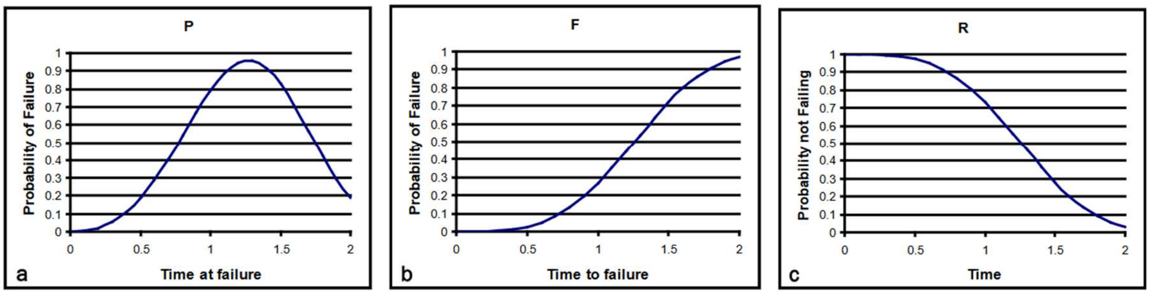

Figure 2: BUILDER hypothetical Probabilities of Failure for time t, failure before time t, and reliability beyond year t (Grussing, 2012)

Overall, accurate condition and cost data is needed to best use asset management principles. Having projections allows for proactive and predictive programming with justification, rather than fixing what's broken or using a "worst-first" method for repairs.

Limitations of BUILDER.

The degradation model within BUILDER does not provide an accurate representation of the degradation of assets. As Lamm (2021) describes, "these asset condition forecasts are calculated using standardized, self-correcting distribution models that rely on poorly-fit, continuous functions" and "these approaches focus on population life-cycle expectations to make future probabilistic life-cycle predictions of individual assets." The current model does, however, keep the system simple and relatively easy-to-use, and while inaccurate, the model is better than nothing. The Weibull distribution is used to model the condition life-cycle curve according to USACE Construction

Engineering Research Laboratory (CERL) (Grussing, 2012); a typical trend is shown in Figure 3.

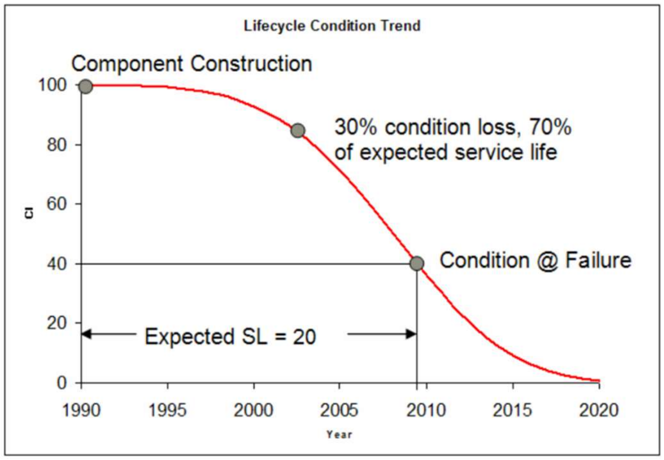

Figure 3: Example initial life-cycle condition trend (Grussing, 2012)

A study in New Jersey investigated the feasibility and benefits of transferring data between Autodesk Revit and BUILDER SMS for sustainable facility management (SFM) (Loeh et al., 2021). The USAF does not currently use Revit, a Building Information Modeling (BIM) program, but uses the facility management (FM) program NexGenIT, for a wide range of CE functions – from service requests, through logging man-hours spent on a work task, to programming and executing projects. Loeh's study highlighted the shortcomings and benefits of having a program that contains condition data and adding it to a visualization software. The Air Force uses data visualization in a program called Tableau, and for visualization at a mapping level, the program ArcGIS.

Loeh highlighted the lack of integration between BUILDER and other systems that the military, or outside organizations use. The need to move data by hand adds inefficiencies, and leaves gaps where missing data may be in programs like NexGen IT. Some relevant concerns his study found include data incompatibility between software programs, challenges in maintaining information quality, cyber security and data ownership challenges, and lack of sufficient knowledge of the FM program by stakeholders (Loeh et al., 2021), in the Air Force's case, the stakeholders are building users and facility managers. The USAF has several of the same concerns with the lack of interoperability in BUILDER SMS. Interoperability would add needed efficiencies and consistency across systems. Table 1 shows the Loeh et al.'s summary of strengths and weaknesses of manually transferring data vs using an intermediate database (Loeh et al., 2021). An intermediate database could be a solution for the lack of interoperability between NexGen IT and BUILDER SMS.

Table 1: Summary comparison for data transfer methods (Loeh et al., 2021)

Strengths	Weaknesses
Method 1 (manual)	
Most intuitive method since it resembles simple data entry Little initial setup required; data transfer is the majority of time spent	Longer completion time for single data transfer Slowest method for frequent updates of databases Possibility of human error due to large amounts of individual data points being inputted manually
Method 2 (intermediate database)	
Easier to interpret data in spreadsheet-like view Transfer/import process is faster than previous method Ideal for frequent updates	Setup process is slowed down by manually inputting BUILDER SMS identifiers and setting up Access queries for multiple facilities Requires both Revit and BRED database exports to be accurate and compatible

Another limitation to BUILDER is that "while the USAF employs standardized maintenance plans, routine inspections, and uniform condition metrics, data quality and consistency vary across locations based on the subjectivity of technician ratings of the assets and projects that improve an asset's condition" (Lamm, 2021). The information on these limitations can positively and negatively affect the long-term investment strategies informed by using data from BUILDER SMS. Knowing the limitations of the system can help inform decision-makers the amount of uncertainty in the data being presented if using one of the forecasting tools. On the other hand, if just using the condition data as-is, it provides better justification to decision-makers that due diligence was accomplished, and they have a more complete picture of the current state of facilities. AFCEC and policy makers should strive to better incorporate data systems.

Alternate SMS Tools Used in Industry to Accomplish Goals of BUILDER.

IBM's Maximo Software is a computerized maintenance management system that helps manage assets, schedule maintenance, and track work orders. Browsing IBM's sections on system abilities, this software looks to contain a database of assets like BUILDER, and also can accomplish Work Order Management, schedule preventative maintenance, and contains materials and inventory management (*Maximo*, 2022). The last three capabilities mirror the USAF's uses for NexGen IT. A facet Maximo can incorporate is autonomous sensing systems, which is something that could benefit the Air Force on assets that are hard to assess visually, like bridges and towers, or underground infrastructure like water distribution, wastewater, and stormwater networks. Using this product as a guide to incorporate BUILDER and NexGen IT could provide many benefits to the USAF CE enterprise.

Community Planning

Urban sprawl in the United States followed the invention of the automobile and the implementation of zoning laws. The Freeway Act of 1956 encouraged expansion into the neighboring areas that have become suburban developments (*A Brief History of U.S. City Planning - YouTube*, 2019). Chapin's 2012 analysis broke the history of American urban sprawl into four general growth management policy time periods: (1) Era of Growth Controls, roughly 1950–1975, (2) Era of Comprehensive Planning, roughly

1975–2000, (3) Era of Smart Growth, roughly 1999–present, and (4) Era of Sustainable Growth, which is emerging (Chapin, 2012). Dense cities, where buildings and infrastructure were built up vertically, rather than out horizontally, typically have dramatically reduced per-capita emissions compared to neighboring suburban communities of the same population, and in places like Manhattan, include a focus on walking or public transit rather than driving, and smaller-sized housing (Owen, 2014). A large focus of the literature on urban sprawl has focused on the environmental impact of spreading infrastructure into previously undeveloped land or agricultural land. Additional research, which led to the principles of New Urbanism, has focused on how to slow, stop, or solve the problems caused by the unrestrained expansion that has characterized the last 100 years of the United States' development. Andres Duany, who champions the principles of New Urbanism, characterizes "suburban sprawl" with four elements, all necessary for typical American life: (1) housing clusters, (2) shopping centers, (3) office parks, and (4) meeting places (schools, post offices, etc.) (Andres Duany, 1991). The Congress for the New Urbanism has a charter of 27 principles which aim to apply to "new development, urban infill and revitalization, and preservation" and reflect "how cities and towns had been built for the last several centuries: walkable blocks and streets, housing and shopping in close proximity, and accessible public spaces" (CNU, 2015).

Beyond the environmental and social impacts of expansion, a growing problem is the vast per-building increase in horizontal infrastructure such as roads, electrical lines, and water/sewer systems, that is required to support the more dispersed buildings. Services such as schools and emergency services (fire and police stations) also must increase for safety and accessibility. This added infrastructure brings a large price tag for the initial investment and an even larger price tag for the cost maintenance over the development's life cycle. These costs of sprawl have been assessed as a major concern for financial sustainability by local and federal entities. Burchell's 2005 book on the costs of sprawl presents "[t]he three traits used to define sprawl here include (1) unlimited outward extension into undeveloped areas, (2) low density, and (3) leapfrog development" (Burchell et al., 2005). Burchell's book includes suggested fixes for the problems including focusing on mixed land use, compact building design, walkable communities, and preserving open space.

Federal US military installations have had similar problems since their initial construction, base development, and resulting maintenance; for the USAF, that has been the last 80 years. The terrorist attacks of the 1990's, then 9/11 in 2001, drove new antiterrorism construction requirements that had a major focus on stand-off distances and largely required 82 feet between a building and other buildings, parking, or roads. These standoff distances further encouraged sprawl on installations and the consequences of the excessive infrastructure are being felt with the limited annual budget the Air Force has for Facilities Sustainment, Restoration, and Modernization (FSRM). This consequence is best shown in the $33 billion backlog of deferred infrastructure maintenance and recapitalization as of 2019 (Wilson & Goldfein, 2019), which has developed due to the delayed implementation of asset management principles, inefficient development patterns, and restricted budget. Fortunately, these requirements were reduced in 2018 with the release of the new UFC 4-010-01, *DoD Minimum Antiterrorism Standards for Buildings*.

Urban sprawl is typically quantified using population and infrastructure density metrics (Burchell et al., 2005). In my research, I could not find a proven method for quantifying urban sprawl when a dataset already exists in a program like ArcGIS. Most methods centered around arial photographs over time and associated population growth. This meant that I needed to use a modified density metric to quantify sprawl on an Air Force base, and Burchell's explanation of using infrastructure density was the starting point for creating those metrics. The distinction between housing areas, which are largely privatized, and work facilities may have to remain when assessing the sprawl. Trying to achieve New Urbanism principles, such as bringing work facilities closer together to minimize current and future infrastructure costs may remain the focus rather than mixing the working and living facilities for true "mixed-use" concept implementations on an installation. UFC 2-100-01, *Installation Master Planning*, incorporates some of the new urbanism principles into how the DoD and USAF should be tackling the issue of too much infrastructure, and its resulting backlogged maintenance. Some of these requirements include a focus on constructing multi-story buildings when possible, clustering "functionally compatible" buildings to reduce the footprint (which also benefits security), and the minimization of pavements by including on-street parking and focusing on "walkable" campuses. As policy, these concepts must be considered for all future planning actions taken by installations and informed my model to include planning aspects such as land capacity, building configuration, and siting configurations for the district planning model.

III. Methods

Chapter Overview

This chapter includes background on the selected methodologies of MAUT and AHP, the explanation of the utility curves for my selected criteria adapted from the original model, the two new criteria for the proposed model, and explanation of the case study for the proposed model. This project began by using the Navy Shore Infrastructure Investment Support strategy (Streicher, 2008) and the DoD and Air Force land development strategies to identify criteria that may have been left out in the initial model. Figure 4 shows the methodology process I used to create my proposed model.

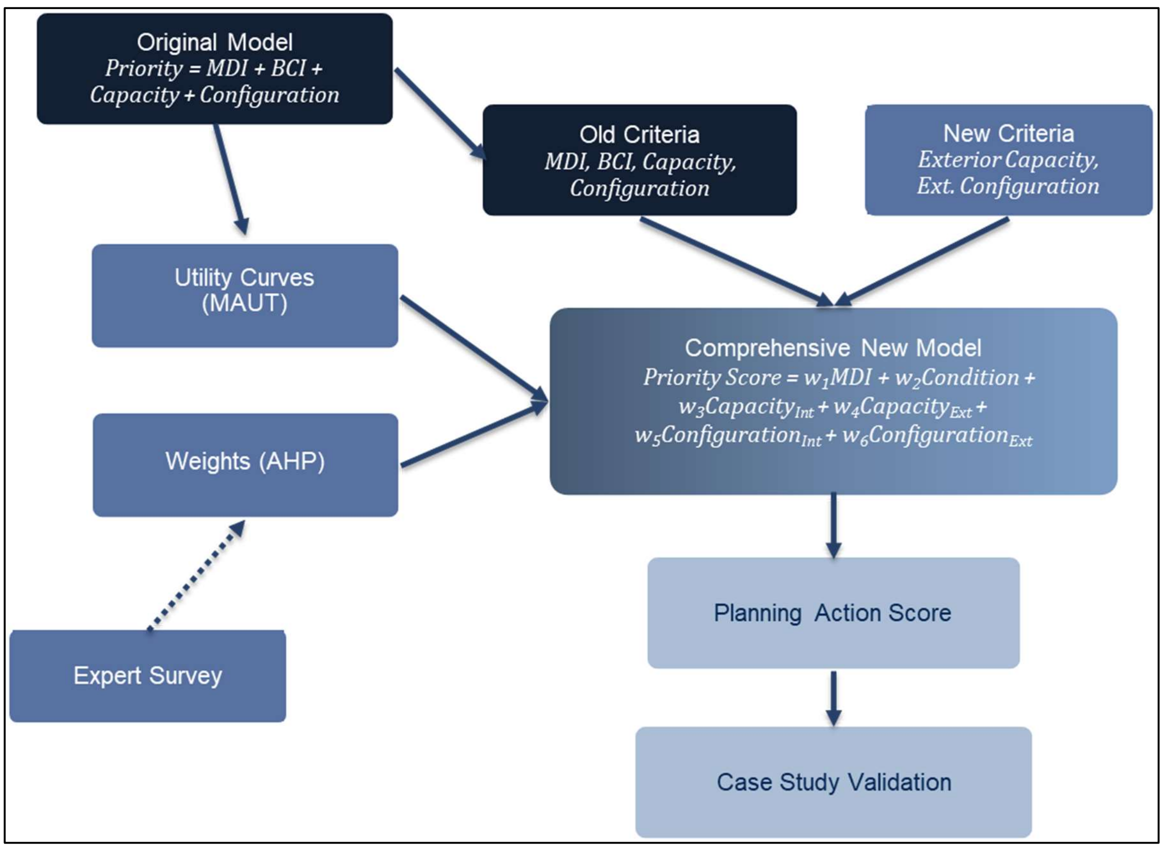

Figure 4: Methodology Process Diagram

Multi-Attribute Utility Theory

MAUT can be used to evaluate alternatives with respect to relevant attributes (Jansen, 2011), especially when the attributes are have differing scales or units of measure. In this research, the alternatives are the potential projects being assessed, and the attributes are denoted with the selected criteria, described in detail in a later section of this chapter. Abu-Samra (Abu-Samra et al., 2017) used MAUT to identify factors and determine, through relative weights, which of those factors have the highest influence on strategies to enable keeping the studied pavements in the highest condition. Arif (2016) also discussed how the MAUT could be used to enable decision making for future planning of infrastructure projects with limited funding. Arif's (2016) paper provided a support framework that I used to create my model. Deng (1999), Dweiri & Al-Oqla (2006) note that AHP is a tool ideal for solving multi-criteria decision analysis (similar to MAUT) problems. Additionally, Lee (2015) discussed using AHP to quantify fuzzy criteria, which were used in this paper for the criteria which are not typically quantified, such as configuration. Beula & Prasad (2013) discussed the need for decision-maker involvement in quantifying fuzzy criteria, which is in part, why several of the selected criteria were adapted from the already-approved criteria in the existing model, onto the scale (zero to one) used for utility curves. A consistent limitation in the literature is in the inherent subjectivity of AHP; this subjectivity can be counteracted by using the methods of creating consistent weights and MAUT.

