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# Developing an Adaptable Best Value Contractor Selection Tool for Federal Construction Projects

Robert B. Kitson

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THESIS

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**Developing an Adaptable Best Value Contractor Selection Tool for Federal Construction Projects**

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DEVELOPING AN ADAPTABLE BEST VALUE CONTRACTOR SELECTION TOOL FOR FEDERAL CONSTRUCTION PROJECTS

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## Abstract

Currently, there is no Air Force-wide best practice or standard for using an other-than lowest price source selection process for construction projects. Installations often award contracts using Lowest Price Technically Acceptable (LPTA) because of perceived cost and time savings. However, a heavy reliance on LPTA often leads to long-term decreases in quality and value. To allow the Air Force to receive the best value for its construction funding, a simple and adaptable tool was developed that allows installations to pursue contractor selection for construction projects by other-than lowest price methods. This research conducted a systematic literature review to obtain a list of the most frequently used contractor selection criteria from research. Using the PRISMA Process guidelines, a research question was developed to identify evaluation criteria that could be used to assess and select construction contractors and subcontractors from those bidding on a construction project. Using these criteria, a Multi-Criteria Decision-Making tool was built that uses the Analytic Hierarchy Process to weigh each criterion. Multi-Attribute Utility Theory is then used to score contractor data for each criterion. The final Performance Index shows the most qualified contractor based on the inputs to the source selection tool. This source selection tool will allow the Air Force to maximize the value of its construction funds within federal guidelines and the aggregated list of most frequently used criteria may benefit other construction contractor selection research.

*Dedication*

**Acknowledgments**

I would like to thank my advisor and my other faculty for allowing me to pursue an exciting research topic that could have real-world impacts on the Air Force and our construction programs.  I found my time learning here at AFIT to be one of the best experiences in my career to date.  The tools you all gave me will stick with me throughout the rest of my Air Force career and beyond.

I would also like to thank my wife for her unwavering support for me over the last 18 months.  You were the rudder that has kept my ship steady and, at times, also the motor that pushed me forward to the finish line.  I am so grateful for all of the little things you have helped with during this thesis process, especially the proofreading!  The effort you put towards helping me be my best while going through your own struggles inspired me to achieve more academically than I have in a very long time.  All of my achievements would not be possible if not for you.  Thank you!

Robert Kitson

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## I. Introduction

Background

Almost half of all construction projects within the Department of Defense (DoD) over the last 10 years have experienced a cost and/or schedule overrun (Teston and Stout 2021). A 2012 study found 18 factors that lead to overruns in construction projects (Ramanathan et al. 2012). Over half of the factors presented can link back to the contractor selected for the project. If the wrong contractor is awarded a construction project contract, it could lead to an increase in overruns for project owners, like the DoD.

Construction project contracts are awarded using a variety of methods. Sometimes the contract to build a project goes to the lowest priced bidder. Other times, a factor such as past work experience in a specific field of construction may be the reason for choosing one contractor over another. Often, the choices a project owner has on how they can solicit bids is legally constrained based on what kind of an organization to which they belong. For example, a private corporation wishing to build a new headquarters building has more leeway in how it selects a contractor for carrying out the construction project than a government organization like the United States Air Force. According to Federal Acquisition Regulations (FAR) Part 15.101, the Air Force can use several source selection approaches to meet mission objectives. These approaches fall under two

categories: the Tradeoff Process and Lowest Price Technically Acceptable (LPTA) (General Services Administration 2020).

Although there are two approaches available for source selection of Air Force projects, LPTA is often the chosen approach due to perceived cost and time savings during the acquisition process. However, lower quality and value can result from relying too heavily on LPTA, which can create an environment of cost-cutting above all else (Gansler and Lucyshyn 2013). Conversely, there is no best practice or standard for using the Tradeoff Process for source selection of Air Force construction projects. This disincentivizes Civil Engineer (CE) and Contracting Squadrons from using an other-than lowest price selection method. In order to utilize the Tradeoff Process of source selection, a list of evaluation factors needs to be presented during the solicitation phase. These factors must be ranked by relative importance to each other and to the cost or price of the bid (General Services Administration 2020). Creating a simple and flexible contractor selection tool that allows individual Air Force installations to adapt to their mission needs could increase the value the Air Force receives from its construction program.

## Objectives

An Air Force-wide source selection tool would need to meet three main goals to be accepted and used by both the CE and Contracting career fields. These goals are:

(1) Design the tool to meet FAR requirements of the Tradeoff Process

(2) Maintain simplicity to allow easy use by minimally trained base personnel

(3) Allow for adaptability to meet specific mission or installation needs and priorities

The first step in creating this tool would be to meet FAR requirements. This means a list of evaluation factors will need to be created. Currently, there is not a consensus on which criteria should be used by public entities for their contractor selection process. Using a systematic literature review, a synthesized listing of criteria can be obtained from both industry and research. The criteria will then be built into the multi-criteria decision-making (MCDM) tool that can be used by individual installations. The Analytic Hierarchy Process (AHP) will be used to compare the criteria and determine weighted importance. The AHP method of decision-making uses pairwise comparisons to achieve a hierarchy of importance for the factors in a decision (Saaty 1990). The final list of criteria and rankings of relative importance will meet the specific requirements of FAR Part 15-101-1, thus satisfying the first goal of the source selection tool.

The second goal of the source selection tool is that it is simple to use. One of the main justifications for using AHP in the construction management field is its simplicity (Darko et al. 2019). A scoring method will also be needed for the selection criteria being evaluated. Multi-Attribute Utility Theory (MAUT) is one method that can perform this function in the source selection process. Using AHP and MAUT together provides a consistent, repeatable, and defendable process for prioritizing and scoring multi-criteria decisions (Karydas and Grifun 2006). Minimally trained base personnel using this

MDCM tool will be able to simply and repeatably select the optimal contractor for each construction project.

The third and final goal of the source selection tool is to be adaptable for different mission and installation needs.  By utilizing AHP to weigh and compare criteria, users can modify the pairwise comparisons for a specific installation or even a specific project. Flexibility in valuing specific criteria based on importance is beneficial to project owners when considering different projects and their requirements.  For example, a Military Construction (MILCON) project to build a new taxiway might need to have a higher weight for the past project experience criteria regarding previous pavement projects. When put together, this tool will be applicable for any Air Force installation to use in their contractor selection process, allowing them to pursue an other-than Lowest Price Technically Acceptable source selection process.

## II. Literature Review

In order to determine which contractor selection criteria to include in the federal source selection tool, it was important to look to industry and past research for the most-utilized factors. A 2014 review of literature by Kog and Yaman performed a meta classification and analysis of contractor selection and pre-qualifications. Their findings showed that statistical models, fuzzy set theory, and AHP are the most preferred methods for selecting a contractor, but they do not discuss specific criteria (Kog and Yaman 2014). Another literature review also showed ranking tools/analysis, fuzzy theory, and AHP as the most prominent areas of research regarding contractor selection (Acheamfour et al. 2021).

Two recent studies reviewed literature to determine the top criteria used in contractor selection; however, both were limited in size and scope. The first study only included 26 papers and was focused on contractor pre-qualification (Acheamfour et al. 2020). The second study, while more thorough (reviewing 71 publications), analyzed no studies from the United States and only one publication from the United Kingdom (Khoso and Yusof 2020). The trend shown in large-scale reviews has the United Kingdom as the highest historical contributor of publications in the field of contractor selection (Acheamfour et al. 2021; Kog and Yaman 2014). Because of the limitations of these previous literature reviews, it was determined that a full systematic review of contractor selection literature was required to determine a comprehensive and complete list of selection criteria.

A systematic literature review was conducted to obtain this comprehensive list of criteria. A systematic review is a review which follows established guidelines to systematically find and review research publications (Grant and Booth 2009). Conducting a literature review allowed this research to identify specific criteria that can benefit public entities in the construction realm. By following a systematic approach, the final list produced is current, verifiable, and relevant for wide spread use within the construction management career field.

One of the more prominent sets of systematic review guidelines is the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Process (Moher et al. 2009). This process was developed for the medical research community to establish credibility among review articles by providing a standard that can be recognized and understood by readers to assess the quality and scope of the review. This standard allows authors to better identify and reduce biases in their reviews based on the steps they did or did not follow in selecting the publications to review (Moher et al. 2009). Using the PRISMA process ensured this review was thorough and free from potential biases when selecting articles to review.

## Research Question

The first step in this process was to identify a research question or questions addressed within the systematic review. This question should reference the participants, interventions, comparisons, outcomes, and study design (PICOS) of the overall research topic (Moher et al. 2009). This framework stems from the field of clinical studies, where

clearly defined research goals for a clinical trial are needed to identify the various facets of the study. While this review was not a clinical study involving medical research, the basic framework of developing a research question by using the PICOS template was still applicable. Following this template, the research question asked: “What evaluation criteria are used to assess and select construction contractors and subcontractors from those bidding on a construction project?”

From this research question, the review process began. Databases containing published material were identified by the author and used to search for journal articles, conference papers, and other material. The selected databases were SCOPUS and Web of Science Core Collection. These two databases contain a large number of reputable journals that are among the top databases in the science community. For both databases, a Title-Abstract-Keyword search string was created.

Search String

Using the research question as a guideline, the search string was defined as: (construction AND contractor OR subcontractor OR contract OR bid AND selecti* OR procur* OR tender* OR bid* OR evaluat* AND criteria OR criterion OR qualification*). This string contained four parts. The first is the term “construction.” This term ensured that the appropriate field of study was obtained in the search results. Articles and papers that talk about contractors and selection criteria in fields other than construction were outside of the scope of the research question, which asks explicitly about assessing and selecting construction contractors and subcontractors.

The next part of the search string is a set of terms defining the "population" of the research question: the contractors. The terms "contractor," "subcontractor," "contract," and "bid" were all included in this section of the search string. While the end goal of this review was to use the evaluation criteria to build a tool for selecting Air Force construction project contractors, reviewing criteria for subcontractors as well as contractors provided a broader list of criteria that could similarly be applied for selecting either position. Including terms like "contract" and "bid" helped to grab publications that discussed selecting a contractor with reference to the documents and not necessarily the people. Criteria used in those assessments would still be valid for inclusion in this review.

The third section of the search string is the "interventions" part of the research question. For this part, the roots of the words "selection," "procurement," "tendering," "bidding," and "evaluation" were all included. The terms can each take a different form (like "selection," "selected," "selecting," etc.) that were all relevant for the search, hence the inclusion of the (*) symbology. All five of the words in this third section are industry-standard terms that could isolate publications which discuss the process of assessing and choosing the best contractor for a specific job.

The final part of the search string is the "objectives" section. This section included the terms "criteria," "criterion," and "qualification" (with the (*) again present on "qualification" to include other words like "qualifications"). These terms isolated publications that explicitly discuss the requirements for selecting a contractor for a

project.  The objective of the review was to gather these requirements and apply them to the source selection tool.

## Identification

After defining the search string, a search was performed in the selected databases. This step in the PRISMA Process is called “Identification” (Moher et al. 2009).  Using the PRISMA Flow Chart in Fig. 1, the number of results from the various database searches was reported at this phase.  The search results were initially screened with two inclusion criteria for both the SCOPUS and the Web of Science reviews.  First, the reported language of the publication must be English.  Second, the publication type must be an article, conference paper, or a review.  With these initial criteria and the search string, 1,140 publications were identified in SCOPUS, while 984 publications were identified in Web of Science.