Utility curves were created for each of the criteria; the four from the original, unchanged criteria were built based on the scoring that came with the criteria which have already been approved by AFCEC. These utility curves essentially put all criteria on the same scale of zero to one, and in the case of my model, with higher scores representing projects with opportunities for investment. This proposed model currently only accounts for vertical construction (buildings) projects falling under facility sustainment, or restoration and modernization (FSRM) repair projects. Construction, whether submitted through Unspecified Minor Military Construction (UMMC) or Military Construction (MILCON), which must be scored, selected, and funded at higher levels (Air Force Comprehensive Asset Management Plan Business Rules, 2021), are not considered in this equation/model, and will need to be taken into account separately because they inherently don't have assigned values for most of my selected criteria to be able to assess the 'current state.' An assumed-value approach will need to be investigated for scoring projects on facilities (or additions to facilities) that do not yet exist if they are to be scored using my proposed model.

Selected Criteria

Overview.

This section includes an explanation of the selected criteria, the initial starting point for the criteria, and how they were adapted to build utility curves. The initial four criteria from AFCEC were adapted into utility curves, modifying the scale, which removed the integrated weights from the initial point allocation. Utility curves were also created for the two new proposed criteria. Higher utility scores represent facilities with opportunities for investment.

Interior Configuration.

The metric follows the original configuration criterion, which is subjectively based on how a facility functions for the mission accomplished in that facility. It also objectively takes into consideration existing deficiencies including fire safety deficiencies (FSD) and life-health-safety deficiencies (LHS), and uses a category system numbered 1 to 4 where:

(1) Indicates a deficiency exists but has no impacts to the use of the facility for its designated functions, no workarounds are required.

(2) Indicates a deficiency is present and moderately restricts the use of the facility's designated functions, minimal workarounds are required.

(3) Indicates a deficiency or deficiencies are present significantly restricts the use of the facility's designated functions and is impacting operational expenses. Deficiency currently has a wavier or exemption, which is required to be rectified at the time of the next major renovation or replacement.

(4) Indicates a deficiency or deficiencies are present and prohibit or severely restrict the use of the facility for its designated functions and have caused a significant increase in operational expenses.

FSD and LHS deficiencies will be used as indicator flags in the project planning considerations; community planners must assess, with the help of other CE personnel, as to the feasibility to resolving existing deficiency. Points for this criterion in the original model were allocated as: (1) = 20 points, (2) = 40 points, (3) = 60 points, and (4) = 80 points. To adapt this scoring to the utility score-based model, the scale was changed to 0-1.00, which produced the utility values of (1) = 0.25, (2) = 0.50, (3) = 0.75, and (4) = 1.00, which means buildings with the highest deficiencies receive higher interior configuration scores, indicating an investment or improvement opportunity. The utility curve shown in Figure 5 was created as a step function given that there are only 4 categories with no in-between values possible.

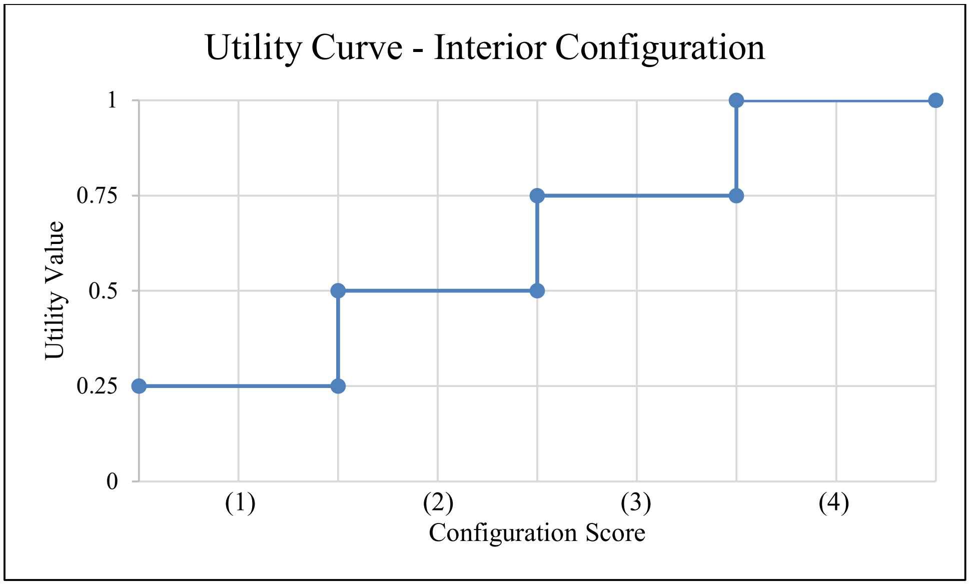

Figure 5: Utility Curve for Interior Configuration parameter

Condition – Building Condition Index (BCI).

The Condition criterion is based on the BCI of the facility, which is kept in BUILDER SMS, with a BCI range of 0-100. Points for this criterion in the existing model are allocated as:

- BCI < 40 = 150 points
- BCI > 80 = 0 points
- For all others, score = 100 – BCI points (Total possible points 60; minimum is 20 points)
- Exception: Buildings older than 50 years old and BCI less than 50 = 80 points (this assumes they are on a trajectory over time for replacement or divestiture)

AFCEC has stated that the existing point allocation does not incentivize repair at their stated ideal BCI range for renovation or repair of 60 ≤ BCI ≤ 80 (FY 20-23 BCAMP Business Rules). Due to that disconnect, the scoring from the existing model was not adapted as the utility curve for the proposed model. The utility curve in Figure 5 shows the utility value (UV) scores, which are adapted from the FY20-23 BCAMP Business Rules PoF calculator:

- BCI $<$ 60, UV = $\frac{BCI}{100} * \frac{1}{3} + 0.8$
- 60 $\leq$ BCI $\leq$ 80, UV = 1
- BCI $>$ 80, UV = $1 - [5 * (\frac{BCI}{100} - 0.8)]$

To follow the guidance in the BCAMP Business Rules for FY22-26 and FY20-23, an indicator flag will be placed on a project to consider consolidation or demolition for facilities with BCI < 40, as the facility may cost more to repair than it is worth. The ideal renovation range of 60 $\leq$ BCI $\leq$ 80 will receive maximum points on the utility curve. If a facility has BCI $>$ 80, it is likely too soon to renovate or repair in situations other than non-condition-based (NCB) repair projects. The exception in the existing scoring for buildings older than 50 years is not included in the new utility curve because all buildings with BCI < 40 will be flagged for consolidation or demolition, regardless of age.

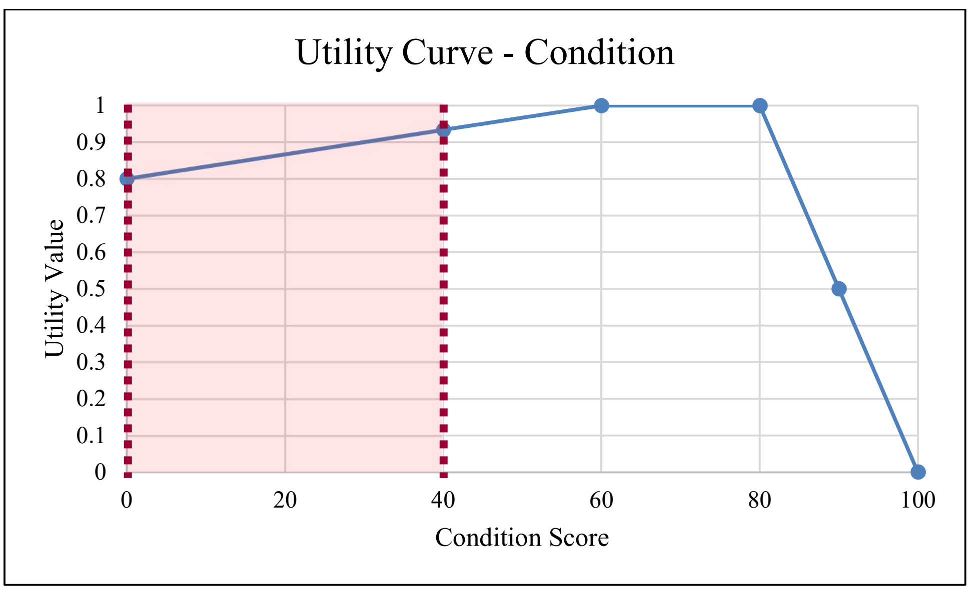

Figure 6: Utility Curve for Condition parameter

As of the FY24-28 AFCAMP Business Rules, AFCEC guidance has moved away from requiring PoF and CoF calculations to determine the "technical score" for projects requesting funding, in favor of the Major Commands (MAJCOMs) allocating priority points to projects. This allows MAJCOMs to have more say over which projects at the bases under their commands are pushed for funding and reduces the administrative burden on the bases submitting projects. MAJCOMs are, however, allowed to require their bases to continue scoring each project with these metrics.

Facility Importance - Mission Dependency Index (MDI).

The USAF adopted MDI in 2008 and is initially scored based on the Category Code (CATCODE) of the facility. In recent years, the Tactical MDI has been created to reflect a facility's importance to a specific base more accurately when the local criticality does not line up with the CATCODE MDIs (Weniger, 2018). The components used for assigning a Tactical MDI, interruptability and replicability, are shown in Figure 7.

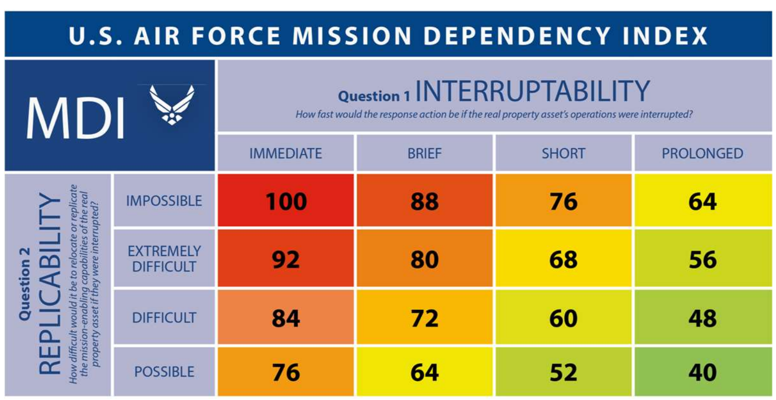

Figure 7: Tactical MDI Decision Matrix (USAF, 2018)

The linear MDI utility curve adapted the decision matrix in Figure 8. The utility values are higher with facilities that have higher relative importance because they typically need to be prioritized for investment to ensure mission continuation.

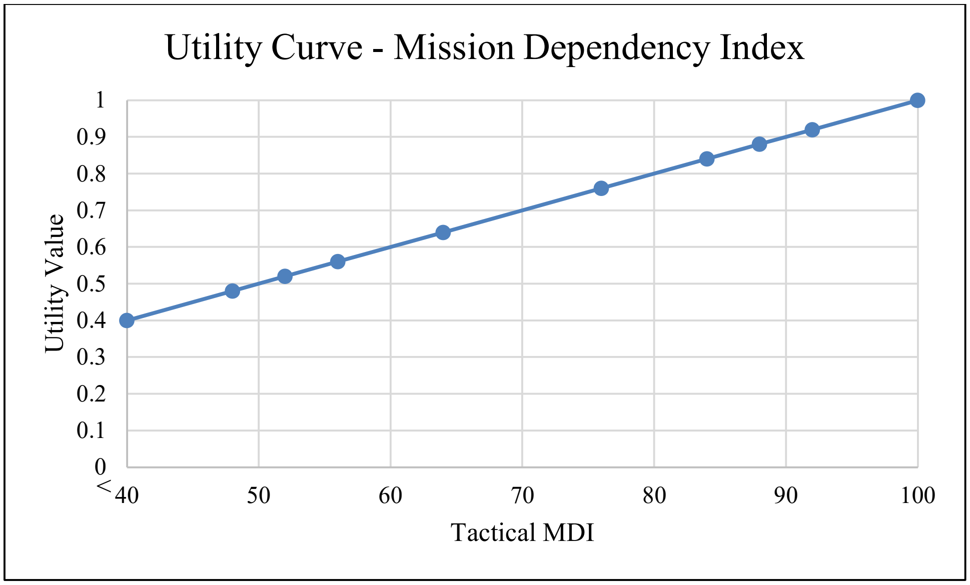

Figure 8: Utility Curve for MDI parameter

Interior Capacity – Utilization Rate.

Interior Capacity is based on AFCEC's original capacity criterion. It measures the existing utilization of a building. Utilization rates (UR) are calculated for every building and represent the amount of utilized square footage assigned to one or more units compared to the total square footage of the building. The point scores for each utilization rate range from AFCEC's existing model are:

- UR > 100% = 50 points
- UR < 50% = 100 points (consider for consolidation or divestiture)
- 81-100% UR = 0 points (I2S goal is to have more than 80% utilization)
- 50-79% UR = 100 – UR (consider alternatives which improve utilization)

The point scores were converted from the range of 0-100 points to 0-1.0 utility values. The utility curve was adapted based on these values and is shown in Figure 9. Utilization Rate < 50% will get the highest utility value of 1.0 to trigger an indicator flag for community planners to consider mission consolidation with other facilities or demolition of the underutilized facility.

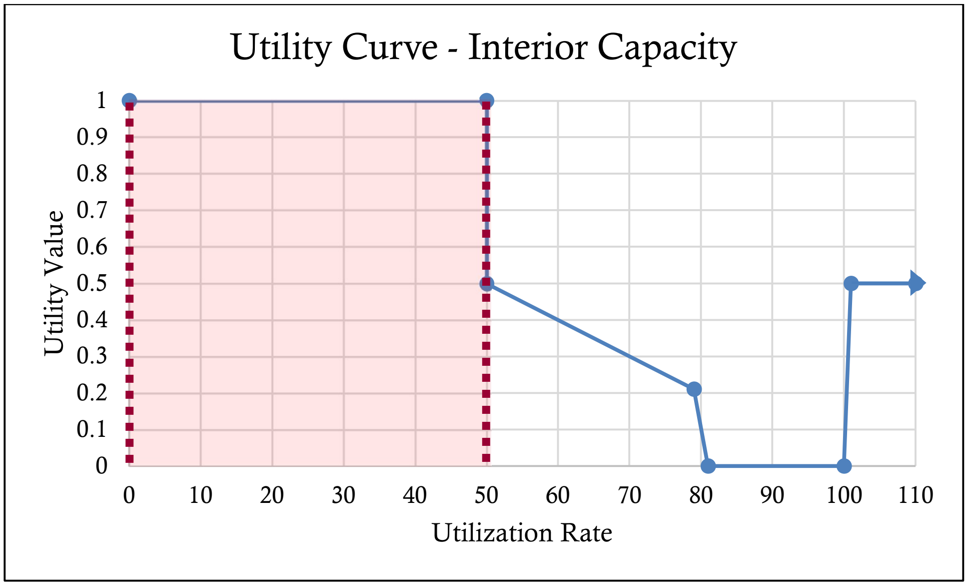

Figure 9: Utility Curve for Interior Capacity parameter

Exterior Capacity.

During the District Planning Process, districts are broken into parcels and those parcels are assigned acceptable uses (such as administrative, light industrial, commercial, residential, etc.) through a Regulating Plan, similar to how zoning works in public communities. Exterior capacity is a newly proposed criterion measuring the undeveloped footprint of a parcel based on the square footage of existing facilities compared to the square footage of the parcel or district. Parcels are used in these calculations because they are the prescribed way the Air Force uses to break up land based on function, which impacts the expected density of the parcel.

This criterion uses Geographic Information System (GIS) data that is already required to be collected and up to date in each installation's local ArcGIS database in accordance with AFI 32-10112, *Installation Geospatial Information and Services objectives*, following schema 4.0.3.2 based upon the SDSFIE Gold 4.0 standard. The layers to be used are the facility areas (may be labeled slightly differently base-to-base, but is typically labeled as layer "Buildings_A"), and the parcel layer (this may be labeled "Regulating Parcels"). In GIS, the Erase tool is used to remove the building footprints from the regulating parcel layer, then the area of the parcel before and after removing the footprints is compared. The resulting percentage of remaining land is used as the symbology in ten "bucket" groupings, and the scores are based on where the project location lands in those buckets. An example of the resulting map is demonstrated in Figure 10.

The ten building footprint density ranges (buckets) produced by the GIS analysis were combined into a step function utility curve shown in Figure 11 where the lowest facility density or highest available area (bucket 1) has the highest utility value of 1.0 in the range of 0-1.00, and lowest available area (bucket 10) has the lowest value of 0.1. Highest utility value with the lowest density was decided to have projects in non-ideal locations rise as an opportunity for investment through relocation or otherwise.

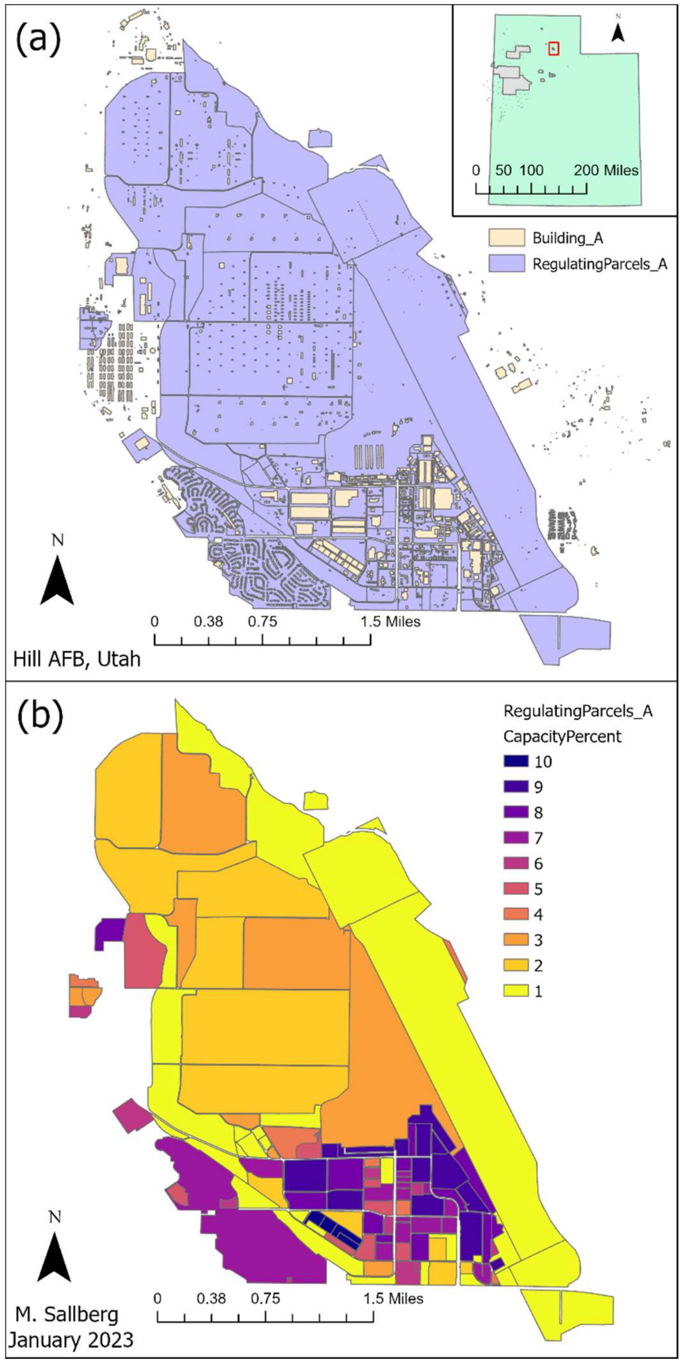

Figure 10: Example of Exterior Capacity Criterion at Site A of Hill AFB, Utah. (a) Shows the regulating parcels of Hill AFB Site A; (b) shows the land area ratio remaining of the regulating parcels in 10 equal buckets of Hill AFB Site A, with bucket 1 as the lowest infrastructure density and bucket 10 the highest density.

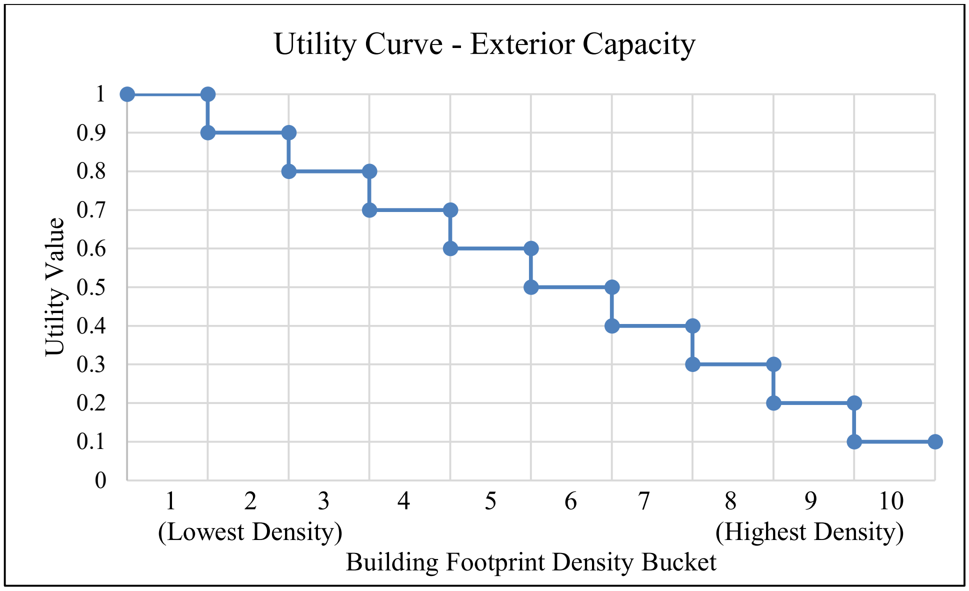

Figure 11: Utility Curve for Exterior Capacity parameter

Exterior Configuration.

Exterior configuration considers where the facility is located based on infrastructure density. Low density is less desired as infrastructure costs more per facility when facilities are spread out. The analysis to use this criterion uses ArcGIS data maintained by the base using the layers for electrical, natural gas, water, and wastewater as polylines. The layers are combined into a single linear infrastructure layer using the Merge tool. Then, the Line Density tool is used with an input of the linear infrastructure layer, with a cell size of 36 square feet, and a boundary (mask) on creating the raster of the main base site (Often named “Site_A”). This factor includes extra indicators for buildings in flood zones or areas requiring waivers such as airfield clear zones not shown in the map or utility curve. An example of what this criterion looks like is shown in Figure 12, with first in (a) the whole of base linear infrastructure (electrical, natural gas, water, wastewater networks), and the infrastructure density map in (b).

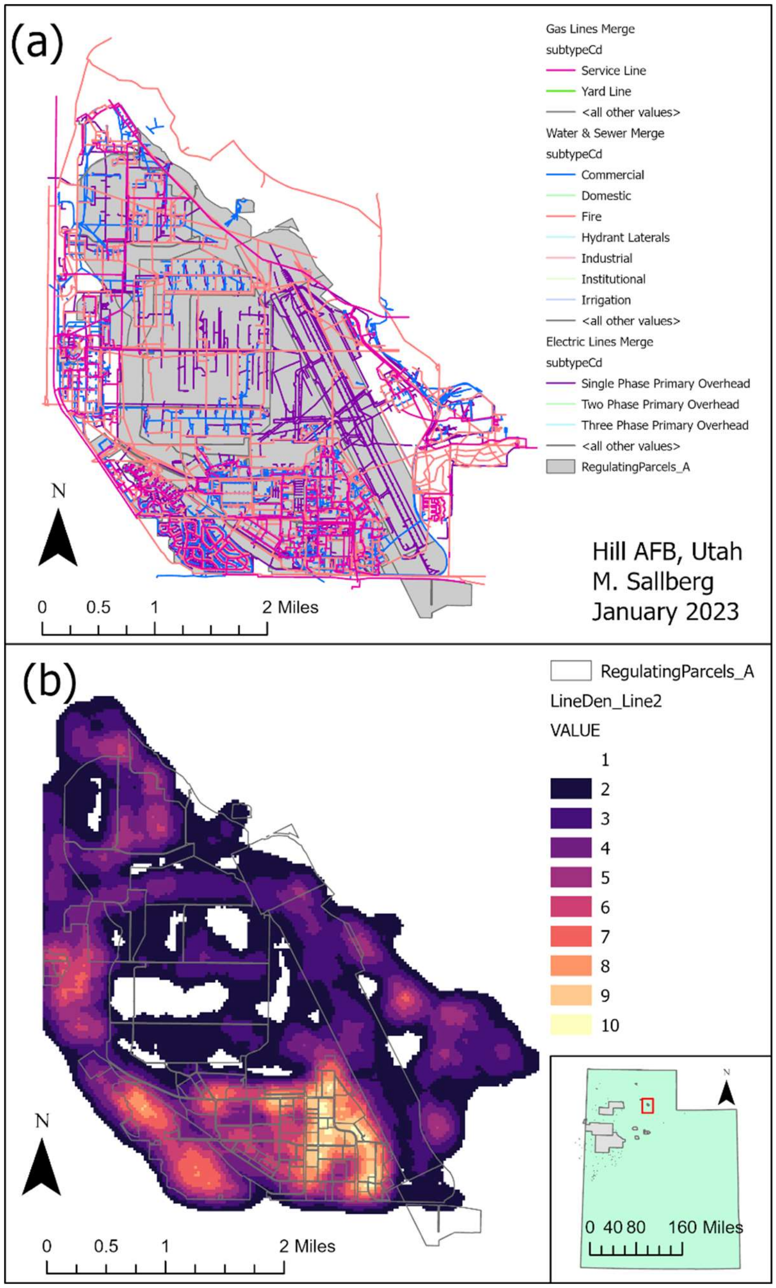

Figure 12: Example of Exterior Configuration Criterion at Site A of Hill AFB, Utah (a) shows the total merged linear infrastructure of the electric, natural gas, water, and wastewater systems that were used to find the infrastructure line density. (b) shows the linear infrastructure line density of Hill AFB broken into 10 equal-sized buckets with bucket 1 as the lowest infrastructure density and bucket 10 the highest.