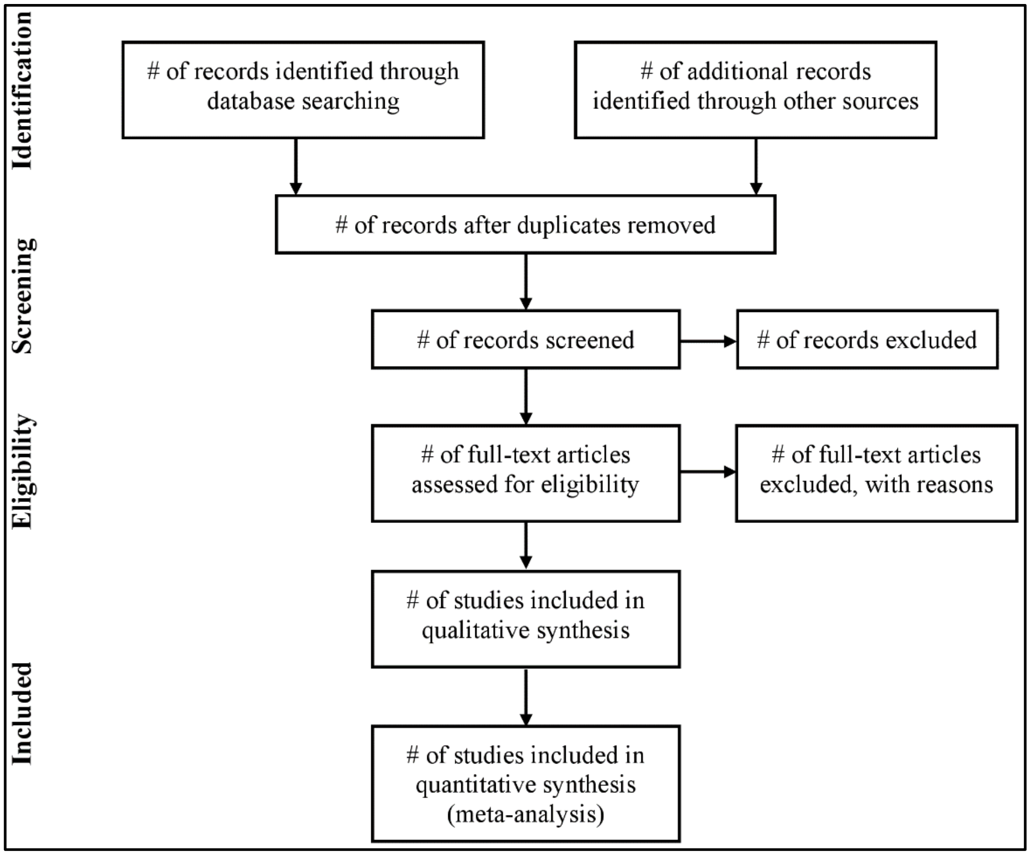



**Fig. 1.** PRISMA Flow Chart (Moher et al. 2009)

<u>Screening</u>

The next phase of the PRISMA Process, as shown in Fig. 1, is screening. Records, or publications in this case, were removed based on inclusion and exclusion criteria. Any publication considered a duplicate was removed, as well. The duplicates in both the SCOPUS and Web of Science search results totaled 494 records. The total number of publications after removing the duplicates was 1,630.

The remaining steps of screening are a title-level pass and an abstract-level pass. These two screenings involve reading the publication's title (and subsequently its

abstract) to determine if it is appropriate for inclusion in the study. To accomplish this step, a set of pre-defined inclusion and exclusion criteria were needed. Papers not related to the construction industry were identified, despite having “construction” as one of the search string terms. Along with the two criteria applied at the database search level, inclusion in this study required the publications to relate to the construction industry. Papers must also have discussed an owner or contractor hiring a contractor or subcontractor, respectively, in order to pass the inclusion criteria. This ensured that the articles included related to the research question’s goal of identifying criteria for selecting a contractor or subcontractor. Finally, the last inclusion criterion was that the publication must consider multiple criteria. Since the final source selection tool will be utilizing a multiple criteria decision-making process, the papers included need to consider more than one criterion for selecting a construction contractor or subcontractor.

Next, the review required exclusion criteria to identify publications that did not answer the research question. “Equipment purchasing” and “supplier selection” were two of these exclusion criteria. Papers with these phrases, while likely discussing selection criteria, do not cover selecting a company (contractor or subcontractor) as a whole. An additional set of terms used to exclude articles was “penalties” and “delays,” as these indicated topics that covered contractor performance but not initial selection. “Submittals” and “bidding strategies” indicated papers that examine the source selection process from the contractor side instead of from the project owner side. Since this review was not focusing on the financial processes of construction companies, “bonding/surety”

was also used as an exclusion criterion. The final exclusion criterion was "project delivery systems." While this topic impacts how a contractor can be selected by a project owner, papers that discuss delivery systems tend not to discuss selection criteria, instead, taking a broader look at the process as a whole. Therefore, those articles and papers were not included in the review.

The screening process, using the defined inclusion and exclusion criteria, was conducted on both the title-level pass and the abstract-level pass. For the title-level pass, the author found that 416 publications met the screening criteria while 1,214 publications were excluded. For the abstract-level pass, the author found that 201 publications met the screening criteria, excluding 215 publications.

Eligibility and Inclusion

After completing the screening process for both the title and abstract levels, the next step in the PRISMA Process was assessing full-text articles for eligibility (Moher et al. 2009). Reasons for excluding an article at this review step included not having access to an article or excluding an article for not meeting the screening criteria after reading the full text. Eighteen articles were excluded due to not meeting the screening criteria, while 71 were excluded due to a lack of access to those journals, leaving the final included total as 112 publications. The final numbers of records included and excluded at each step is shown in Fig. 2.

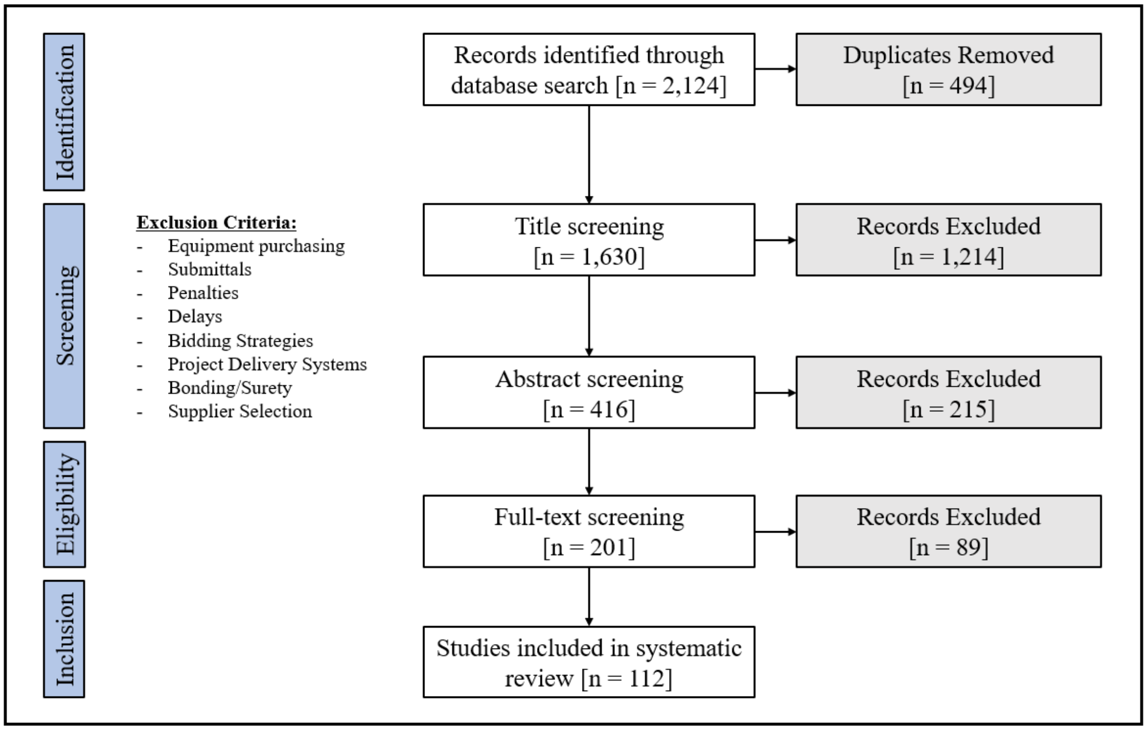



**Fig. 2.** Completed Steps of PRISMA Process

<u>Bibliometrics</u>

The 112 publications obtained through the PRISMA process were analyzed using the bibliometric tool VOSviewer. Fig. 3 shows the Keyword Co-Occurrences for these 112 papers for keywords that occurred six or more times. In total, there are 29 keywords shown in Fig. 3. The three important features of the analysis were the circle size (occurrences), line weight (co-occurrences), and color (relationship). A larger circle indicates more occurrences throughout the 112 publications. The top five keywords by occurrence were contractors, construction industry, project management, decision making, and contractor selection. These are all terms expected from the search string used to perform this systematic review.