The ten local infrastructure density ranges produced by the GIS analysis were combined into a step function utility curve where the lowest infrastructure density (bucket 1) has the highest utility value of 1.0 in the range of 0-1.0, and the highest infrastructure density (bucket 10) has the lowest utility value of 0.1. This point scheme encourages development in areas with the highest density to minimize the cost of supporting infrastructure.

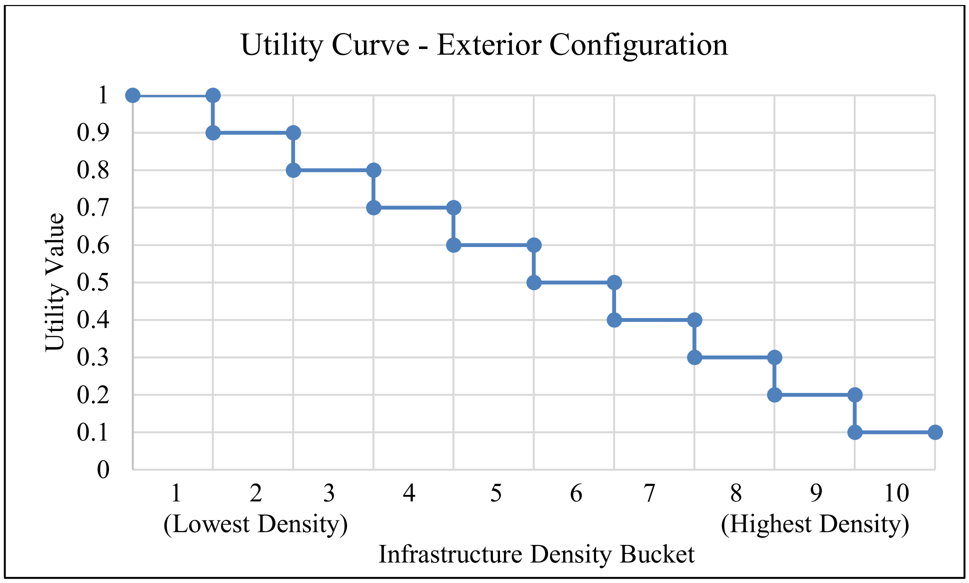

Figure 13: Utility Curve for Exterior Configuration parameter

Analytic Hierarchy Process

In models involving disparate criteria, especially when both objective and subjective factors are included, it is often challenging to determine relative importance of those criteria. In 1971-1975, Saaty developed a framework to allow consideration of several factors with numerical tradeoffs decided based on feedback for pairwise comparisons (Saaty, 1987). Rowe (2011), found promise in utilizing a hierarchy to develop a scoring model.

AHP was utilized to develop weighting for the criteria in the proposed model. To calculate the weights, an expert elicitation study was done with base-level community planners and AFCEC Comprehensive Planning (CPP) Division personnel. This study gathered data on each participant's opinion of the relative importance of each criterion using SurveyMonkey. AHP pairwise comparison ratings were created based on the scale of values shown in Table 3, which represents the rating of the preferred criterion, and by how much that criterion is preferred. The survey form used a scale of -9 to +9, with +/- denoting which criteria is preferred, which allowed the responses to be converted into the correct scale in Table 3. Fifteen pairs were created from the six criteria, and experts ranked the criteria based on the scale in Table 4. The target expert audience included base-level community planners, and community planners within AFCEC's CPP division; there were 34 total respondents, 4 were not in the target audience, and 11 were deemed inconsistent and not used in the averages to determine the pairwise rankings. These ranks gained from the elicitation study are shown in Table 4 located in Chapter IV Results.

Table 2: Ranking scale for pair-wise comparisons of model criteria

Scale	Numerical Rating	Reciprocal
Extremely Preferred	9	1/9
Very strong to extremely	8	1/8
Very Strongly Preferred	7	1/7
Strongly to very strongly	6	1/6
Strongly Preferred	5	1/5
Moderately to strongly	4	1/4
Moderately Preferred	3	1/3
Equally to moderately	2	1/2
Equally Preferred	1	1

Table 3: Criteria Pairs rated in expert elicitation study

Pair	Criteria 1	Criteria 2
1	Interior Capacity	Exterior Capacity
2	Interior Capacity	Interior Configuration
3	Interior Capacity	Exterior Configuration
4	Interior Capacity	Condition (BCI)
5	Interior Capacity	Importance (MDI)
6	Exterior Capacity	Interior Configuration
7	Exterior Capacity	Exterior Configuration
8	Exterior Capacity	Condition (BCI)
9	Exterior Capacity	Importance (MDI)
10	Interior Configuration	Exterior Configuration
11	Interior Configuration	Condition (BCI)
12	Interior Configuration	Importance (MDI)
13	Exterior Configuration	Condition (BCI)
14	Exterior Configuration	Importance (MDI)
15	Condition (BCI)	Importance (MDI)

The data from the expert elicitation was cleaned to exclude respondents that were not from the intended audience and exclude respondents that had a calculated consistency ratio (CR) below 10%. A 10% CR limit, which measures the inconsistency of the pairwise comparison ratings, comes directly from Saaty's (1987) AHP framework, which states:

> The priority of consistency to obtain a coherent explanation of a set of facts must differ by an order of magnitude from the priority of inconsistency which is an error in the measurement of consistency. Thus, on a scale from 0-1, inconsistency should not exceed 0.10 by very much. Note that the requirement of 10% should not be made much smaller such as 1% or 0.1%. The reason is that inconsistency itself is important, for without it, new knowledge which changes preference order cannot be admitted. Assuming all knowledge to be consistent contradicts experience which requires continued adjustment in understanding. (Saaty, 1987:12)

The CR will also be used once the weights for the proposed model are calculated, to ensure consistency for the model.

To calculate the criteria weights, first, the product of the values of each row were taken to the n-th root and entered in the "Product ^ nth root" column. In this case with 6 criteria, the value was found with $product^{1/6}$. The values of that column were added and used to calculate the weights. Next, the row value in the "Product ^ nth root" column was divided by the sum of the column's values, effectively normalizing the values to calculate the weight for each criteria row.

To calculate the CR for the pairwise comparison rankings and weights, first, two columns, W' and W'' must be calculated, and the sum of column W'' divided by the number of criteria is the max eigenvalue (**λ$_{\text{Max}}$**), which is used to find the consistency index (CI), then CR. To find the W' and W'' vector values, the comparison rating was multiplied by each weight for the respective pairing – for example: $\sum_{i=1}^{N} Rating_i * W_i$, where i is the criteria, and W_i is the weight of that criteria. This follows the methods laid out by Saaty (1987). To find W' and W'', Equations 1 and 2 were used for each row:

$$W' = Crit_1 * W_{crit1} + Crit_2 * W_{crit2} + Crit_1 * W_{crit3} + Crit_4 * W_{cri} \quad + \\ Crit_5 * W_{crit5} + Crit_6 * W_{crit6} \tag{1}$$

$$W''_{row1} = \frac{W'_{row1}}{W_{crit1}} \tag{2}$$

Once the sum of the W'' column is calculated, the consistency ratio is calculated using the Random Consistency Index (RI) of 1.24 from Saaty's (1987) table based on the number of criteria (six). The CI is calculated using Equation 3, where $n = 6$:

$$CI = \frac{\boldsymbol{\lambda_{\text{Max}} - n}}{\boldsymbol{n - 1}} \tag{3}$$

To score projects, the input value is viewed on the x-axis of the associated utility curve to obtain the utility values for all criteria. The utility values then are multiplied by the associated weights for the criteria and summed to get the score, then ordered to get the rank as seen in Equation 4.

$$U_j = \sum_{n=1}^{N} W_i * u_{ij} \quad (4)$$

Where U_j is the overall utility score for alternative j; N is number of projects being ordered, W_i is weight of criteria i; and u_{ij} is the utility value of criteria i at alternative j.

A sensitivity analysis was conducted on the weights to see how the rankings change as the weights for the criteria change. To check sensitivity, +/− 2% was used for the criteria being tested, and $+/-0.4\%$ was added to the remaining criteria to ensure the weights remain totaling to 100%.

IV. Results

Pairwise Comparison Outputs

Table 4: AHP pairwise comparison matrix showing scores of model criteria from expert elicitation study, and CR calculation

	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Weights	W'	W''
Building Condition	1.00	0.50	2.00	3.00	2.00	2.00	0.2186	1.3284	6.0774
Building Importance	2.00	1.00	4.00	4.00	3.00	2.00	0.3469	2.1126	6.0885
Interior Capacity	0.50	0.25	1.00	2.00	1.00	0.50	0.1022	0.6257	6.1256
Exterior Capacity	0.33	0.25	0.50	1.00	0.50	0.50	0.0675	0.4106	6.0815
Exterior Configuration	0.50	0.33	1.00	2.00	1.00	1.00	0.1203	0.7269	6.0426
Interior Configuration	0.50	0.50	2.00	2.00	1.00	1.00	0.1444	0.8869	6.1390
						Sum	1.0	**Sum =**	36.555
								λ_{Max} =	6.092
								CI =	0.0185
								$RI_{(table)}$ =	1.24
								CR =	0.01491

When the weights were checked for (in)consistency, CR < 0.1, so the paired rankings are consistent. Weights created using the Analytic Hierarchy Process are shown in Table 5:

Table 5: Initial Weights from AHP Pairwise Comparisons

Criteria	Weights
Importance (MDI)	0.3469
Condition (BCI)	0.2186
Interior Configuration	0.1444
Exterior Configuration	0.1203
Interior Capacity	0.1022
Exterior Capacity	0.0675

The weights produce the proposed objective function shown in Equation 5, where each criterion is the utility value found on each respective Utility Curve.

$$Project\ Priority\ = 0.3469 * MDI + 0.2186 * BCI + 0.1444 * Config_{Int} + 0.1203 * Config_{Ext} + 0.1022 * Capacity_{Int} + 0.0675 * Capacity_{Ext} \tag{5}$$

The AFCAMP scoring model of the last several years has used the risk-based scoring model multiplying PoF (based on BCI) and CoF (based on MDI), with the highest scoring projects receiving centralized funding. The above prioritization model in Equation 5 represents investment opportunities for the community planners using the model to then take and further develop. Higher scores do not necessarily mean *better* projects, or projects that can receive funding, but facilities that look to need investment, or a second look by community planners.

V. Case Study

Data

GIS geodatabase files for Hill AFB were obtained through AFCEC/CP. The data for projects used are from Hill AFB's District Planning process and were obtained from Hill AFB's community planner with the values needed for scoring the projects using the original model, and facility numbers so the two new criteria could be scored using the example exterior capacity and configuration density maps for Hill AFB in Figures 10 and 12. The list of projects is in Table 6 and was scored using the criteria utility curves.

Table 6: Case Study Project Listing

Project	Importance (MDI)	Condition (BCI)	Utilization Rate (%)	Interior Configuration
A	100	99	100	2
B	100	76	95	2
C	100	100	80	2
D	100	77	49	3
E	100	98	88	3
F	92	78	75	3
G	72	100	100	2
H	52	80	100	2
I	80	100	79	1
J	40	100	50	2

Analysis

The utility values were found using the given values in Table 6, and values found on the exterior capacity and exterior configuration maps in Figures 10 and 12; these inputs were applied to the utility curves in Figures 5, 6, 8, 9, and 11 and seen in the UV columns in Table 7.

Table 7: Utility Values for all criteria by project

Project	Criteria Scores & Utility Values											
	MDI	UV	BCI	UV	Interior Config.	UV	Exterior Config.	UV	Interior Capacity	UV	Exterior Capacity	UV
A	100	1	99	0.05	2	0.5	7	0.4	100	0	9	0.2
B	100	1	76	1	2	0.5	6	0.5	95	0	8	0.3
C	100	1	100	0	2	0.5	4	0.7	80	0.1	2	0.9
D	100	1	77	1	3	0.75	5	0.6	49	1	3	0.8
E	100	1	98	0.1	3	0.75	7	0.4	88	0	8	0.3
F	92	0.92	78	1	3	0.75	9	0.2	75	0.25	9	0.2
G	72	0.72	100	0	2	0.5	5	0.6	100	0	8	0.3
H	52	0.52	80	1	2	0.5	5	0.6	100	0	3	0.8
I	80	0.8	100	0	1	0.25	5	0.6	79	0.2	6	0.5
J	40	0.4	100	0	2	0.5	4	0.7	50	1	1	1

The weights used in the +/-2% sensitivity analysis are shown in Table 8, where the targeted weight increased or decreased 2%, the other five weights were adjusted up or down 0.4% to ensure the weights still summed to 1.0 or 100%. Results for how these tested weights changed the model outcomes are shown in Table 11.

Table 8: Sensitivity Analysis of weights with +/-2%

		Importance		Condition		Int Configuration	
	Weights	Weight +2	Weight -2	Weight +2	Weight -2	Weight +2	Weight -2
Importance (MDI)	0.3469	0.3669	0.3269	0.3429	0.3509	0.3429	0.3509
Condition (BCI)	0.2186	0.2146	0.2226	0.2386	0.1986	0.2146	0.2226
Interior Configuration	0.1444	0.1404	0.1484	0.1404	0.1484	0.1644	0.1244
Exterior Configuration	0.1203	0.1163	0.1243	0.1163	0.1243	0.1163	0.1243
Interior Capacity	0.1022	0.0982	0.1062	0.0982	0.1062	0.0982	0.1062
Exterior Capacity	0.0675	0.0635	0.0715	0.0635	0.0715	0.0635	0.0715
Weight Total:	1.00	1.00	1.00	1.00	1.00	1.00	1.00

		Ext Configuration		Int Capacity		Ext Capacity	
	Weights	Weight +2	Weight -2	Weight +2	Weight -2	Weight +2	Weight -2
Importance (MDI)	0.3469	0.3429	0.3509	0.3429	0.3509	0.3429	0.3509
Condition (BCI)	0.2186	0.2146	0.2226	0.2146	0.2226	0.2146	0.2226
Interior Configuration	0.1444	0.1404	0.1484	0.1404	0.1484	0.1404	0.1484
Exterior Configuration	0.1203	0.1403	0.1003	0.1163	0.1243	0.1163	0.1243
Interior Capacity	0.1022	0.0982	0.1062	0.1222	0.0822	0.0982	0.1062
Exterior Capacity	0.0675	0.0635	0.0715	0.0635	0.0715	0.0875	0.0475
Weight Total:	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Results

The Case Study assessed a list of projects from Hill Air Force Base, Utah. Table 6 shows the project scores for the criteria when using the scoring from the original model. Table 9 shows the utility values, utility values multiplied with the weights for the respective criteria, and the overall projects scores using the data in the proposed model.

Table 9: Project Scores using AFCEC original model

Utility Score (Value given)	Project									
	A	B	C	D	E	F	G	H	I	J
Configuration	40 (2)	40 (2)	40 (2)	60 (3)	60 (3)	60 (3)	40 (2)	40 (2)	20 (1)	40 (2)
Condition (BCI)	0 (99)	24 (76)	0 (100)	23 (77)	0 (98)	22 (78)	0 (100)	20 (80)	0 (100)	0 (100)
Importance (MDI)	100	100	100	100	100	92	72	52	80	40
Capacity	0 (100%)	0 (95%)	20 (80%)	100 (49%)	0 (88%)	25 (75%)	0 (100%)	0 (100%)	21 (79%)	50 (50%)
Total Score	**140**	**164**	**160**	**283**	**160**	**199**	**112**	**112**	**121**	**130**
Rank	**6**	**3**	**4**	**1**	**4**	**2**	**9**	**9**	**8**	**7**

Table 10: Project Scores and Ranking from initial weights of proposed model

	MDI		BCI		Interior Configuration		Exterior Configuration		Interior Capacity		Exterior Capacity			
W	0.3469		0.2186		0.1444		0.1203		0.1022		0.0675			
Proj	UV	UV*W	UV	UV*W	UV	UV*W	UV	UV*W	UV	UV*W	UV	UV*W	Score	Rank
A	1	0.3669	0.05	0.0107	0.5	0.0702	0.4	0.0465	0	0.0000	0.2	0.0127	0.5864	5
B	1	0.3669	1	0.2146	0.5	0.0702	0.5	0.0582	0	0.0000	0.3	0.0191	0.7723	2
C	1	0.3669	0	0.0000	0.5	0.0702	0.7	0.0814	0.1	0.0098	0.9	0.0572	0.4963	7
D	1	0.3669	1	0.2146	0.75	0.1053	0.6	0.0698	1	0.0982	0.8	0.0508	0.7640	3
E	1	0.3669	0.1	0.0215	0.75	0.1053	0.4	0.0465	0	0.0000	0.3	0.0191	0.6259	4
F	0.92	0.3375	1	0.2146	0.75	0.1053	0.2	0.0233	0.25	0.0246	0.2	0.0127	0.8193	1
G	0.72	0.2642	0	0.0000	0.5	0.0702	0.6	0.0698	0	0.0000	0.3	0.0191	0.4433	8
H	0.52	0.1908	1	0.2146	0.5	0.0702	0.6	0.0698	0	0.0000	0.8	0.0508	0.5528	6
I	0.8	0.2935	0	0.0000	0.25	0.0351	0.6	0.0698	0.2	0.0196	0.5	0.0318	0.4249	9
J	0.4	0.1468	0	0.0000	0.5	0.0702	0.7	0.0814	1	0.0982	1	0.0635	0.2698	10

Table 11 shows the sensitivity analysis results in the form of the project rankings for each of the 12 sensitivity tests, +/−2%, for all six criteria. The average ranks for the projects across the 12 sensitivity tests are shown alongside the ranks from the AFCEC existing model and the ranks using the original weights of the proposed model. The consistency of the ranks in the sensitivity tests shows the proposed model is stable during small adjustments, which increases confidence in the model.

Table 11: Results of sensitivity analysis on proposed model for +/−2% of all criteria, comparing project ranks of AFCEC existing model and average model ranks

Project	AFCEC Model	New Model Weights	Importance		Condition		Interior Config		Exterior Config		Interior Capacity		Exterior Capacity		Average Rank
			+2	-2	+2	-2	+2	-2	+2	-2	+2	-2	+2	-2	
A	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7
B	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
C	4	5	5	5	5	4	5	5	5	5	5	5	5	5	4.92
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
E	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6
F	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3
G	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10
H	9	4	4	4	4	5	4	4	4	4	4	4	4	4	4.08
I	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9
J	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8

VI. Conclusions

Incorporating methodologies with criteria that intend to introduce a quantified measure of sprawl allows community planning principles to help drive long-term planning activities, and can promote development in "good" locations, with high infrastructure density and high facility footprint density. Asset management is an important contribution to community planning processes but needs to be combined with community planning principles especially for long-term installation plans.

Using AHP yielded a slightly different ranking from the initial model using AFCEC's equation with weighted criteria. Most of the projects scored within one place of the existing model scores except Project H, which moved up from tied for last place in the existing model to an average of 4th-highest score. This looks to be because while it has a low MDI as an administrative headquarters building, it is in the ideal renovation range, and in a parcel with lots of undeveloped land. This is the only inhabited facility in its parcel, which increases the exterior capacity score to disincentivize sprawl. Additionally, with the changes made to the condition criteria, the proposed model encourages planning actions for buildings in the ideal renovation range, so Project H with a BCI of 80 gets a utility value of 1.0. The sensitivity analysis showed that the proposed model is stable, and not sensitive to small changes to the weighting by 2% increments.

The methods used in this paper are not intended to be used as the sole decision-maker of whether a project should be further developed by community planners producing a District Plan – it is a tool that provides indicators for projects with likely investment opportunities, whether the opportunity is moving of a facility due to poor location and poor condition, renovating a building in a good location with poor condition, or demolition of a facility.

Expected Contributions

GIS data is typically managed by the GeoBase section within an Engineering Flight in a CE Squadron and is used mostly for its mapping functions and as a central repository of facility and infrastructure footprints on the base. This research shows additional ways that GIS data can be used and analyzed beyond providing necessary records of infrastructure locations during project execution and maintaining location data. This research also adds a way to quantify sprawl on installations, creating a way for GIS data to be used for community planners, and a way for principles to be incorporated when they are challenging to quantify the success of implementation.

The model hopes to influence improvements to the initial objective function in the 2022 District Planning Playbook, and if used and expanded, should alert planners' attention and installation resources on the projects with opportunities for investment that best provide value in supporting and aligning with the long-range planning objectives.

VII. Limitations and Future Work

Limitations

Analytic Hierarchy Process.

The expert elicitation did not come to a full consensus on each pairwise comparison. The data had to be cleaned and inconsistent responses (defined as CR < 0.1, (Saaty, 1987)) removed from the analysis. Possible inconsistencies in the subjective assessments of "which of the criteria is preferred and by how much" may be due to a combination of having little experience using the existing criteria that were introduced in the *District Planning Playbook* January 2022, differing professional experiences including installation location (city, rural, overseas, etc.), MAJCOM associated with their installation and differing installation goals associated with the MAJCOM, time in the position, community planning experience and education level, the order of pairs presented, and understanding of the proposed criteria.

Multi-Attribute Utility Theory.

Utility curves have been adapted from various locations, mostly based on the original model. These adaptations and combinations of attempts of quantifying criteria, could have inaccuracies introduced, or could be not the best way to quantify the criteria. In the future, these utility curves could be adapted without dramatic changes to the model as the weights could remain, just the utility values for the criteria when assessing projects would change.

Future Work Opportunities

The methods and resulting model presented in this paper can be converted into a tool to use, where entering the raw data from projects could calculate the projects scores and attach indicators for LHS or FSD deficiencies, locations in which airfield waivers or flood zones exist, poor condition and utilization recommend demolition, and more. The weights for the new model can be built back into the scores which can be used in easier application of the proposed model. Right now, the model requires using the utility curves to calculate scores and uses conditional formatting to flag scores as indicators for condition, interior capacity, and the top, middle, and bottom bucket thirds of exterior capacity and exterior configuration. An interface beyond conditional formatting in Microsoft Excel, in which the utility curves are calculated with the utility functions, would provide ease of use to community planners.

Appendix A. Data Cleaning

Appendix A shows the matrices compiled from the survey respondents on their pairwise comparisons. All respondents were checked for consistency, requiring CR < 0.1. This cleaning was essential due to the inconsistencies in survey answers of each pairwise comparison. Once the data was cleaned and inconsistent responses removed, scores were able to be taken and used in the resulting final AHP matrix in Table 4, with a CR = 0.014. Responses were anonymous, so the assigned response numbers were used to label tables.

128.202.204.245

Ranking is L/R	**BCI**	**MDI**	**Int Cap**	**Ext Cap**	**Ext Config**	**Int Config**	**Product^nth root**	**Weights**	**W'**	**W''**
Condition	1.00	1.00	1.00	2.00	4.00	1.00	1.4142	0.2089	1.3048	6.2448
MDI	1.00	1.00	1.00	3.00	5.00	2.00	1.7627	0.2604	1.5845	6.0841
Int Capacity	1.00	1.00	1.00	3.00	4.00	2.00	1.6984	0.2509	1.5133	6.0310
Ext Capacity	0.50	0.33	0.33	1.00	1.00	1.00	0.6177	0.0913	0.5546	6.0772
Ext Config	0.25	0.20	0.25	1.00	1.00	1.00	0.4817	0.0712	0.4468	6.2769
Int Config	1.00	0.50	0.50	1.00	1.00	1.00	0.7937	0.1173	0.7443	6.3474
						Sum	**6.7685**	**1.0000**	**Sum**	37.0613
									λMax	6.1769
									CI =	0.0354
									RI =	1.24
									CR =	0.028529

129.52.221.183

Ranking is L/R	**BCI**	**MDI**	**Int Cap**	**Ext Cap**	**Ext Config**	**Int Config**	**Product^nth root**	**Weights**	**W'**	**W''**
Condition	1.00	0.20	6.00	4.00	0.33	0.25	0.8584	0.0966	0.6329	6.5513
MDI	5.00	1.00	9.00	8.00	1.00	3.00	3.2031	0.3605	2.4876	6.8999
Int Capacity	0.17	0.11	1.00	0.20	0.17	0.11	0.2023	0.0228	0.1512	6.6382
Ext Capacity	0.25	0.13	5.00	1.00	0.25	0.17	0.4321	0.0486	0.3255	6.6920
Ext Config	3.00	1.00	6.00	4.00	1.00	0.25	1.6189	0.1822	1.2361	6.7837
Int Config	4.00	0.33	9.00	6.00	4.00	1.00	2.5698	0.2892	2.0215	6.9889
						Sum	**8.8846**	**1.0000**	**Sum**	40.5540
									λMax	6.7590
									CI =	0.1518
									RI =	1.24
									CR =	0.122419

131.25.63.50

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.20	3.00	0.14	7.00	6.00	1.2380	0.1239	1.0531	8.4963
MDI	5.00	1.00	6.00	0.13	3.00	8.00	2.1169	0.2120	1.5755	7.4334
Int Capacity	0.33	0.17	1.00	0.14	0.20	7.00	0.4724	0.0473	0.3527	7.4568
Ext Capacity	7.00	8.00	7.00	1.00	7.00	7.00	5.1750	0.5181	4.1032	7.9191
Ext Config	0.14	0.33	5.00	0.14	1.00	7.00	0.7873	0.0788	0.6166	7.8230
Int Config	0.17	0.13	0.14	0.14	0.14	1.00	0.1983	0.0199	0.1590	8.0118
						Sum	**9.9879**	**1.0000**	**Sum**	47.1404
									λMax	7.8567
									CI =	0.3713
									RI =	1.24
									CR =	0.299473

131.35.193.70

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	3.00	9.00	2.00	5.00	9.00	3.6666	0.4241	2.6514	6.2521
MDI	0.33	1.00	7.00	1.00	5.00	8.00	2.1298	0.2463	1.5819	6.4218
Int Capacity	0.11	0.14	1.00	0.20	0.33	1.00	0.3192	0.0369	0.2278	6.1706
Ext Capacity	0.50	1.00	5.00	1.00	2.00	2.00	1.4678	0.1698	1.0585	6.2352
Ext Config	0.20	0.20	3.00	0.50	1.00	1.00	0.6257	0.0724	0.4526	6.2544
Int Config	0.11	0.13	1.00	0.50	1.00	1.00	0.4368	0.0505	0.3226	6.3857
						Sum	**8.6459**	**1.0000**	**Sum**	37.7199
									λMax	6.2866
									CI =	0.0573
									RI =	1.24
									CR =	0.046233

131.36.207.8

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	2.00	3.00	1.00	0.33	3.00	1.3480	0.1761	1.0930	6.2071
MDI	0.50	1.00	6.00	1.00	0.25	2.00	1.0699	0.1398	0.9371	6.7050
Int Capacity	0.33	0.17	1.00	0.20	0.17	2.00	0.3933	0.0514	0.3389	6.5950
Ext Capacity	1.00	1.00	5.00	1.00	0.50	6.00	1.5704	0.2051	1.2713	6.1972
Ext Config	3.00	4.00	6.00	2.00	1.00	4.00	2.8845	0.3768	2.3860	6.3323
Int Config	0.33	0.50	0.50	0.17	0.25	1.00	0.3891	0.0508	0.3335	6.5606
						Sum	**7.6553**	**1.0000**	**Sum**	38.5972
									λMax	6.4329
									CI =	0.0866
									RI =	1.24
									CR =	0.069817

131.46.29.16

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.50	1.00	1.00	1.00	1.00	0.8909	0.1397	0.8603	6.1597
MDI	2.00	1.00	2.00	4.00	2.00	1.00	1.7818	0.2793	1.7293	6.1907
Int Capacity	1.00	0.50	1.00	1.00	0.50	1.00	0.7937	0.1244	0.7662	6.1575
Ext Capacity	1.00	0.25	1.00	1.00	0.33	0.50	0.5888	0.0923	0.5770	6.2507
Ext Config	1.00	0.50	2.00	3.00	1.00	1.00	1.2009	0.1883	1.1694	6.2110
Int Config	1.00	1.00	1.00	2.00	1.00	1.00	1.1225	0.1760	1.0923	6.2072
						Sum	**6.3786**	**1.0000**	**Sum**	37.1768
									λMax	6.1961
									CI =	0.0392
									RI =	1.24
									CR =	0.031635