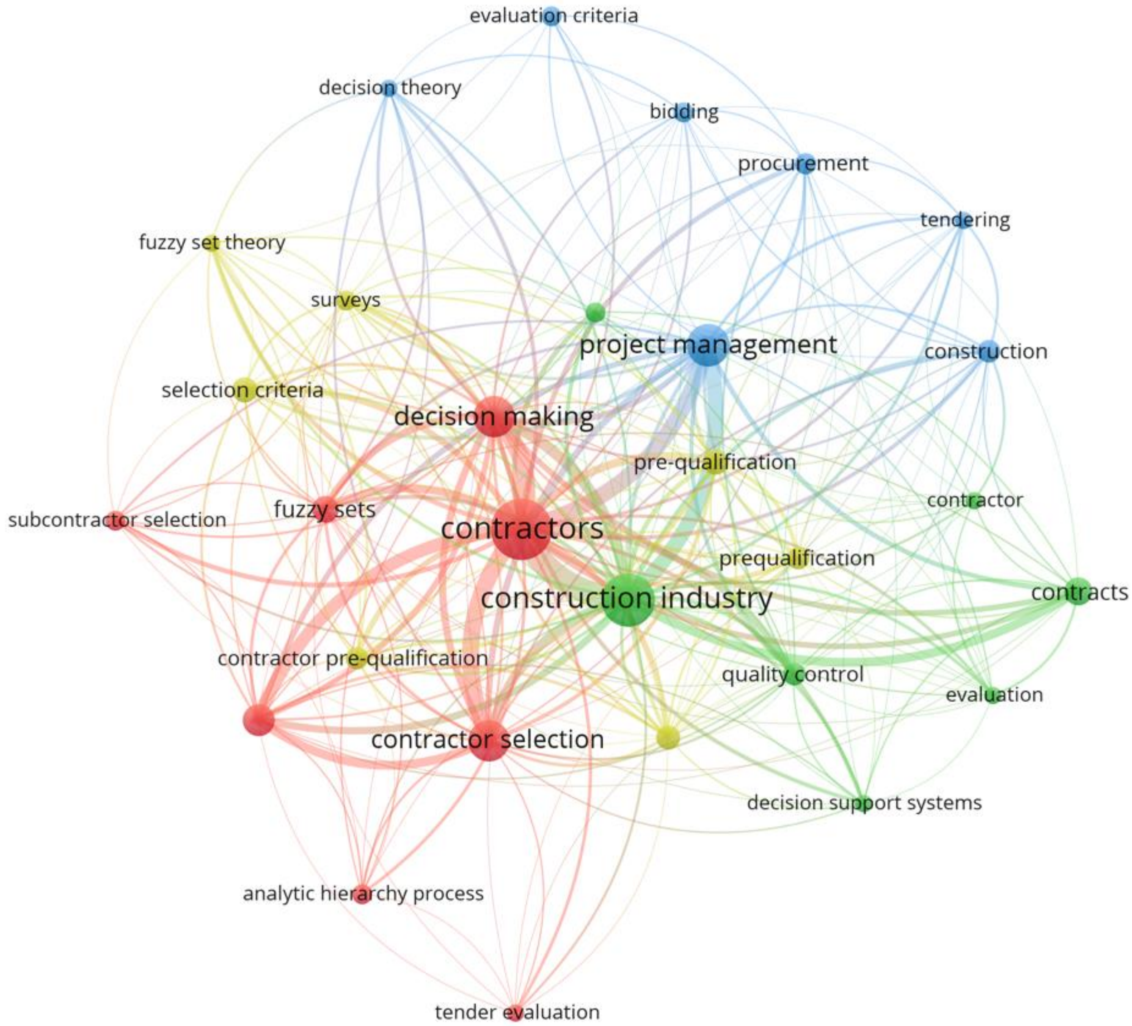



**Fig. 3.** Keyword Co-Occurrence Analysis

Another analysis of these keywords showed the average date of publication for each keyword. The color indicates the year as shown in Fig. 4. One trend that can be seen is the more contemporary usage of fringe terms like *fuzzy sets*, *fuzzy set theory*, *analytic hierarchy process*, and *subcontractor selection*. This indicates those topics are

newer compared to topics like *pre-qualification*, *tender evaluation*, and *contracts* which have likely been studied more in-depth by earlier research.

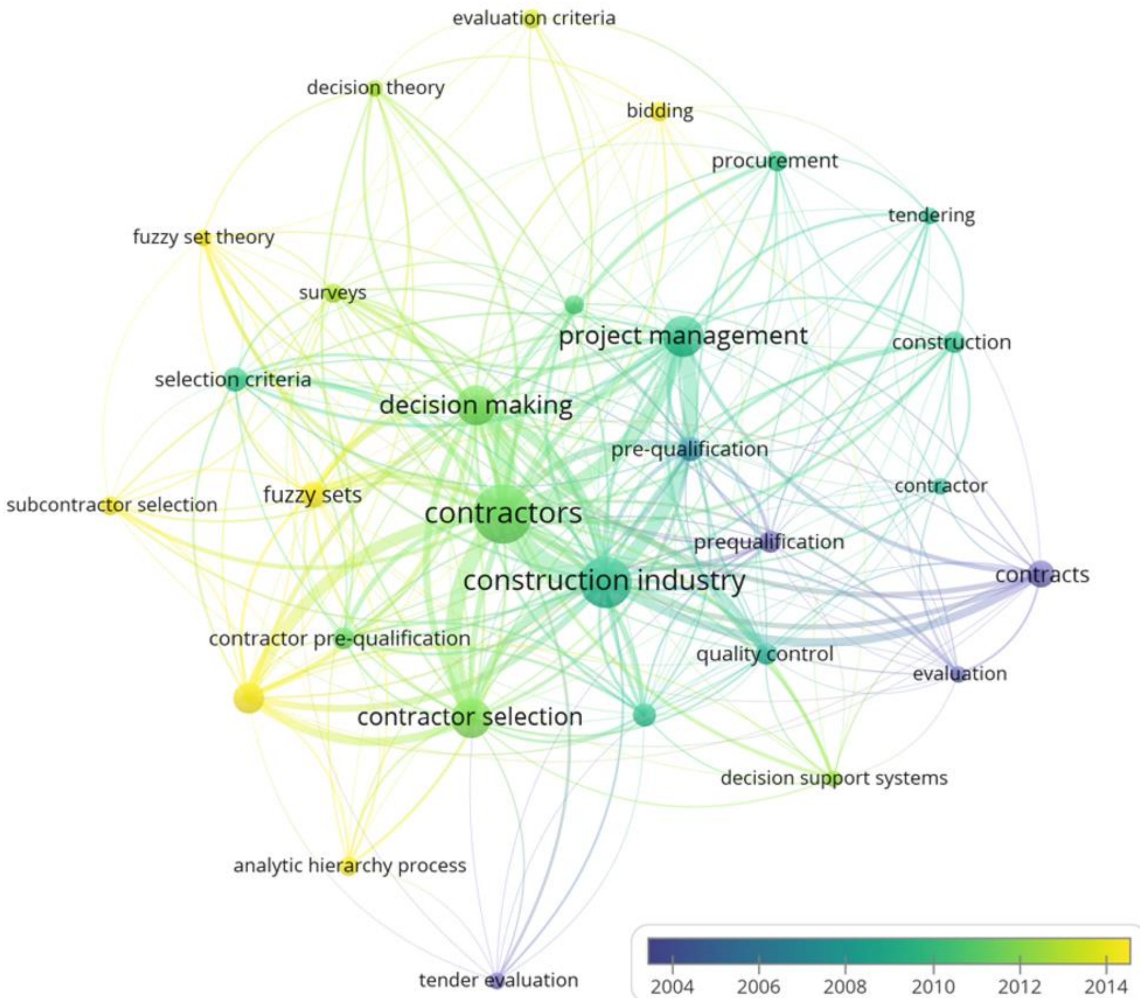



**Fig. 4.** Keyword Co-Occurrence Analysis by Average Publishing Date

The Co-Authorship analysis (Fig. 5) showed links between authors that published together. The 20 authors included have at least 2 publications included in this review. The circle size (publications) indicates Holt as the most prominent author in this review

with eight publications. The lack of links between the majority of the authors indicated a less collaborative environment among researchers in this field.

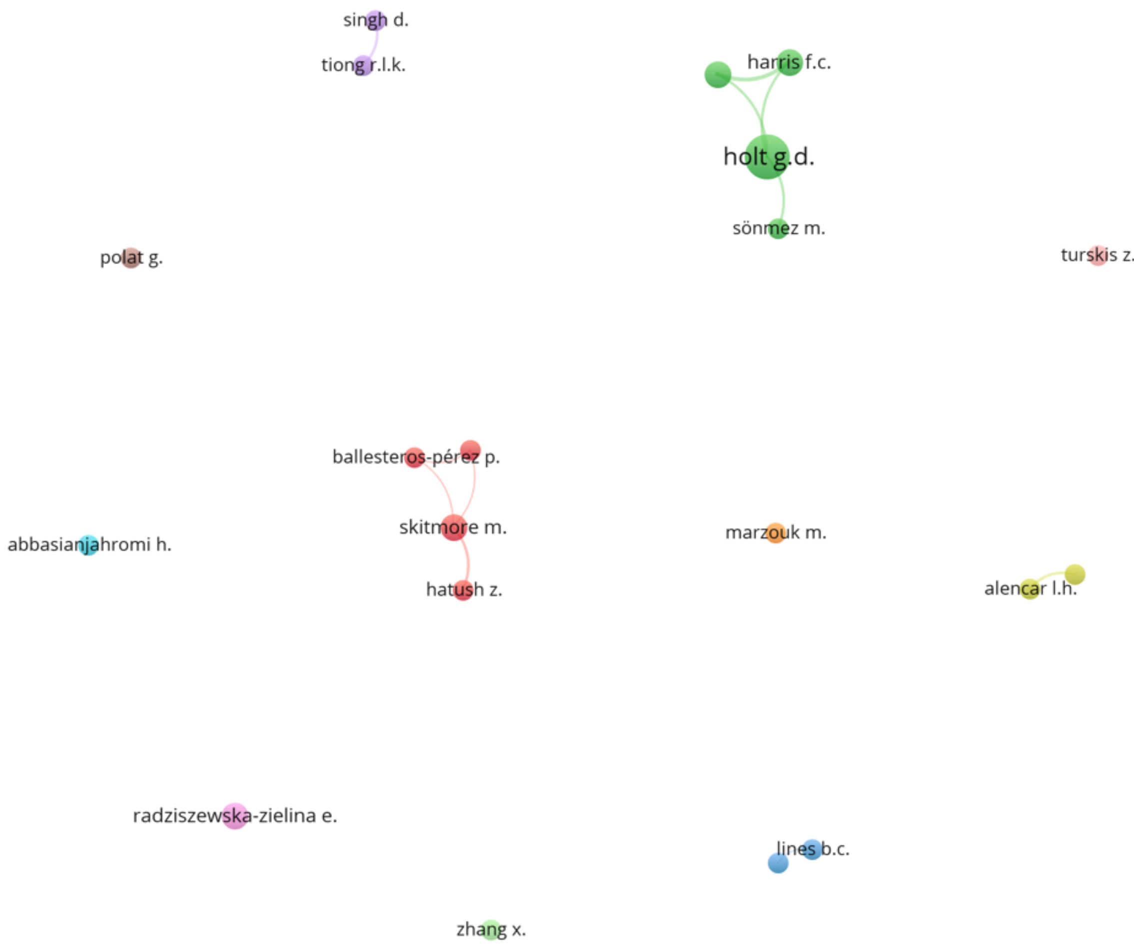



**Fig. 5.** Co-Authorship Analysis

One of the limitations of the existing literature reviews was the limited scope of publications. The included articles in this review were from many countries. The top countries by citation were United Kingdom, United States, Turkey, Australia, and Malaysia. Fig. 6 shows the citation links for each country. This backed up previous

studies which found the United Kingdom to have the most contributions to this field of study and showed that countries like Turkey and Malaysia are becoming important contributors to this field.