131.48.25.143

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.33	1.00	2.00	1.00	2.00	1.0491	0.1296	0.8239	6.3548
MDI	3.00	1.00	5.00	6.00	6.00	6.00	3.8467	0.4754	3.1741	6.6774
Int Capacity	1.00	0.20	1.00	1.00	0.20	0.33	0.4870	0.0602	0.4160	6.9125
Ext Capacity	0.50	0.17	1.00	1.00	0.33	1.00	0.5503	0.0680	0.4097	6.0242
Ext Config	1.00	0.17	5.00	3.00	1.00	6.00	1.5704	0.1941	1.3444	6.9276
Int Config	0.50	0.17	3.00	1.00	0.17	1.00	0.5888	0.0728	0.4977	6.8401
						Sum	**8.0923**	**1.0000**	**Sum**	39.7365
									λMax	6.6228
									CI =	0.1246
									RI =	1.24
									CR =	0.100444

131.51.84.138

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	0.1663	1.0000	6.0134
MDI	1.00	1.00	0.50	1.00	1.00	1.00	0.8909	0.1482	0.9067	6.1198
Int Capacity	1.00	2.00	1.00	1.00	1.00	1.00	1.1225	0.1867	1.1482	6.1510
Ext Capacity	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	0.1663	1.0000	6.0134
Ext Config	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	0.1663	1.0000	6.0134
Int Config	1.00	1.00	1.00	1.00	1.00	1.00	1.0000	0.1663	1.0000	6.0134
						Sum	**6.0134**	**1.0000**	**Sum**	36.3242
									λMax	6.0540
									CI =	0.0108
									RI =	1.24
									CR =	0.008716

131.56.41.53

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	2.00	2.00	2.00	2.00	1.5874	0.2452	1.4924	6.0850
MDI	1.00	1.00	2.00	3.00	2.00	2.00	1.6984	0.2624	1.5833	6.0341
Int Capacity	0.50	0.50	1.00	2.00	2.00	0.50	0.8909	0.1376	0.8691	6.3145
Ext Capacity	0.50	0.33	0.50	1.00	1.00	0.50	0.5888	0.0910	0.5564	6.1162
Ext Config	0.50	0.50	0.50	1.00	1.00	1.00	0.7071	0.1092	0.6774	6.2003
Int Config	0.50	0.50	2.00	2.00	1.00	1.00	1.0000	0.1545	0.9748	6.3094
						Sum	**6.4726**	**1.0000**	**Sum**	37.0595
									λMax	6.1766
									CI =	0.0353
									RI =	1.24
									CR =	0.028480

131.59.144.34

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	1.00	9.00	7.00	9.00	2.8769	0.3225	1.9980	6.1961
MDI	1.00	1.00	1.00	9.00	4.00	3.00	2.1822	0.2446	1.5048	6.1521
Int Capacity	1.00	1.00	1.00	7.00	7.00	7.00	2.6458	0.2966	1.8183	6.1314
Ext Capacity	0.11	0.11	0.14	1.00	1.00	0.25	0.2759	0.0309	0.1975	6.3881
Ext Config	0.14	0.25	0.14	1.00	1.00	1.00	0.4149	0.0465	0.2860	6.1489
Int Config	0.11	0.33	0.14	4.00	1.00	1.00	0.5259	0.0590	0.3889	6.5967
						Sum	**8.9217**	**1.0000**	**Sum**	37.6132
									λMax	6.2689
									CI =	0.0538
									RI =	1.24
									CR =	0.043365

131.6.95.104

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.14	1.00	1.00	1.00	0.50	0.6441	0.0851	0.5285	6.2102
MDI	7.00	1.00	3.00	8.00	4.00	2.00	3.3220	0.4389	2.6783	6.1022
Int Capacity	1.00	0.33	1.00	3.00	1.00	0.33	0.8327	0.1100	0.6958	6.3243
Ext Capacity	1.00	0.13	0.33	1.00	0.50	0.33	0.4368	0.0577	0.3567	6.1813
Ext Config	1.00	0.25	1.00	2.00	1.00	1.00	0.8909	0.1177	0.7285	6.1893
Int Config	2.00	0.50	3.00	3.00	1.00	1.00	1.4422	0.1906	1.2011	6.3032
						Sum	**7.5688**	**1.0000**	**Sum**	37.3106
									λMax	6.2184
									CI =	0.0437
									RI =	1.24
									CR =	0.035230

132.18.180.144

Ranking is L/R	**BCI**	**MDI**	**Int Cap**	**Ext Cap**	**Ext Config**	**Int Config**	**Product^nth root**	**Weights**	**W'**	**W''**
Condition	1.00	1.00	3.00	6.00	4.00	4.00	2.5698	0.3146	1.9621	6.2363
MDI	1.00	1.00	6.00	6.00	4.00	6.00	3.0862	0.3779	2.4091	6.3758
Int Capacity	0.33	0.17	1.00	2.00	1.00	0.25	0.5503	0.0674	0.4370	6.4861
Ext Capacity	0.17	0.17	0.50	1.00	1.00	0.50	0.4368	0.0535	0.3280	6.1338
Ext Config	0.25	0.25	1.00	1.00	1.00	0.33	0.5246	0.0642	0.3990	6.2128
Int Config	0.25	0.17	4.00	2.00	3.00	1.00	1.0000	0.1224	0.8332	6.8053
						Sum	**8.1676**	**1.0000**	**Sum**	38.2501
									λMax	6.3750
									CI =	0.0750
									RI =	1.24
									CR =	0.060487

132.2.123.183

Ranking is L/R	**BCI**	**MDI**	**Int Cap**	**Ext Cap**	**Ext Config**	**Int Config**	**Product^nth root**	**Weights**	**W'**	**W''**
Condition	1.00	0.33	7.00	3.00	0.50	6.00	1.6610	0.2025	1.3245	6.5402
MDI	3.00	1.00	7.00	4.00	3.00	7.00	3.4760	0.4238	2.6310	6.2079
Int Capacity	0.14	0.14	1.00	0.50	0.25	1.00	0.3696	0.0451	0.2777	6.1611
Ext Capacity	0.33	0.25	2.00	1.00	0.17	3.00	0.6609	0.0806	0.5398	6.6989
Ext Config	2.00	0.33	4.00	6.00	1.00	1.00	1.5874	0.1935	1.4581	7.5335
Int Config	0.17	0.14	1.00	0.33	1.00	1.00	0.4466	0.0545	0.4142	7.6069
						Sum	**8.2016**	**1.0000**	**Sum**	40.7484
									λMax	6.7914
									CI =	0.1583
									RI =	1.24
									CR =	0.127646

132.24.26.94

Ranking is L/R	**BCI**	**MDI**	**Int Cap**	**Ext Cap**	**Ext Config**	**Int Config**	**Product^nth root**	**Weights**	**W'**	**W''**
Condition	1.00	0.33	9.00	0.20	0.25	1.00	0.7289	0.0806	0.5856	7.2625
MDI	3.00	1.00	9.00	5.00	1.00	4.00	2.8536	0.3157	2.0295	6.4290
Int Capacity	0.11	0.11	1.00	0.11	0.11	0.11	0.1602	0.0177	0.1269	7.1567
Ext Capacity	5.00	0.20	9.00	1.00	0.13	0.17	0.7565	0.0837	0.7778	9.2934
Ext Config	4.00	1.00	9.00	8.00	1.00	5.00	3.3604	0.3717	2.4917	6.7029
Int Config	1.00	0.25	9.00	6.00	0.20	1.00	1.1800	0.1305	1.0261	7.8608
						Sum	**9.0398**	**1.0000**	**Sum**	44.7053
									λMax	7.4509
									CI =	0.2902
									RI =	1.24
									CR =	0.234013

132.25.117.49

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	7.00	3.00	0.33	0.17	0.33	0.8544	0.1005	0.7101	7.0676
MDI	0.14	1.00	0.13	0.14	0.25	0.20	0.2244	0.0264	0.2006	7.6039
Int Capacity	0.33	8.00	1.00	0.20	0.25	0.25	0.5673	0.0667	0.4928	7.3870
Ext Capacity	3.00	7.00	5.00	1.00	3.00	5.00	3.4110	0.4012	2.7191	6.7783
Ext Config	6.00	4.00	4.00	0.33	1.00	4.00	2.2449	0.2640	1.9380	7.3403
Int Config	3.00	5.00	4.00	0.20	0.25	1.00	1.2009	0.1412	0.9877	6.9932
						Sum	**8.5029**	**1.0000**	**Sum**	43.1703
									λMax	7.1951
									CI =	0.2390
									RI =	1.24
									CR =	0.192751

132.42.225.47

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.50	2.00	8.00	5.00	3.00	2.2209	0.2838	1.7755	6.2554
MDI	2.00	1.00	5.00	8.00	3.00	2.00	2.7982	0.3576	2.2711	6.3509
Int Capacity	0.50	0.20	1.00	7.00	0.50	1.00	0.8395	0.1073	0.7648	7.1285
Ext Capacity	0.13	0.13	0.14	1.00	1.00	0.33	0.3010	0.0385	0.2556	6.6445
Ext Config	0.20	0.33	2.00	1.00	1.00	0.33	0.5952	0.0761	0.5507	7.2395
Int Config	0.33	0.50	1.00	3.00	3.00	1.00	1.0699	0.1367	0.8610	6.2971
						Sum	**7.8247**	**1.0000**	**Sum**	39.9159
									λMax	6.6526
									CI =	0.1305
									RI =	1.24
									CR =	0.105265

132.46.201.70

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.25	0.50	0.50	0.50	1.00	0.5612	0.0842	0.5247	6.2307
MDI	4.00	1.00	8.00	2.00	1.00	2.00	2.2449	0.3369	2.2791	6.7657
Int Capacity	2.00	0.13	1.00	1.00	0.50	1.00	0.7071	0.1061	0.6949	6.5493
Ext Capacity	2.00	0.50	1.00	1.00	1.00	1.00	1	0.1501	0.9158	6.1029
Ext Config	2.00	1.00	2.00	1.00	1.00	1.00	1.2599	0.1891	1.1903	6.2960
Int Config	1.00	0.50	1.00	1.00	1.00	1.00	0.8909	0.1337	0.8316	6.2203
						Sum	**6.6641**	**1.0000**	**Sum**	38.1648
									λMax	6.3608
									CI =	0.0722
									RI =	1.24
									CR =	0.058192

137.11.48.120

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.50	0.50	0.50	0.33	0.20	0.4503	0.0665	0.4561	6.8602
MDI	2.00	1.00	2.00	0.33	0.33	2.00	0.9806	0.1448	0.9588	6.6216
Int Capacity	2.00	0.50	1.00	0.25	1.00	5.00	1.0379	0.1533	1.1964	7.8062
Ext Capacity	2.00	3.00	4.00	1.00	0.50	2.00	1.6984	0.2508	1.7699	7.0573
Ext Config	3.00	3.00	1.00	2.00	1.00	3.00	1.9442	0.2871	1.8685	6.5087
Int Config	5.00	0.50	0.20	0.50	0.33	1.00	0.6609	0.0976	0.7542	7.7278
						Sum	**6.7722**	**1.0000**	**Sum**	42.5818
									λMax	7.0970
									CI =	0.2194
									RI =	1.24
									CR =	0.176931

137.242.171.70

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	1.00	9.00	1.00	1.00	1.4422	0.1993	1.1976	6.0093
MDI	1.00	1.00	1.00	9.00	1.00	1.00	1.4422	0.1993	1.1976	6.0093
Int Capacity	1.00	1.00	1.00	9.00	1.00	1.00	1.4422	0.1993	1.1976	6.0093
Ext Capacity	0.11	0.11	0.11	1.00	0.17	0.14	0.1788	0.0247	0.1495	6.0507
Ext Config	1.00	1.00	1.00	6.00	1.00	1.00	1.3480	0.1863	1.1235	6.0316
Int Config	1.00	1.00	1.00	7.00	1.00	1.00	1.3831	0.1911	1.1482	6.0078
						Sum	**7.2366**	**1.0000**	**Sum**	36.1180
									λMax	6.0197
									CI =	0.0039
									RI =	1.24
									CR =	0.003173

137.3.99.71

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	6.00	9.00	9.00	1.00	2.8040	0.2866	1.7746	6.1910
MDI	1.00	1.00	6.00	9.00	9.00	1.00	2.8040	0.2866	1.7746	6.1910
Int Capacity	0.17	0.17	1.00	8.00	2.00	0.11	0.6057	0.0619	0.4183	6.7563
Ext Capacity	0.11	0.11	0.13	1.00	0.20	0.11	0.1802	0.0184	0.1319	7.1572
Ext Config	0.11	0.11	0.50	5.00	1.00	0.11	0.3883	0.0397	0.2606	6.5636
Int Config	1.00	1.00	9.00	9.00	9.00	1.00	3	0.3067	1.9603	6.3922
						Sum	**9.7822**	**1.0000**	**Sum**	39.2513
									λMax	6.5419
									CI =	0.1084
									RI =	1.24
									CR =	0.087400

143.146.99.124

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	4.00	4.00	1.00	1.00	3.00	1.9064	0.2873	2.0242	7.0457
MDI	0.25	1.00	1.00	0.50	0.50	0.25	0.5	0.0754	0.4593	6.0958
Int Capacity	0.25	1.00	1.00	1.00	1.00	0.50	0.7071	0.1066	0.6649	6.2396
Ext Capacity	1.00	2.00	1.00	1.00	1.00	0.33	0.9347	0.1409	0.9159	6.5021
Ext Config	1.00	2.00	1.00	1.00	1.00	0.50	1	0.1507	0.9557	6.3418
Int Config	0.33	4.00	2.00	3.00	2.00	1.00	1.5874	0.2392	1.5735	6.5774
						Sum	**6.6355**	**1.0000**	**Sum**	38.8024
									λMax	6.4671
									CI =	0.0934
									RI =	1.24
									CR =	0.075334

166.205.218.68

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	2.00	1.00	1.00	1.00	1.1225	0.1838	1.1082	6.0293
MDI	1.00	1.00	3.00	1.00	1.00	1.00	1.2009	0.1967	1.2164	6.1856
Int Capacity	0.50	0.33	1.00	1.00	1.00	0.50	0.6609	0.1082	0.6851	6.3303
Ext Capacity	1.00	1.00	1.00	1.00	1.00	1.00	1	0.1638	1.0000	6.1068
Ext Config	1.00	1.00	1.00	1.00	1.00	1.00	1	0.1638	1.0000	6.1068
Int Config	1.00	1.00	2.00	1.00	1.00	1.00	1.1225	0.1838	1.1082	6.0293
						Sum	**6.1068**	**1.0000**	**Sum**	36.7880
									λMax	6.1313
									CI =	0.0263
									RI =	1.24
									CR =	0.021184

215.70.214.194

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.33	7.00	0.25	0.20	5.00	0.9141	0.1022	0.7175	7.0214
MDI	3.00	1.00	8.00	0.20	0.25	5.00	1.3480	0.1507	1.0643	7.0629
Int Capacity	0.14	0.13	1.00	0.17	0.14	4.00	0.3455	0.0386	0.2912	7.5401
Ext Capacity	4.00	5.00	6.00	1.00	0.50	7.00	2.7366	0.3059	2.0876	6.8241
Ext Config	5.00	4.00	7.00	2.00	1.00	5.00	3.3447	0.3739	2.5132	6.7217
Int Config	0.20	0.20	0.25	0.14	0.20	1.00	0.2566	0.0287	0.2074	7.2293
						Sum	**8.9455**	**1.0000**	**Sum**	42.3995
									λMax	7.0666
									CI =	0.2133
									RI =	1.24
									CR =	0.172028

215.71.39.163

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	0.25	3.00	0.33	0.33	0.6609	0.1041	0.8027	7.7076
MDI	1.00	1.00	1.00	6.00	2.00	1.00	1.5131	0.2384	1.6553	6.9423
Int Capacity	4.00	1.00	1.00	2.00	1.00	1.00	1.4142	0.2229	1.4098	6.3259
Ext Capacity	0.33	0.17	0.50	1.00	1.00	2.00	0.6177	0.0973	0.7890	8.1058
Ext Config	3.00	0.50	1.00	1.00	1.00	1.00	1.0699	0.1686	1.0891	6.4594
Int Config	3.00	1.00	1.00	0.50	1.00	1.00	1.0699	0.1686	1.1596	6.8778
						Sum	**6.3457**	**1.0000**	**Sum**	42.4187
									λMax	7.0698
									CI =	0.2140
									RI =	1.24
									CR =	0.172547

215.71.55.131

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	7.00	9.00	5.00	7.00	7.00	4.9898	0.4986	3.6246	7.2692
MDI	0.14	1.00	0.20	0.17	0.17	0.17	0.2257	0.0226	0.1748	7.7505
Int Capacity	0.11	5.00	1.00	0.17	0.17	0.17	0.3702	0.0370	0.2788	7.5377
Ext Capacity	0.20	6.00	6.00	1.00	4.00	5.00	2.2894	0.2288	1.6147	7.0579
Ext Config	0.14	6.00	6.00	0.25	1.00	5.00	1.3636	0.1363	1.0059	7.3817
Int Config	0.14	6.00	6.00	0.20	0.20	1.00	0.7683	0.0768	0.5783	7.5320
						Sum	**10.0070**	**1.0000**	**Sum**	44.5290
									λMax	7.4215
									CI =	0.2843
									RI =	1.24
									CR =	0.229274

131.10.22.72

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.50	0.50	6.00	2.00	0.50	1.0699	0.1476	0.9298	6.3016
MDI	2.00	1.00	3.00	6.00	2.00	1.00	2.0396	0.2813	1.7804	6.3294
Int Capacity	2.00	0.33	1.00	4.00	4.00	0.33	1.2354	0.1704	1.1619	6.8194
Ext Capacity	0.17	0.17	0.25	1.00	0.50	0.20	0.2976	0.0410	0.2531	6.1677
Ext Config	0.50	0.50	0.25	2.00	1.00	0.50	0.6300	0.0869	0.5624	6.4735
Int Config	2.00	1.00	3.00	5.00	2.00	1.00	1.9786	0.2729	1.7393	6.3743
						Sum	**7.2511**	**1.0000**	**Sum**	38.4659
									λMax	6.4110
									CI =	0.0822
									RI =	1.24
									CR =	0.066288

131.6.95.77

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	3.00	1.00	0.25	3.00	1.1447	0.1691	1.3103	7.7477
MDI	1.00	1.00	3.00	1.00	0.20	0.25	0.7289	0.1077	0.7499	6.9629
Int Capacity	0.33	0.33	1.00	0.20	0.25	0.33	0.3504	0.0518	0.3177	6.1353
Ext Capacity	1.00	1.00	5.00	1.00	1.00	2.00	1.4678	0.2169	1.4063	6.4846
Ext Config	4.00	5.00	4.00	1.00	1.00	0.33	1.7285	0.2554	1.9607	7.6778
Int Config	0.33	4.00	3.00	0.50	3.00	1.00	1.3480	0.1992	1.7162	8.6171
						Sum	**6.7683**	**1.0000**	**Sum**	43.6253
									λMax	7.2709
									CI =	0.2542
									RI =	1.24
									CR =	0.204981

134.131.184.23

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	1.00	2.00	1.00	0.50	1.00	1	0.1565	0.9819	6.2722
MDI	1.00	1.00	3.00	1.00	1.00	1.00	1.2009	0.1880	1.1610	6.1756
Int Capacity	0.50	0.33	1.00	0.33	0.33	1.00	0.5144	0.0805	0.4959	6.1590
Ext Capacity	1.00	1.00	3.00	1.00	3.00	2.00	1.6189	0.2534	1.6798	6.6281
Ext Config	2.00	1.00	3.00	0.33	1.00	2.00	1.2599	0.1972	1.2729	6.4536
Int Config	1.00	1.00	1.00	0.50	0.50	1.00	0.7937	0.1243	0.7747	6.2346
						Sum	**6.3878**	**1.0000**	**Sum**	37.9231
									λMax	6.3205
									CI =	0.0641
									RI =	1.24
									CR =	0.051696

140.175.44.56

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.13	5.00	4.00	3.00	0.50	1.2464	0.1188	0.7487	6.3027
MDI	8.00	1.00	9.00	9.00	9.00	9.00	6.1189	0.5831	4.2161	7.2299
Int Capacity	0.20	0.11	1.00	1.00	0.50	0.17	0.3504	0.0334	0.2120	6.3478
Ext Capacity	0.25	0.11	1.00	1.00	0.33	0.14	0.3313	0.0316	0.2040	6.4600
Ext Config	0.33	0.11	2.00	3.00	1.00	0.25	0.6177	0.0589	0.3683	6.2568
Int Config	2.00	0.11	6.00	7.00	4.00	1.00	1.8282	0.1742	1.1335	6.5057
						Sum	**10.4930**	**1.0000**	**Sum**	39.1030
									λMax	6.5172
									CI =	0.1034
									RI =	1.24
									CR =	0.083413

143.146.79.197

Ranking is L/R	BCI	MDI	Int Cap	Ext Cap	Ext Config	Int Config	Product^nth root	Weights	W'	W''
Condition	1.00	0.50	0.25	0.25	0.17	0.20	0.3184	0.0429	0.2663	6.2143
MDI	2.00	1.00	0.50	0.33	0.25	0.33	0.5503	0.0741	0.4494	6.0671
Int Capacity	4.00	2.00	1.00	0.33	0.20	1.00	0.9005	0.1212	0.7805	6.4383
Ext Capacity	4.00	3.00	3.00	1.00	1.00	2.00	2.0396	0.2746	1.7075	6.2191
Ext Config	6.00	4.00	5.00	1.00	1.00	1.00	2.2209	0.2990	1.9214	6.4271
Int Config	5.00	3.00	1.00	0.50	1.00	1.00	1.3991	0.1883	1.1823	6.2779
						Sum	**7.4289**	**1.0000**	**Sum**	37.6437
									λMax	6.2740
									CI =	0.0548
									RI =	1.24
									CR =	0.044186

Of the 30 responses, 11 were inconsistent, so the weights were calculated with the consistent remaining 19 responses.

Appendix B. Sensitivity Analysis

Appendix B shows the sensitivity analysis of +/–2% for each of the six criteria.

MDI (+2%)

Weights	0.3669		0.2146		0.1404		0.1163		0.0982		0.0635		
Project	**MDI UV**	**UV*W**	**BCI UV**	**UV*W**	**Interior Config UV**	**UV*W**	**Exterior Config UV**	**UV*W**	**Interior Capacity UV**	**UV*W**	**Exterior Capacity UV**	**UV*W**	**Score**
A	1	0.3669	0.05	0.0107	0.5	0.0702	0.4	0.0465	0	0.0000	0.2	0.0127	0.5071
B	1	0.3669	1	0.2146	0.5	0.0702	0.5	0.0582	0	0.0000	0.3	0.0191	0.7289
C	1	0.3669	0	0.0000	0.5	0.0702	0.7	0.0814	0.1	0.0098	0.9	0.0572	0.5855
D	1	0.3669	1	0.2146	0.75	0.1053	0.6	0.0698	1	0.0982	0.8	0.0508	0.9056
E	1	0.3669	0.1	0.0215	0.75	0.1053	0.4	0.0465	0	0.0000	0.3	0.0191	0.5592
F	0.92	0.3375	1	0.2146	0.75	0.1053	0.2	0.0233	0.25	0.0246	0.2	0.0127	0.7180
G	0.72	0.2642	0	0.0000	0.5	0.0702	0.6	0.0698	0	0.0000	0.3	0.0191	0.4232
H	0.52	0.1908	1	0.2146	0.5	0.0702	0.6	0.0698	0	0.0000	0.8	0.0508	0.5962
I	0.8	0.2935	0	0.0000	0.25	0.0351	0.6	0.0698	0.2	0.0196	0.5	0.0318	0.4498
J	0.4	0.1468	0	0.0000	0.5	0.0702	0.7	0.0814	1	0.0982	1	0.0635	0.4601

MDI (-2%)

Weights:	0.3269		0.2226		0.1484		0.1243		0.1062		0.0715		**Score**
Project:	**MDI UV**	**UV*W**	**BCI UV**	**UV*W**	**Interior Config UV**	**UV*W**	**Exterior Config UV**	**UV*W**	**Interior Capacity UV**	**UV*W**	**Exterior Capacity UV**	**UV*W**	
A	1	0.3269	0.05	0.0111	0.5	0.0742	0.4	0.0497	0	0.0000	0.2	0.0143	0.4763
B	1	0.3269	1	0.2226	0.5	0.0742	0.5	0.0622	0	0.0000	0.3	0.0215	0.7073
C	1	0.3269	0	0.0000	0.5	0.0742	0.7	0.0870	0.1	0.0106	0.9	0.0644	0.5631
D	1	0.3269	1	0.2226	0.75	0.1113	0.6	0.0746	1	0.1062	0.8	0.0572	0.8988
E	1	0.3269	0.1	0.0223	0.75	0.1113	0.4	0.0497	0	0.0000	0.3	0.0215	0.5316
F	0.92	0.3007	1	0.2226	0.75	0.1113	0.2	0.0249	0.25	0.0266	0.2	0.0143	0.7004
G	0.72	0.2354	0	0.0000	0.5	0.0742	0.6	0.0746	0	0.0000	0.3	0.0215	0.4056
H	0.52	0.1700	1	0.2226	0.5	0.0742	0.6	0.0746	0	0.0000	0.8	0.0572	0.5986
I	0.8	0.2615	0	0.0000	0.25	0.0371	0.6	0.0746	0.2	0.0212	0.5	0.0358	0.4302
J	0.4	0.1308	0	0.0000	0.5	0.0742	0.7	0.0870	1	0.1062	1	0.0715	0.4697

Condition (+2%)

Weights:	0.3429		0.2386		0.1404		0.1163		0.0982		0.0635		**Score**
Project:	**MDI UV**	**UV*W**	**BCI UV**	**UV*W**	**Interior Config UV**	**UV*W**	**Exterior Config UV**	**UV*W**	**Interior Capacity UV**	**UV*W**	**Exterior Capacity UV**	**UV*W**	
A	1	0.3429	0.05	0.0119	0.5	0.0702	0.4	0.0465	0	0.0000	0.2	0.0127	0.4843
B	1	0.3429	1	0.2386	0.5	0.0702	0.5	0.0582	0	0.0000	0.3	0.0191	0.7289
C	1	0.3429	0	0.0000	0.5	0.0702	0.7	0.0814	0.1	0.0098	0.9	0.0572	0.5615
D	1	0.3429	1	0.2386	0.75	0.1053	0.6	0.0698	1	0.0982	0.8	0.0508	0.9056
E	1	0.3429	0.1	0.0239	0.75	0.1053	0.4	0.0465	0	0.0000	0.3	0.0191	0.5376
F	0.92	0.3155	1	0.2386	0.75	0.1053	0.2	0.0233	0.25	0.0246	0.2	0.0127	0.7199
G	0.72	0.2469	0	0.0000	0.5	0.0702	0.6	0.0698	0	0.0000	0.3	0.0191	0.4059
H	0.52	0.1783	1	0.2386	0.5	0.0702	0.6	0.0698	0	0.0000	0.8	0.0508	0.6077
I	0.8	0.2743	0	0.0000	0.25	0.0351	0.6	0.0698	0.2	0.0196	0.5	0.0318	0.4306
J	0.4	0.1372	0	0.0000	0.5	0.0702	0.7	0.0814	1	0.0982	1	0.0635	0.4505

Condition (-2%)

Weights:	0.3509		0.1986		0.1484		0.1243		0.1062		0.0715		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3509	0.05	0.0099	0.5	0.0742	0.4	0.0497	0	0.0000	0.2	0.0143	0.4991
B	1	0.3509	1	0.1986	0.5	0.0742	0.5	0.0622	0	0.0000	0.3	0.0215	0.7073
C	1	0.3509	0	0.0000	0.5	0.0742	0.7	0.0870	0.1	0.0106	0.9	0.0644	0.5871
D	1	0.3509	1	0.1986	0.75	0.1113	0.6	0.0746	1	0.1062	0.8	0.0572	0.8988
E	1	0.3509	0.1	0.0199	0.75	0.1113	0.4	0.0497	0	0.0000	0.3	0.0215	0.5532
F	0.92	0.3228	1	0.1986	0.75	0.1113	0.2	0.0249	0.25	0.0266	0.2	0.0143	0.6984
G	0.72	0.2526	0	0.0000	0.5	0.0742	0.6	0.0746	0	0.0000	0.3	0.0215	0.4229
H	0.52	0.1825	1	0.1986	0.5	0.0742	0.6	0.0746	0	0.0000	0.8	0.0572	0.5870
I	0.8	0.2807	0	0.0000	0.25	0.0371	0.6	0.0746	0.2	0.0212	0.5	0.0358	0.4494
J	0.4	0.1404	0	0.0000	0.5	0.0742	0.7	0.0870	1	0.1062	1	0.0715	0.4793