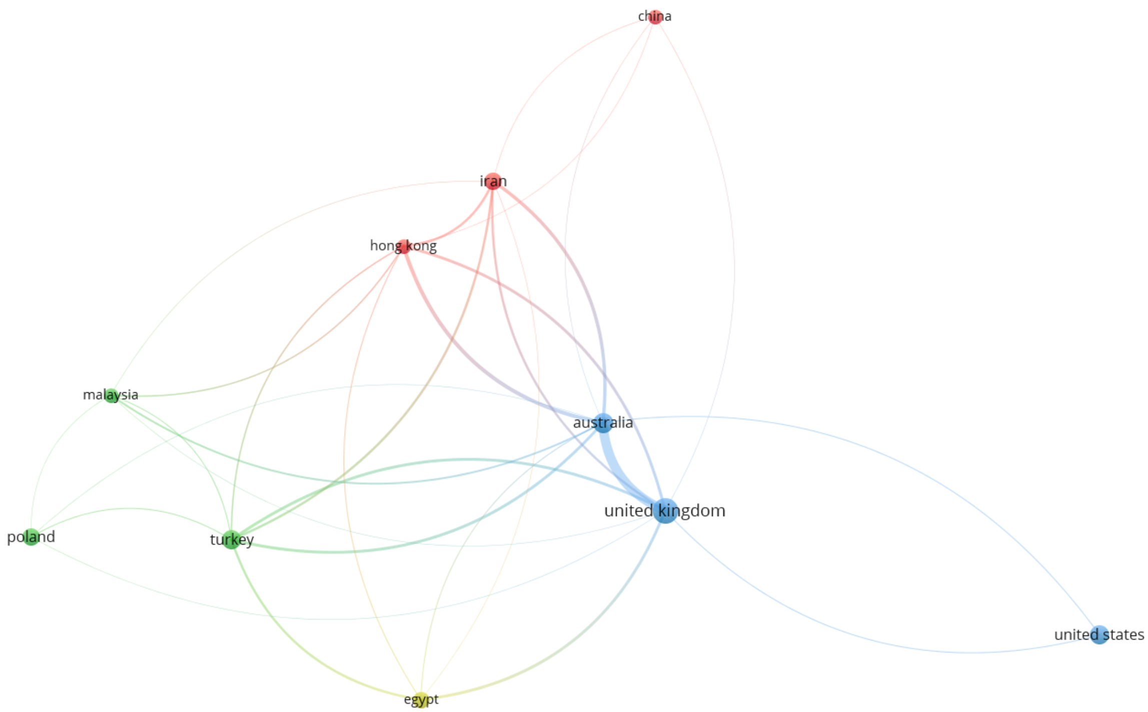



**Fig. 6.** Citations by Country

<u>Review</u>

One of the main goals of the literature review was to obtain a list of construction contractor selection criteria that were used in industry and academia. The criteria and sub-criteria referenced in each study were documented and tabulated across all publications. In total, of the 112 articles included in the review, 83 listed the criteria used in their decision-making process. Appendix 1 shows a list of the frequency of all criteria

and sub-criteria found in the publications.  The list included 154 unique criteria, with 86 criteria appearing in at least two separate publications.  Only two criteria appeared in more than 50 percent of papers; *Past Experience (on Similar Projects)* and *Financial Stability (Soundness/Capability)*.  *Bid Price/Tender Sum* was only the fourth most commonly used criteria.

The frequent usage of certain criteria throughout literature was indicative of their importance within the contractor selection process.  Looking into how each of these most frequently cited criteria were used within individual studies and models will help shape their usage in the contractor selection tool being developed by this research.  The earliest publication in this systematic literature review found that the evaluation of a contractor's bid involved an analysis of the proposed cost, the contractor's past project experience, and factors that served as a prediction into the performance expected from the contractor on the current job (Nguyen 1985).  This is the most basic framework which can be used to approach the contractor selection problem.  The third area of evaluation (performance predicting criteria) was where the most variability was seen across various contractor selection methods.

There exist many differences across literature regarding which criteria are perceived to be the most important in predicting project success.  However, there has been minimal research into the actual relationship of contractor selection criteria and project success factors.  Hatush and Skitmore found, through the use of expert interviews, several criteria to have the most effect on the project success factors of Time, Cost, and

Quality (1997b). Table 1 shows these criteria as well as the criteria with the least effect on the project success factors. It was also found that criteria such as *Past Performance*, *Bank Arrangements*, *Project Management Organization*, and *Plant and Equipment* only affected one or two of the project success factors (Hatush and Skitmore 1997b).

**Table 1**. Contractor Selection Criteria (Hatush and Skitmore 1997b)

| Most Effective | Least Effective |
|---|---|
| Past Failures | Safety |
| Financial Status | Experience Modification Rate |
| Financial Stability | OSHA Incidence Rate |
| Credit Ratings | Management Safety Accountability |
| Experience | Length of Time in Business |
| Ability | |
| Management Personnel | |
| Management Knowledge | |

Alzahrani and Emsley used factor analysis and logistic regression to identify which "critical success factors" had the greatest impact on construction project success (2013). Their results showed *Turnover History*, *Quality Policy*, *Adequacy of Labor Resources*, *Adequacy of Plant Resources*, *Waste Disposal*, *Size of Past Project Completed*, and *Company Image* were the seven factors that had significant statistical impact on the success of construction projects (Alzahrani and Emsley 2013). Between the two studies there were no shared criteria for determining project success. Almost every other study which addressed contractor selection criteria focused on the decision-making process rather than correlation of specific criteria to project success.

The most common decision processes seen throughout the literature involved hierarchies of criteria and sub-criteria. Two studies laid the groundwork for more advanced frameworks that utilized criteria and sub-criteria for contractor selection. The first used five main categories of *Contractor's Organization*, *Financial Considerations*, *Management Resource*, *Past Experience*, and *Past Performance* (Holt et al. 1994). The second also used five categories. They are *Financial Soundness, Technical Ability*, *Management Capability*, *Health and Safety*, and *Reputation* (Hatush and Skitmore 1997a). Between the two studies, almost every contractor selection criterion found during this systematic review could be classified as one of these ten categories. These two papers formed the foundation for many of the hierarchies used in subsequent research. They are also among the highest cited papers.

The final hierarchy used in the source selection tool development should follow the pattern of previous research by using the main criteria to consider all aspects of contractor selection. The main criteria used in Holt et al. (1994) and Hatush and Skitmore (1997a) fall into the two types of categories laid out by Nguyen (1985). Table 2 shows the criteria used in the two studies and how they loosely fall into each category.

**Table 2**. Criteria Categorization

| Publication | Past Experience Criteria | Performance Prediction Criteria |
|---|---|---|
| (Holt et al. 1994) | Past Experience | Contractor's Organization |
| | Past Performance | Financial Considerations |
| | | Management Resources |
| (Hatush & Skitmore 1997a) | Health and Safety | Financial Soundness |
| | Reputation | Technical Ability |
| | | Management Capability |

Using these two studies as a foundation, many other studies built on the idea of a hierarchy of criteria and sub-criteria for contractor selection. The number of main criteria varied from as few as three (Ackay and Manisali 2018, Singh and Tiong 2005) and as many as eight (Nieto-Morote and Ruz-Vila 2012). Most of the proposed hierarchies used five or six main criteria. The arrangement of sub-criteria within the main criteria varied far more. Sönmez et al utilized a hierarchy that included three to six sub-criteria for each of the five main criteria selected (2002). Birjandi et al, however, only used two to three sub-criteria for each of their six main selection criteria (2019). The highest number of sub-criteria used totaled 48 across six main criteria (Singh and Tiong 2006).

The most cited study among the 112 publications in this literature review applied the Analytic Hierarchy Process (AHP) to the final selection of a contractor for a construction project (Fong and Choi 2000). Their criteria list totaled to 15 and included 13 of the top 18 criteria (those included in at least 20% of studies) from across all of the publications. These included *Price, Financial Capability, Past Performance, Failure to*

*have Contract Completed*, *Delay*, *Actual Quality Achieved*, *Past Experience*, *Resource*, *Physical Resource*, *Human Resource*, *Current Workload*, *Past Client/Contractor Relationship*, and *Safety Performance* (Fong and Choi 2000). Fong and Choi showed the flexibility of using AHP to match the uniqueness of individual construction projects (2000).

The variations in methods and criteria used that has been seen across the literature review did not establish a common approach to contractor selection. Rather, they indicated the inherent variability in how the construction contractor selection process can be approached. By applying the methods used in these foundational studies and utilizing the most commonly used criteria from across this literature review, an applicable source selection tool can be built and used to address the contractor selection problem in the Department of Defense.

# III. Methods

With a list of the most essential construction contractor selection criteria, the next step in developing an Air Force-wide source selection tool is to select the decision-making tool for this process. Two of the three goals of the source selection tool were to be simple and adaptable. The AHP method of decision-making uses pairwise comparisons to achieve a hierarchy of importance for the factors in a decision (Saaty 1990). The simplicity of AHP is that any individual can make these comparisons and determine the importance for each included factor. Darko et al. (2019) identified one of the main justifications for using AHP in the construction management field is its simplicity. An AHP tool will allow the user to value certain criteria as more or less important for a specific project or even a specific installation. As seen in various systematic literature reviews, AHP is one of the prominent decision-making techniques used in the construction contractor selection industry (Acheamfour et al. 2021; Kog and Yaman 2014).

## Developing the Hierarchy

The first step in creating the AHP source selection tool was to build the hierarchy of main criteria and sub-criteria for the contractor selection process. The top 18 criteria from Appendix 1 were included in the hierarchy. These criteria all met the threshold of inclusion in more than 20 percent of reviewed publications. Since there was no empirical evidence from literature that dictated a specific set of criteria to determine construction project success, the author used their best judgement to set the threshold at 20 percent.

This threshold is used to maintain a reasonable number of criteria used in the source selection tool while not ignoring important aspects of contractor selection.

To determine the main criteria for the source selection tool hierarchy, guidance was taken from the Air Force Supplement to the Federal Acquisition Regulations. Specifically, AFARS 5315.3 discusses the evaluation process for source selection using the best value continuum. The procedures do not include specific evaluation factors, but lay out four categories to evaluate: bid price, technical, risk, and past performance. Using these categories as guidelines, the author developed the hierarchy seen in Fig. 7. Each of the sub-criteria fits into one of the following: evaluating a contactor's mission/technical capabilities, the risk of awarding a contractor the specific work, and the contractor's past performance.


**Fig. 7.** Hierarchy of Construction Contractor Selection Criteria

Defining the Criteria

The criteria shown in Fig. 7 must have clear definitions to allow for consistent and repeatable application of the source selection process. These definitions are based in existing Air Force processes as well as examples from literature. The first main criterion, *Bid Price*, is the price proposed by the bidding contractors on the given project. This criterion should be compared with the Independent Government Estimate (IGE) when considering scoring.

The second main criterion is *Mission and Technical Capability*. The sub-criteria in this category are primarily used to evaluate the contractors' capabilities related to the given project. The first of these sub-criteria is *Past Experience*. This criterion evaluates a contractor's prior experience in similar projects in terms of both size and scope. The more specialized the project scope, the more important a contractor's familiarity with that type of work will be. Scoring experience based on size of projects completed as well shows a contractor's potential to adequately manage large amounts of resources for large projects, but also not over commit resources for smaller projects (Holt et al. 1994).

The second sub-criterion is *Technology and Equipment*, an indication of a contractor's ability to perform specific work tasks with the technology they have available. Enshassi et al provides examples of this, including condition of equipment, suitability of equipment to the project size, efficiency of proposed technology level to the project type, and availability of owned construction equipment (2013). *Technical Resources* is a measure of a contractor's technical knowledge and expertise and how

these and other resources have been applied in the technical portions of the proposal. This is different from *Technology and Equipment* as that criterion covers the physical technology used by each contractor.

*Quality (or Workmanship)* is a measure of a contractor's quality of work achieved on past projects. Hartmann et al defined quality by how well the work performed met project requirements (2009). *Quality Assurance (or Management)* is used to grade a contractor's quality control systems. This could include assessing quality assurance programs and other programs like warranty management that affect the life cycle of the project (Doloi 2009).