Interior Configuration (+2%)

Weights:	0.3429		0.2146		0.1644		0.1163		0.0982		0.0635		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3429	0.05	0.0107	0.5	0.0822	0.4	0.0465	0	0.0000	0.2	0.0127	0.4951
B	1	0.3429	1	0.2146	0.5	0.0822	0.5	0.0582	0	0.0000	0.3	0.0191	0.7169
C	1	0.3429	0	0.0000	0.5	0.0822	0.7	0.0814	0.1	0.0098	0.9	0.0572	0.5735
D	1	0.3429	1	0.2146	0.75	0.1233	0.6	0.0698	1	0.0982	0.8	0.0508	0.8996
E	1	0.3429	0.1	0.0215	0.75	0.1233	0.4	0.0465	0	0.0000	0.3	0.0191	0.5532
F	0.92	0.3155	1	0.2146	0.75	0.1233	0.2	0.0233	0.25	0.0246	0.2	0.0127	0.7139
G	0.72	0.2469	0	0.0000	0.5	0.0822	0.6	0.0698	0	0.0000	0.3	0.0191	0.4179
H	0.52	0.1783	1	0.2146	0.5	0.0822	0.6	0.0698	0	0.0000	0.8	0.0508	0.5957
I	0.8	0.2743	0	0.0000	0.25	0.0411	0.6	0.0698	0.2	0.0196	0.5	0.0318	0.4366
J	0.4	0.1372	0	0.0000	0.5	0.0822	0.7	0.0814	1	0.0982	1	0.0635	0.4625

Interior Configuration (-2%)

Weights:	0.3509		0.2226		0.1244		0.1243		0.1062		0.0715		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3509	0.05	0.0111	0.5	0.0622	0.4	0.0497	0	0.0000	0.2	0.0143	0.4883
B	1	0.3509	1	0.2226	0.5	0.0622	0.5	0.0622	0	0.0000	0.3	0.0215	0.7193
C	1	0.3509	0	0.0000	0.5	0.0622	0.7	0.0870	0.1	0.0106	0.9	0.0644	0.5751
D	1	0.3509	1	0.2226	0.75	0.0933	0.6	0.0746	1	0.1062	0.8	0.0572	0.9048
E	1	0.3509	0.1	0.0223	0.75	0.0933	0.4	0.0497	0	0.0000	0.3	0.0215	0.5376
F	0.92	0.3228	1	0.2226	0.75	0.0933	0.2	0.0249	0.25	0.0266	0.2	0.0143	0.7044
G	0.72	0.2526	0	0.0000	0.5	0.0622	0.6	0.0746	0	0.0000	0.3	0.0215	0.4109
H	0.52	0.1825	1	0.2226	0.5	0.0622	0.6	0.0746	0	0.0000	0.8	0.0572	0.5990
I	0.8	0.2807	0	0.0000	0.25	0.0311	0.6	0.0746	0.2	0.0212	0.5	0.0358	0.4434
J	0.4	0.1404	0	0.0000	0.5	0.0622	0.7	0.0870	1	0.1062	1	0.0715	0.4673

Exterior Configuration (+2%)

Weights:	0.3429		0.2146		0.1404		0.1403		0.0982		0.0635		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3429	0.05	0.0107	0.5	0.0702	0.4	0.0561	0	0.0000	0.2	0.0127	0.4927
B	1	0.3429	1	0.2146	0.5	0.0702	0.5	0.0702	0	0.0000	0.3	0.0191	0.7169
C	1	0.3429	0	0.0000	0.5	0.0702	0.7	0.0982	0.1	0.0098	0.9	0.0572	0.5783
D	1	0.3429	1	0.2146	0.75	0.1053	0.6	0.0842	1	0.0982	0.8	0.0508	0.8960
E	1	0.3429	0.1	0.0215	0.75	0.1053	0.4	0.0561	0	0.0000	0.3	0.0191	0.5448
F	0.92	0.3155	1	0.2146	0.75	0.1053	0.2	0.0281	0.25	0.0246	0.2	0.0127	0.7007
G	0.72	0.2469	0	0.0000	0.5	0.0702	0.6	0.0842	0	0.0000	0.3	0.0191	0.4203
H	0.52	0.1783	1	0.2146	0.5	0.0702	0.6	0.0842	0	0.0000	0.8	0.0508	0.5981
I	0.8	0.2743	0	0.0000	0.25	0.0351	0.6	0.0842	0.2	0.0196	0.5	0.0318	0.4450
J	0.4	0.1372	0	0.0000	0.5	0.0702	0.7	0.0982	1	0.0982	1	0.0635	0.4673

Exterior Configuration (-2%)

Weights:	0.3509		0.2226		0.1484		0.1003		0.1062		0.0715		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3509	0.05	0.0111	0.5	0.0742	0.4	0.0401	0	0.0000	0.2	0.0143	0.4907
B	1	0.3509	1	0.2226	0.5	0.0742	0.5	0.0502	0	0.0000	0.3	0.0215	0.7193
C	1	0.3509	0	0.0000	0.5	0.0742	0.7	0.0702	0.1	0.0106	0.9	0.0644	0.5703
D	1	0.3509	1	0.2226	0.75	0.1113	0.6	0.0602	1	0.1062	0.8	0.0572	0.9084
E	1	0.3509	0.1	0.0223	0.75	0.1113	0.4	0.0401	0	0.0000	0.3	0.0215	0.5460
F	0.92	0.3228	1	0.2226	0.75	0.1113	0.2	0.0201	0.25	0.0266	0.2	0.0143	0.7176
G	0.72	0.2526	0	0.0000	0.5	0.0742	0.6	0.0602	0	0.0000	0.3	0.0215	0.4085
H	0.52	0.1825	1	0.2226	0.5	0.0742	0.6	0.0602	0	0.0000	0.8	0.0572	0.5966
I	0.8	0.2807	0	0.0000	0.25	0.0371	0.6	0.0602	0.2	0.0212	0.5	0.0358	0.4350
J	0.4	0.1404	0	0.0000	0.5	0.0742	0.7	0.0702	1	0.1062	1	0.0715	0.4625

Interior Capacity (+2%)

Weights:	0.3429		0.2146		0.1404		0.1163		0.1222		0.0635		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3429	0.05	0.0107	0.5	0.0702	0.4	0.0465	0	0.0000	0.2	0.0127	0.4831
B	1	0.3429	1	0.2146	0.5	0.0702	0.5	0.0582	0	0.0000	0.3	0.0191	0.7049
C	1	0.3429	0	0.0000	0.5	0.0702	0.7	0.0814	0.1	0.0122	0.9	0.0572	0.5639
D	1	0.3429	1	0.2146	0.75	0.1053	0.6	0.0698	1	0.1222	0.8	0.0508	0.9056
E	1	0.3429	0.1	0.0215	0.75	0.1053	0.4	0.0465	0	0.0000	0.3	0.0191	0.5352
F	0.92	0.3155	1	0.2146	0.75	0.1053	0.2	0.0233	0.25	0.0306	0.2	0.0127	0.7019
G	0.72	0.2469	0	0.0000	0.5	0.0702	0.6	0.0698	0	0.0000	0.3	0.0191	0.4059
H	0.52	0.1783	1	0.2146	0.5	0.0702	0.6	0.0698	0	0.0000	0.8	0.0508	0.5837
I	0.8	0.2743	0	0.0000	0.25	0.0351	0.6	0.0698	0.2	0.0244	0.5	0.0318	0.4354
J	0.4	0.1372	0	0.0000	0.5	0.0702	0.7	0.0814	1	0.1222	1	0.0635	0.4745

Interior Capacity (-2%)

Weights:	0.3509		0.2226		0.1484		0.1243		0.0822		0.0715		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3509	0.05	0.0111	0.5	0.0742	0.4	0.0497	0	0.0000	0.2	0.0143	0.5003
B	1	0.3509	1	0.2226	0.5	0.0742	0.5	0.0622	0	0.0000	0.3	0.0215	0.7313
C	1	0.3509	0	0.0000	0.5	0.0742	0.7	0.0870	0.1	0.0082	0.9	0.0644	0.5847
D	1	0.3509	1	0.2226	0.75	0.1113	0.6	0.0746	1	0.0822	0.8	0.0572	0.8988
E	1	0.3509	0.1	0.0223	0.75	0.1113	0.4	0.0497	0	0.0000	0.3	0.0215	0.5556
F	0.92	0.3228	1	0.2226	0.75	0.1113	0.2	0.0249	0.25	0.0206	0.2	0.0143	0.7164
G	0.72	0.2526	0	0.0000	0.5	0.0742	0.6	0.0746	0	0.0000	0.3	0.0215	0.4229
H	0.52	0.1825	1	0.2226	0.5	0.0742	0.6	0.0746	0	0.0000	0.8	0.0572	0.6110
I	0.8	0.2807	0	0.0000	0.25	0.0371	0.6	0.0746	0.2	0.0164	0.5	0.0358	0.4446
J	0.4	0.1404	0	0.0000	0.5	0.0742	0.7	0.0870	1	0.0822	1	0.0715	0.4553

Exterior Capacity (+2%)

Weights:	0.3429		0.2146		0.1404		0.1163		0.0982		0.0875		Score
Project:	MDI UV	UV*W	BCI UV	UV*W	Interior Config UV	UV*W	Exterior Config UV	UV*W	Interior Capacity UV	UV*W	Exterior Capacity UV	UV*W	
A	1	0.3429	0.05	0.0107	0.5	0.0702	0.4	0.0465	0	0.0000	0.2	0.0175	0.4879
B	1	0.3429	1	0.2146	0.5	0.0702	0.5	0.0582	0	0.0000	0.3	0.0263	0.7121
C	1	0.3429	0	0.0000	0.5	0.0702	0.7	0.0814	0.1	0.0098	0.9	0.0788	0.5831
D	1	0.3429	1	0.2146	0.75	0.1053	0.6	0.0698	1	0.0982	0.8	0.0700	0.9008
E	1	0.3429	0.1	0.0215	0.75	0.1053	0.4	0.0465	0	0.0000	0.3	0.0263	0.5424
F	0.92	0.3155	1	0.2146	0.75	0.1053	0.2	0.0233	0.25	0.0246	0.2	0.0175	0.7007
G	0.72	0.2469	0	0.0000	0.5	0.0702	0.6	0.0698	0	0.0000	0.3	0.0263	0.4131
H	0.52	0.1783	1	0.2146	0.5	0.0702	0.6	0.0698	0	0.0000	0.8	0.0700	0.6029
I	0.8	0.2743	0	0.0000	0.25	0.0351	0.6	0.0698	0.2	0.0196	0.5	0.0438	0.4426
J	0.4	0.1372	0	0.0000	0.5	0.0702	0.7	0.0814	1	0.0982	1	0.0875	0.4745

Exterior Capacity (-2%)

Weights:	0.3509		0.2226		0.1484		0.1243		0.1062		0.0475		**Score**
Project:	**MDI UV**	**UV*W**	**BCI UV**	**UV*W**	**Interior Config UV**	**UV*W**	**Exterior Config UV**	**UV*W**	**Interior Capacity UV**	**UV*W**	**Exterior Capacity UV**	**UV*W**	
A	1	0.3509	0.05	0.0111	0.5	0.0742	0.4	0.0497	0	0.0000	0.2	0.0095	0.4955
B	1	0.3509	1	0.2226	0.5	0.0742	0.5	0.0622	0	0.0000	0.3	0.0143	0.7241
C	1	0.3509	0	0.0000	0.5	0.0742	0.7	0.0870	0.1	0.0106	0.9	0.0428	0.5655
D	1	0.3509	1	0.2226	0.75	0.1113	0.6	0.0746	1	0.1062	0.8	0.0380	0.9036
E	1	0.3509	0.1	0.0223	0.75	0.1113	0.4	0.0497	0	0.0000	0.3	0.0143	0.5484
F	0.92	0.3228	1	0.2226	0.75	0.1113	0.2	0.0249	0.25	0.0266	0.2	0.0095	0.7176
G	0.72	0.2526	0	0.0000	0.5	0.0742	0.6	0.0746	0	0.0000	0.3	0.0143	0.4157
H	0.52	0.1825	1	0.2226	0.5	0.0742	0.6	0.0746	0	0.0000	0.8	0.0380	0.5918
I	0.8	0.2807	0	0.0000	0.25	0.0371	0.6	0.0746	0.2	0.0212	0.5	0.0238	0.4374
J	0.4	0.1404	0	0.0000	0.5	0.0742	0.7	0.0870	1	0.1062	1	0.0475	0.4553

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14. ABSTRACT
The United States Air Force (USAF) relies on its installations to project military power across the globe. However, due to the deferred infrastructure maintenance and recapitalization backlog of $33 billion as of 2019 (Wilson & Goldfein, 2019), it is more critical than ever for base-level community planners to focus their attention to the projects that will achieve each installation's long-term goals. The recent incorporation of asset management principles into the USAF District Planning Process allows a unique opportunity to improve the existing scoring model for a holistic look at what matters to enterprise leaders and community planners making the plans at the installations. This thesis offers a new model combining asset management and community planning principles. I use Multi-Attribute Utility Theory (MAUT) and the Analytic Hierarchy Process (AHP) to define the scoring for the criteria through utility curves, and the weights for the criteria, through an expert elicitation study of pairwise comparisons. The model was tested in a case study of ten projects at Hill AFB, assessing the projects using the six criteria of building condition, building importance, interior capacity, exterior capacity, interior configuration, and exterior configuration. The results show that facilities in the ideal condition range for investment that are sited poorly as to increase infrastructure maintenance liabilities, rise higher in the scoring to alert the planner to consider action. The methodologies provided in this thesis are expected to help shape the next iteration of guidance in the USAF District Planning Process, enabling the enterprise to reduce the infrastructure maintenance and recapitalization backlog burden on its installations.

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