The last sub-criteria are *Experienced Staff and Personnel* and *Management Capabilities*. *Experienced Staff and Personnel* evaluates the number of key members of the contractor's project management team who will drive the success of the project through their skills and experience when tackling problems or obstacles that arise (Enshassi et al. 2013). This is a measure of key metrics such as levels of education, professional qualifications, and years of managerial experience within the company (Holt et al. 1994). The *Management Capabilities* criterion, in contrast, is a measure of overall management expertise with regards to several factors including organization structure, project planning strategies, and project control (Hatush and Skitmore 1997a). This criterion is less quantitative than *Experienced Staff and Personnel* and should be qualitatively scored.

The third main criterion is *Risk* with four sub-criteria that assess the risk of selecting a given contractor. The first of these is *Financial Stability*. This criterion assesses a contractor's financial viability, credibility, and strength (Doloi 2009; Alptekin and Alptekin 2017). The second criterion is *Length of Time in Industry* and is a simple measure of the number of years the contractor has been in the construction industry (Alptekin and Alptekin 2017). *Health and Safety Concerns* measures a contractor's health and safety policy compared to OSHA (Occupational Safety and Health Administration) standards and those dictated by project specific requirements. The last sub-criterion is *Workload*. This criterion describes a contractor's capacity for completing the required project work by measuring the availability of key disciplines and resources based on their current and projected project workload (Manoliadis et al. 2009).

The final main criterion is *Past Performance*. This category assesses each contractor's past performance by reviewing six sub-criteria. The first is *Safety Record,* which, unlike *Health and Safety Concerns*, measures a contractor's past safety issues. Different metrics can be used including number of days lost to injury and illness, accident rate, or OSHA incidence rate (Afshar et al. 2017; Alptekin and Alptekin 2017; Hatush and Skitmore 1997a). The second sub-criterion, *Performance Reports,* uses the Contractor Performance Assessment Reporting System (CPARS) to review and grade contractors on their past work for the federal government. CPARS is the database that stores all government contractor past performance information and is readily accessible

for base personnel during a source selection process ("Contractor Performance Assessment Reporting System" n.d.).

The next sub-criterion is *Past Relationship with Client*. This criterion is used to evaluate contractors based on their past work experience with the Air Force. *Company Reputation*, on the other hand, is a measure of a contractor's outward image. This could include membership in associations as well as the classification of the contractor (Holt et al. 1994; Enshassi et al. 2013).

The final sub-criteria both are quantitative measures of past project performance. First is *Past Failures*, which counts the number of times a contractor has failed to complete a project. This does not count when the contractor and the project owner mutually agreed to stop work (for a number of potential reasons) (Holt et al. 1994). Second is *Completion of Job withing Time*, which counts time overruns on past projects performed by the contractor. Again, this does not count any delays outside of the contractor's control (Holt et al. 1994).

<u>Developing the Tool</u>

Applying the Analytic Hierarchy Process to Air Force construction contractor selection requires a tool that minimally trained base personnel can utilize. The author developed a spreadsheet that takes the user through the steps of AHP and returns criteria weights which help identify the importance of each selection criteria.

The first step is making the pairwise comparisons. On the first page of the spreadsheet, the user will select their preference between two criteria using the drop-

down menu. The scale ranges from 1/9 to 9 using the linguistic definitions provided in Table 3, which are based on Saaty's 9-point fundamental scale (1990). This procedure is repeated for each pair of main criteria and within each of the three groups of sub-criteria.

**Table 3**. Pairwise Comparison Scale

| **Score** | **Linguistic Definition** |
|---|---|
| 1/9 | Extreme Importance of Criterion 2 over Criterion 1 |
| 1/7 | Very Strong Importance of Criterion 2 over Criterion 1 |
| 1/5 | Strong Importance of Criterion 2 over Criterion 1 |
| 1/3 | Moderate Importance of Criterion 2 over Criterion 1 |
| 1 | Equal Importance between Criteria |
| 3 | Moderate Importance of Criterion 1 over Criterion 2 |
| 5 | Strong Importance of Criterion 1 over Criterion 2 |
| 7 | Very Strong Importance of Criterion 1 over Criterion 2 |
| 9 | Extreme Importance of Criterion 1 over Criterion 2 |

The second step of the process is filling out the AHP matrices. This part of the process is completed automatically on the second sheet. The pairwise comparisons are entered into the matrices, and their reciprocals are calculated automatically to fill in each of the four matrices. The third step of calculating the criteria weights is also performed automatically using the Geometric Mean Method, originally proposed by Crawford and Williams (1985). This method uses Equation 1 by calculating column vectors for each criterion by multiplying across the row and raising that number to the power of 1/n. The weights are then normalized by taking each column vector and dividing by the total sum of all the column vectors (Gao et al. 2010).

$$w_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{kj}\right)^{\frac{1}{n}}} \quad (i = 1,2, \dots, n) \tag{1}$$

The fourth and final step of the process is to check the consistency ratio of each comparison matrix. This step is also performed automatically by first calculating the weighted sum of each row and then dividing that by the criteria weight to get the eigenvalue ($\lambda$) (Equation 2). Then, $\lambda_{max}$ is calculated by taking the average of all the eigenvalues (Equation 3). The Consistency Index (CI) for each matrix is calculated by using Equation 4. The Consistency Ratio (CR) is the CI divided by the Root Index (Equation 5), which depends on the number (n) of criteria in each matrix (see Table 4).

$$\lambda_i = \frac{\sum_{j,k=1}^{n}\left(w_k * a_{ij}\right)}{w_i} \quad (i = 1,2, \dots, n) \tag{2}$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} \lambda_i}{n} \tag{3}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

$$CR = \frac{CI}{RI_n} \tag{5}$$

**Table 4.** Root Index Values for Number of Criteria (n) in Matrix

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

The CR of each matrix must be below 0.1 to be acceptable (Saaty 1990). If the CR is over 0.1, then the user must review and change the pairwise comparisons to

eliminate inconsistency between the preferences of the criteria. Once consistency is achieved, the final criteria weights are displayed on the third sheet, arranged in the hierarchy initially developed.

Scoring the Contractors

Once the user develops the criteria weights, they will grade and score each contractor for each criterion. Multi-Attribute Utility Theory (MAUT) is used to standardize the scoring across different qualitative and quantitative criteria. This process involves developing utility curves that serve to convert each criterion score into a utility score on a scale of 0 (least-preferred value) to 1 (most-preferred value) (Alshamrani et al. 2018). The relationship between criterion score and utility score can take on many forms, including stepwise, linear, and non-linear functions. These functions, while not necessarily defined by a specific mathematical equation, serve the same purpose as an equation by visually relating the two scores together. The flexibility provided by using MAUT allows the user to determine the shape of the curve for each criterion. The shape of the curves can vary from project to project as well.

A criterion that can be modeled as a stepwise function uses discrete values for each level of performance score. For example, *Technical Resources* uses scored values that are qualitative and discrete, meaning there are no intermediate values within levels of scores (see Fig 8). If a contractor was scored as “Poor” in this category, they would receive a utility score of 0.25. A contractor who was scored as “Very Good” would receive a utility score of 0.8.

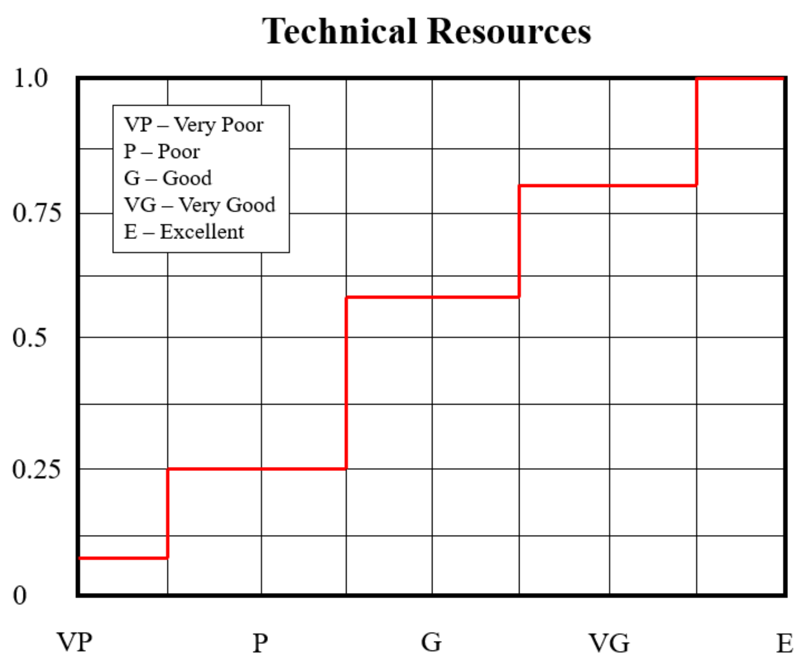



**Fig. 8.** Utility Curve for *Technical Resources* Criterion Scoring

For criteria that are not scored using discrete values, users can develop more complex curves. *Length of Time in Industry* is one of these criteria that uses a continuous range of values (years). Fig. 9 shows one example of drawing a utility curve for *Length of Time in Industry* as a stepwise function. In this case, ranges of years are assigned a utility score. A contractor with zero to three years of experience in the industry is assigned a utility score of 0. Three to six years of experience is given a utility score of 0.25, and so on.

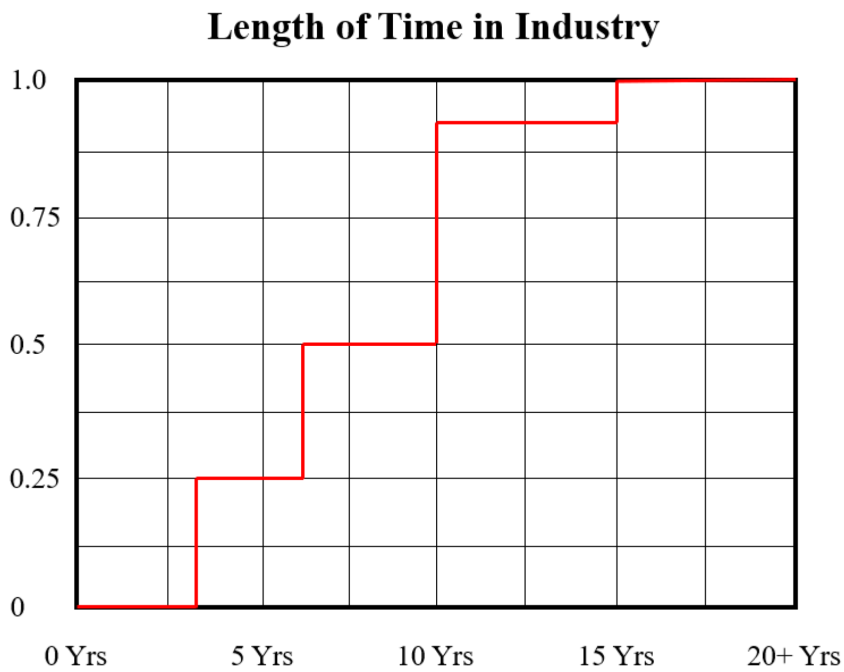



**Fig. 9.** Utility Curve for *Length of Time in Industry* Criterion Scoring (1)

The user could also model a criterion like *Length of Time in Industry* using a set of linear functions. Fig. 10 demonstrates what this utility curve would look like. In this case, the same general preference for contractors with more industry experience is shown as with the stepwise model. The difference is the resulting utility scores are more reflective of minor differences in years in the industry. For example, using Fig. 4, contractors with eight and nine years of experience would both be scored as 0.5. Using Fig. 5, however, the two contractors would receive different scores (approximately 0.6 and 0.75, respectively). The use of linear utility curves provides more flexibility for users to score continuous criteria.

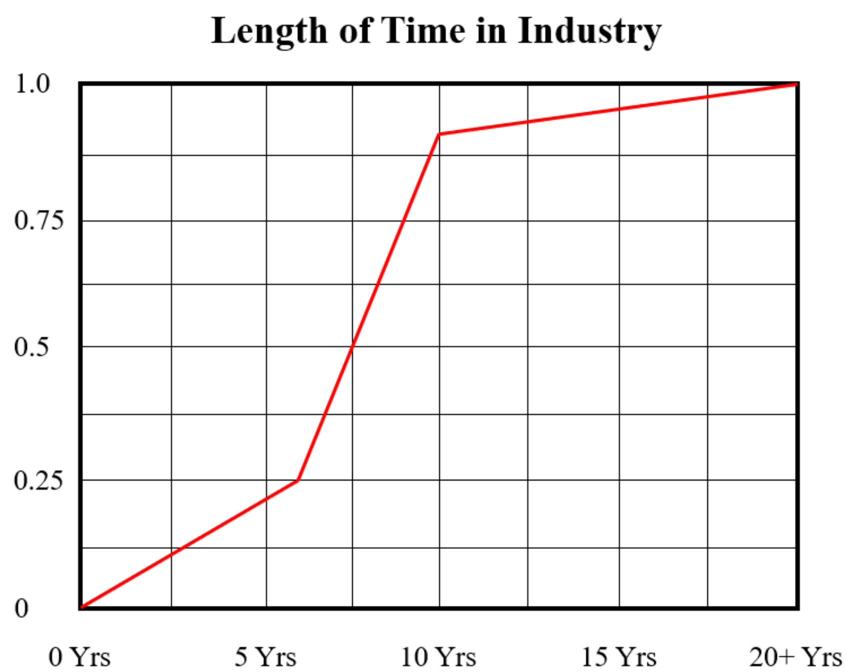



**Fig. 10.** Utility Curve for *Length of Time in Industry* Criterion Scoring (2)

These continuous curves, however, do not need to be linear. They can be non-linear, as can be the case with *Bid Price*. In Fig. 11, a utility curve is shown for a hypothetical project with an Independent Government Estimate (IGE) of $5 million. The user in the example scores a contractor with a *Bid Price* at or slightly below the IGE very high (with a peak score at $4.5M). This drops off with bids that come in well below or above the IGE. A very low bid often indicates a proposal that cuts corners and will not actually meet project requirements. A very high bid is undesirable due to the higher cost the government would have to pay.

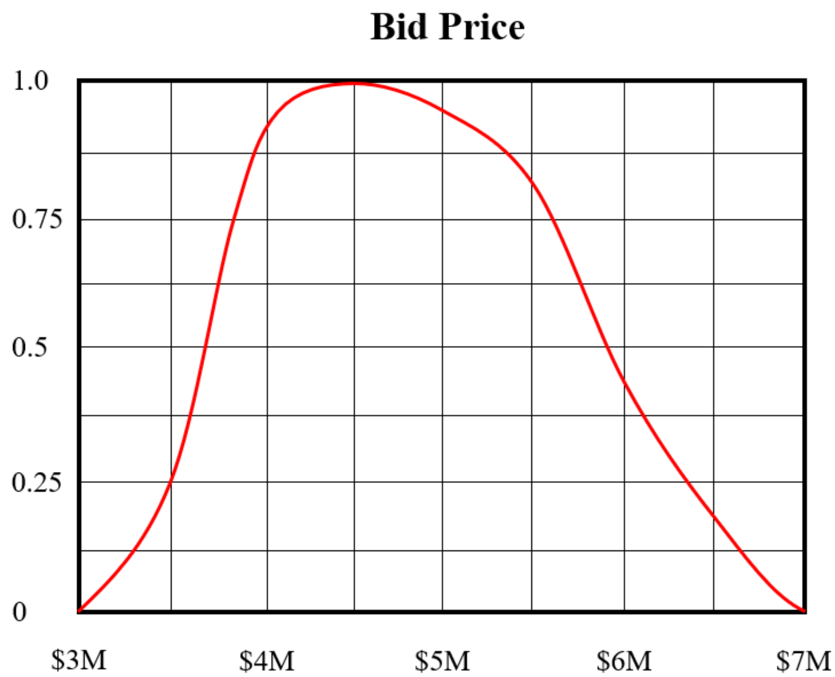



**Fig. 11.** Utility Curve for *Bid Price* Criterion Scoring

The development of these curves will depend on the scoring used by the user for each criterion (discrete or continuous) and their preferences for each criterion (linear or non-linear). The user will build out the curves prior to obtaining the contractor selection criteria information.

Once the utility curves are developed and the information from each contractor is obtained, the utility scores are calculated. This involves taking each criterion score for each contractor and finding the equivalent utility score. An example is shown in Fig 12 for converting a contractor's bid price of $5.5M to a utility score of 0.8.

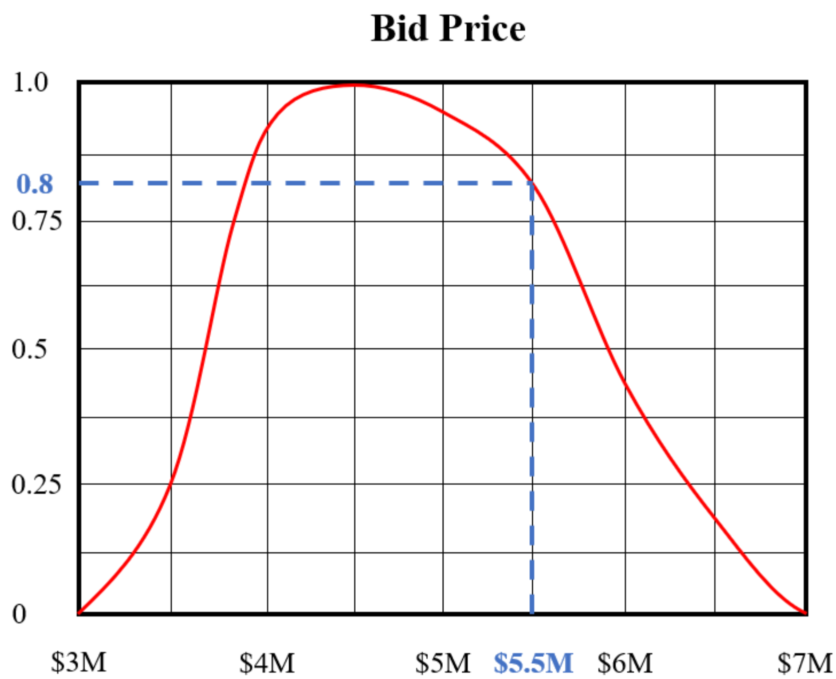



**Fig. 12.** Example Scoring for *Bid Price* Utility Curve

This scoring process will happen outside of the source selection tool. Once all scoring is finalized, the numerical values for the utility scores ($u_{ic}$) can be put into the spreadsheet on the fourth page. The Performance Index (PI) for each contractor is then calculated automatically using Equation 6 (Karydas and Gifun 2006).

$$PI_c = \sum_{i=1}^{n} w_i u_{ic} \tag{6}$$

The contractor with the highest Performance Index is the recommended option to award the project. The source selection tool is included as Appendix 2 in a separate file.

## IV. Results

The goal of this research was to create a simple and flexible contractor selection tool that allows individual Air Force installations to adapt to their mission needs, thereby increasing the value the Air Force receives from its construction program. The literature review performed gave insight into which criteria are being used throughout research and provided a baseline of criteria to include in the source selection tool. The hierarchy framework came from current Air Force acquisition strategies and was aligned with past research as well. The Analytic Hierarchy Process (AHP) was integrated into the source selection tool and Multi-Attribute Utility Theory (MAUT) was used to score contractor selection criteria. In the end, this source selection tool can be a model used by the Air Force and other government entities for their construction contractor selection processes.

### Illustrative Example

It is important to not only define and build the source selection tool but also to demonstrate its use. An illustrative example was developed to highlight the features of the AHP tool and the MAUT process for scoring and selecting a construction contractor. The example used a hypothetical scenario where four contractors were bidding on an estimated $5 million construction project.

The first step performed was the pairwise comparisons on the first tab of the spreadsheet (Appendix 3 in a separate file). The author performed these comparisons by using engineering judgement and leaning on experience as a base-level construction project manager. Fig. 13 shows a screenshot of how the comparisons are input to the

source selection tool. The drop-down menu is used to select the preference of Criterion 1 to Criterion 2. In this example, the author selected 1/5 to show that *Health and Safety Concerns* were 1/5th the importance of *Workload* for this project.

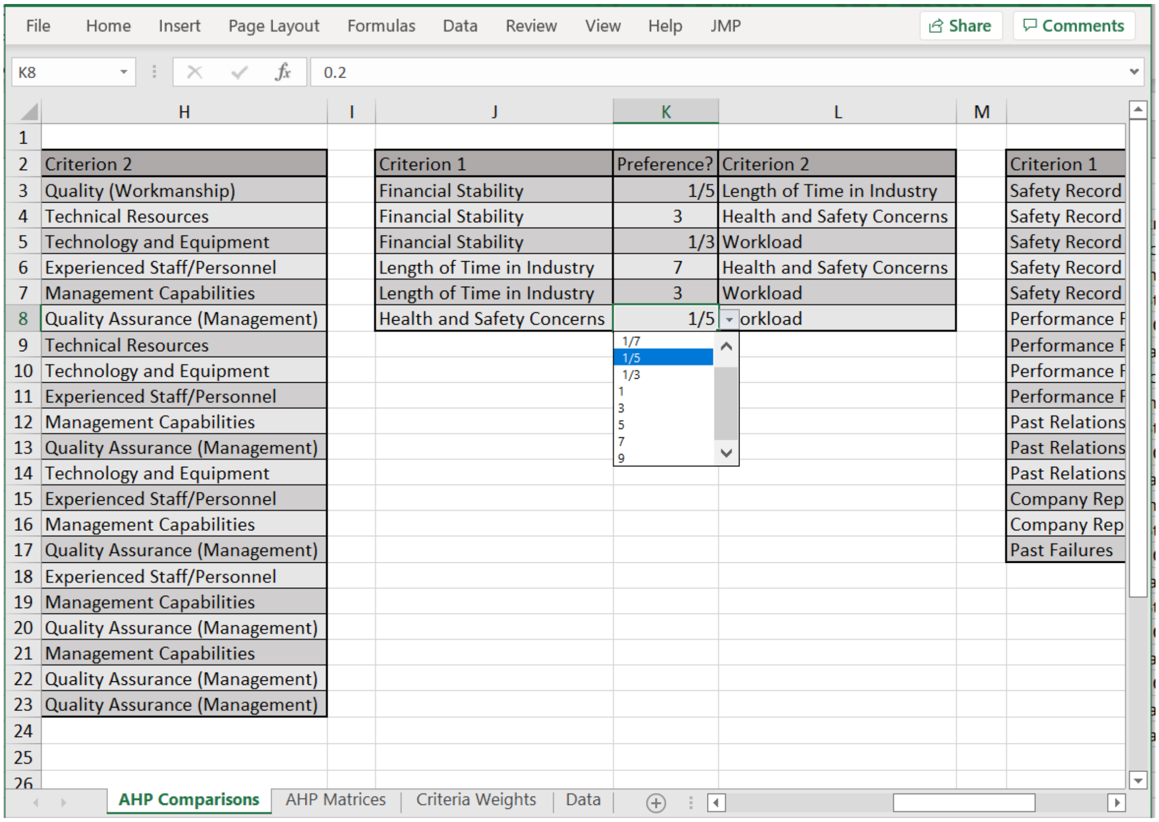
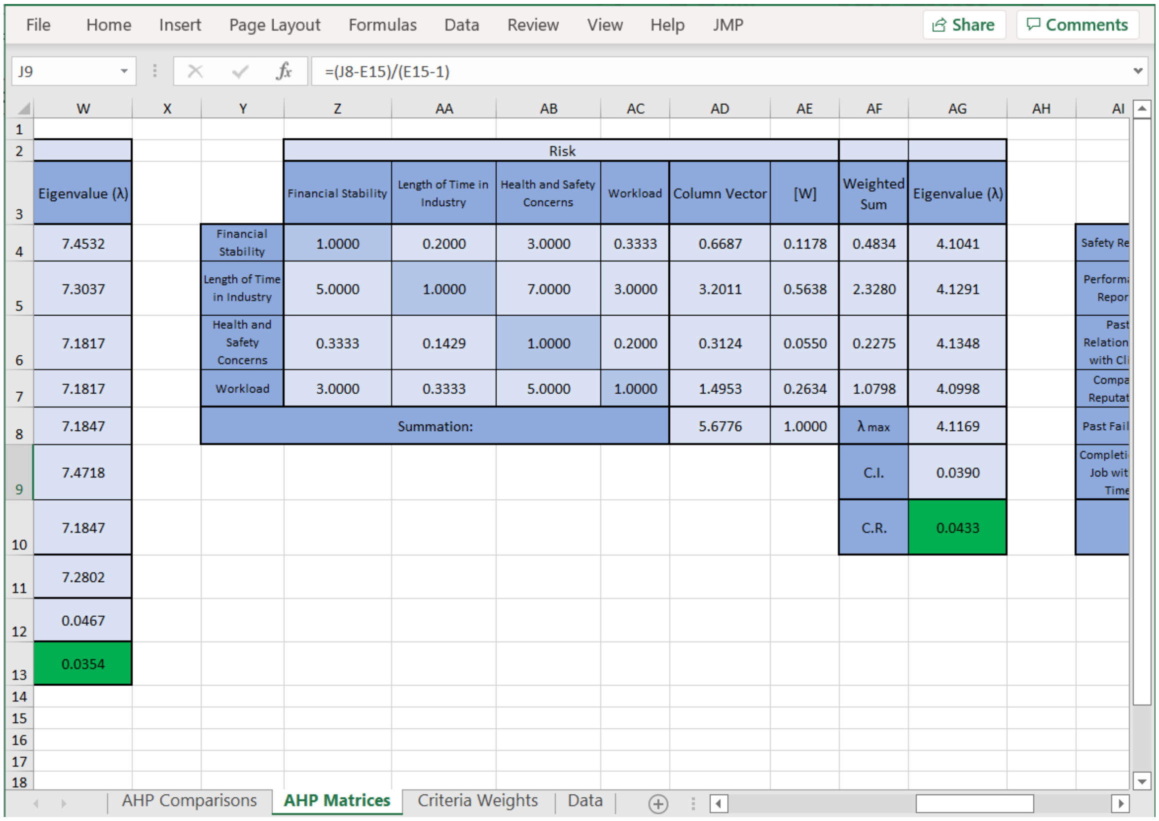



**Fig. 13.** Sample Input of Pairwise Comparisons

The AHP matrices were populated automatically, as shown in Fig. 14, on the AHP Matrices tab. This matrix reflects the author's inputs from the AHP Comparisons tab and calculates the criteria weights using the equations from the Methods Section. The author checked each of the matrices for consistency at this step. The Consistency Ratio

(C.R.) of 0.0433 is highlighted green, indicating it is below 0.1 and is an acceptable value.




| | Risk | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Financial Stability | 1.0000 | 0.2000 | 3.0000 | 0.3333 | 0.6687 | 0.1178 | 0.4834 | 4.1041 |
| Length of Time in Industry | 5.0000 | 1.0000 | 7.0000 | 3.0000 | 3.2011 | 0.5638 | 2.3280 | 4.1291 |
| Health and Safety Concerns | 0.3333 | 0.1429 | 1.0000 | 0.2000 | 0.3124 | 0.0550 | 0.2275 | 4.1348 |
| Workload | 3.0000 | 0.3333 | 5.0000 | 1.0000 | 1.4953 | 0.2634 | 1.0798 | 4.0998 |
| Summation: | | | | | 5.6776 | 1.0000 | λ max | 4.1169 |
| | | | | | | | C.I. | 0.0390 |
| | | | | | | | C.R. | 0.0433 |

**Fig. 14.** AHP Matrix for Risk Criteria

Once all the matrices are checked for consistency, the final criteria weights are displayed on the Criteria Weights tab. Fig. 15 shows this result. The global weights for each criterion are shown. In this example, the author placed greatest emphasis on the Mission/Technical Capability criteria, which is reflected in *Past Experience* having the highest global weight (0.271) of all sub-criteria.

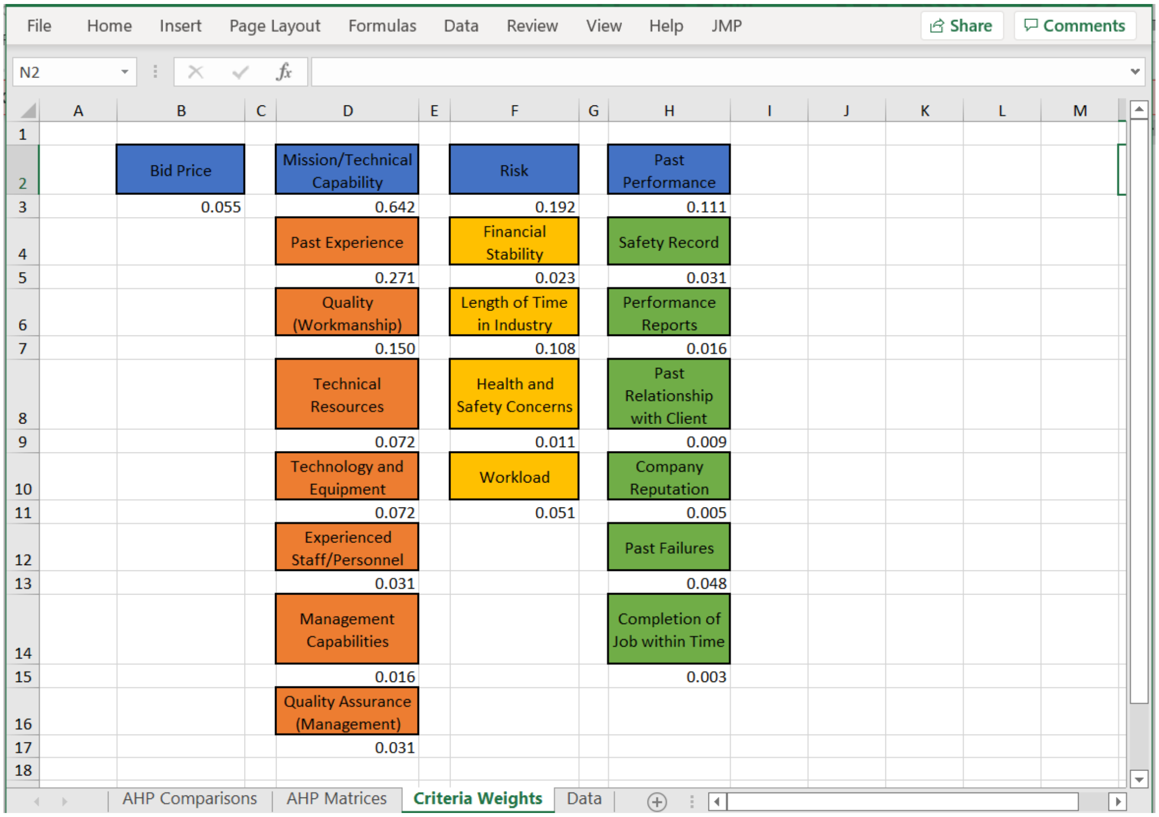



**Fig. 15.** Criteria Weights from AHP

The next step was for the author to build the utility curves for each criterion and score the contractors accordingly. Since this example did not use real contractor data, the utility scores shown in Fig. 16 are representative of general contractor trends. In general, Contractor #1 represented an underqualified contractor bidding just under the Independent Government Estimate (IGE) of $5 million. Contractor #2 was reasonably well qualified technically and had high risk and past performance scores. Contractor #3 was the most technically qualified for the project; however, they had the highest bid price and only average scores in other categories. Contractor #4 was scored at 0.5 for every

criterion and bid the exact price of the IGE. The utility scores are manually entered after scoring each contractor for each criterion using the utility curves.

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time |
| Contractor #1 | 1.0 | 0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.2 | 0.3 | 0.0 | 0.4 | 0.2 | 0.3 | 0.4 | 0.2 | 0.4 | 0.6 | 0.5 |
| Contractor #2 | 0.7 | 0.1 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | 0.5 | 0.8 | 1.0 | 0.9 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 |
| Contractor #3 | 0.1 | 1.0 | 0.8 | 0.9 | 0.9 | 0.8 | 1.0 | 0.8 | 0.5 | 0.5 | 0.7 | 0.4 | 0.7 | 0.6 | 0.4 | 0.7 | 0.9 | 0.7 |
| Contractor #4 | 0.9 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Weights: | 0.055 | 0.271 | 0.150 | 0.072 | 0.072 | 0.031 | 0.016 | 0.031 | 0.023 | 0.108 | 0.011 | 0.051 | 0.031 | 0.016 | 0.009 | 0.005 | 0.048 | 0.003 |

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Total |
| Contractor #1 | 0.055 | 0.027 | 0.030 | 0.021 | 0.014 | 0.013 | 0.006 | 0.006 | 0.007 | 0.000 | 0.004 | 0.010 | 0.009 | 0.006 | 0.002 | 0.002 | 0.029 | 0.001 | 0.244 |
| Contractor #2 | 0.039 | 0.027 | 0.090 | 0.043 | 0.036 | 0.019 | 0.009 | 0.016 | 0.018 | 0.108 | 0.010 | 0.040 | 0.024 | 0.015 | 0.009 | 0.004 | 0.043 | 0.002 | 0.552 |
| Contractor #3 | 0.006 | 0.271 | 0.120 | 0.064 | 0.064 | 0.025 | 0.016 | 0.025 | 0.011 | 0.054 | 0.007 | 0.020 | 0.021 | 0.010 | 0.004 | 0.003 | 0.043 | 0.002 | 0.767 |
| Contractor #4 | 0.050 | 0.135 | 0.075 | 0.036 | 0.036 | 0.016 | 0.008 | 0.016 | 0.011 | 0.054 | 0.005 | 0.025 | 0.015 | 0.008 | 0.004 | 0.002 | 0.024 | 0.001 | 0.522 |

**Fig. 16.** Utility Score and Performance Index Tables

In this example, Contractor #3 is the best option and the tool highlights their total Performance Index of 0.767. This is reflective of their high scores in the technical criteria with an emphasis from the author placed on this main criterion. However, a different user or a different project might dictate that other criteria are deemed more important. A second iteration of the source selection process was performed to demonstrate how the difference in criteria importance (ie. changing the inputs for the pairwise comparisons) can affect the final contractor Performance Index (PI) and subsequent selection (see Appendix 4 is a separate file). In this iteration, greatest preference is given to *Bid Price* over the other main criteria. The resulting criteria weights are shown in Fig. 17.

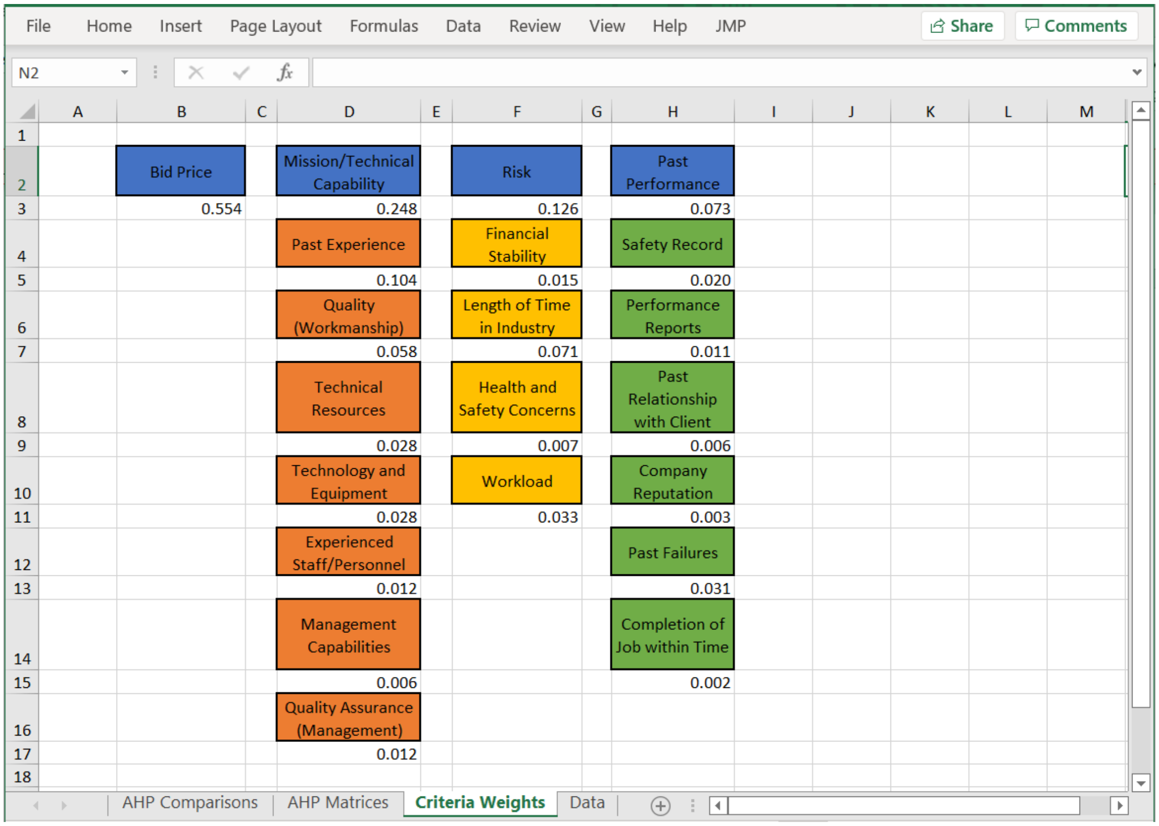
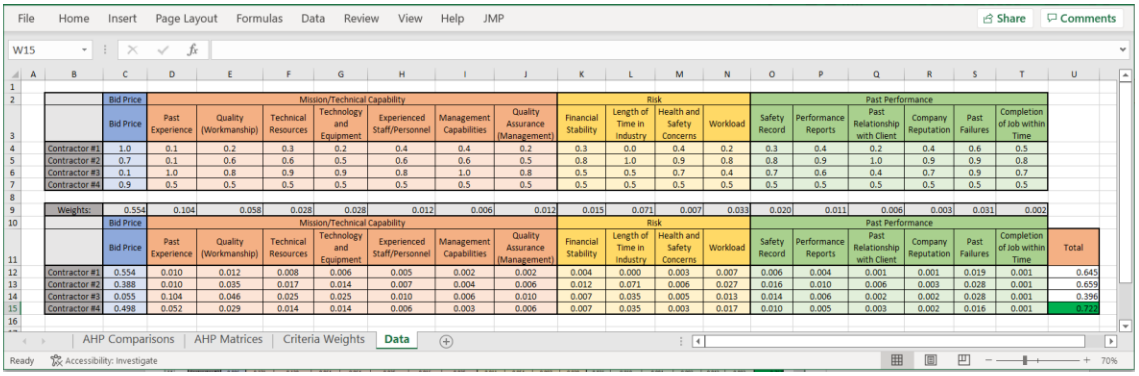



**Fig. 17.** Criteria Weights from AHP (2nd Iteration)

Without changing the contractor scoring from the utility curves, Fig. 18 shows how the PI changes for each contractor. Contractor #3 is no longer the highest scoring option with a low PI of 0.396. The highest scoring contractor is Contractor #4, who bid exactly at the IGE ($5M) and scored 0.5 for every criterion. Contractor #1, who bid below the IGE (at $4.5M) and received a utility score of 1.0 for *Bid Price*, still was only the third highest performing contractor.



| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time |
| Contractor #1 | 1.0 | 0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.2 | 0.3 | 0.0 | 0.4 | 0.2 | 0.3 | 0.4 | 0.2 | 0.4 | 0.6 | 0.5 |
| Contractor #2 | 0.7 | 0.1 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | 0.5 | 0.8 | 1.0 | 0.9 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 |
| Contractor #3 | 0.1 | 1.0 | 0.8 | 0.9 | 0.9 | 0.8 | 1.0 | 0.8 | 0.5 | 0.5 | 0.7 | 0.4 | 0.7 | 0.6 | 0.4 | 0.7 | 0.9 | 0.7 |
| Contractor #4 | 0.9 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Weights: | 0.554 | 0.104 | 0.058 | 0.028 | 0.028 | 0.012 | 0.006 | 0.012 | 0.015 | 0.071 | 0.007 | 0.033 | 0.020 | 0.011 | 0.006 | 0.003 | 0.031 | 0.002 |

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Total |
| Contractor #1 | 0.554 | 0.010 | 0.012 | 0.008 | 0.006 | 0.005 | 0.002 | 0.002 | 0.004 | 0.000 | 0.003 | 0.007 | 0.006 | 0.004 | 0.001 | 0.001 | 0.019 | 0.001 | 0.645 |
| Contractor #2 | 0.388 | 0.010 | 0.035 | 0.017 | 0.014 | 0.007 | 0.004 | 0.006 | 0.012 | 0.071 | 0.006 | 0.027 | 0.016 | 0.010 | 0.006 | 0.003 | 0.028 | 0.001 | 0.659 |
| Contractor #3 | 0.055 | 0.104 | 0.046 | 0.025 | 0.025 | 0.010 | 0.006 | 0.010 | 0.007 | 0.035 | 0.005 | 0.013 | 0.014 | 0.006 | 0.002 | 0.002 | 0.028 | 0.001 | 0.396 |
| Contractor #4 | 0.498 | 0.052 | 0.029 | 0.014 | 0.014 | 0.006 | 0.003 | 0.006 | 0.007 | 0.035 | 0.003 | 0.017 | 0.010 | 0.005 | 0.003 | 0.002 | 0.016 | 0.001 | 0.722 |

**Fig. 18.** Utility Score and Performance Index Tables (2nd Iteration)

These illustrative examples highlight the benefits of the source selection tool and the use of AHP and MAUT. In a similar scenario to the one presented, using Lowest Price Technically Acceptable (LPTA) would lead to the selection of Contractor #1, unless they could be deemed not technically acceptable (which is a difficult process). Instead, the AHP and MAUT process laid out allows users to select the best contractor in a consistent, repeatable, and defendable process that meets the requirements of the Federal Acquisition Regulation, is simple to use, and has flexibility for use on different projects.

## V. Discussion and Conclusions

Discussion

This contractor selection tool should provide the Air Force, as well as other federal contracting agencies (both within the Department of Defense and without), an alternative to using Lowest Price Technically Acceptable (LPTA). This tool meets the Federal Acquisition Regulations (FAR) requirements of the Tradeoff Process by providing a list of verified criteria (with the weighted importance compared to each other and price) for evaluating contractors. As seen in the illustrative examples, the user inputs are simple to understand and adaptable to different projects. In the example, the author initially placed the greatest emphasis on *Mission/Technical Capabilities* and the criteria within that category. The selected contractor was Contractor #3, who scored highest in the *Mission/Technical Capabilities* sub-criterion, despite having the highest *Bid Price*. In the second iteration, the author changed the pairwise comparisons and placed the greatest emphasis on the *Bid Price*, with secondary emphasis on the *Mission/Technical Capabilities*. In this example, the selected contractor was not Contractor #1, despite having the lowest *Bid Price* (with the highest utility score for that criterion).

Through the illustrative examples, the ease of adjusting the importance of each criterion was shown. The inclusion of multiple criteria helped prevent the selection of a contractor who may have under bid on a project without being the most qualified contractor. However, there was still potential for a contractor who failed to meet specific minimum requirements to score high enough in other categories. This scenario

demonstrated the need for user discretion in the scoring process. If a contractor does not meet specific technical or past performance thresholds, they should not be included in this process.

Potential Limitations

The source selection tool examines all selection criteria for determining the best contractor for a specific construction project. This may not always be feasible or allowable based on the fiscal and legal rules that govern source selection within the Air Force and the Department of Defense (DoD). The project cost thresholds often dictate the Source Selection Authority and thus govern the rules for the use of quantitative criteria scoring.

The criteria used in the source selection tool also vary in terms of being quantitative or qualitative in nature. For the criteria that are qualitative, it may be difficult for an individual to accurately convert a qualitative rating of a criterion into a quantitative utility score. This uncertainty between qualitative descriptors (such as "Good" and "Very Good") is not captured in the source selection process laid out. Tools like Fuzzy Theory could be applied to address this limitation at the added cost of complexity for the individual base users.

An alternative application of the Analytic Hierarchy Process (AHP) and Multi-Attribute Utility Theory (MAUT) is to utilize the tool solely for the Technical Review portion of the Air Force source selection process. This review looks at the technical capabilities of bidding contractors and determines if any are unacceptable with regards to

their technical proposals. Because the technical review is the responsibility of the Engineering Flight within the Civil Engineer Squadron, rather than the Contracting Squadron, there is more flexibility in how technical aptitude is determined. An AHP matrix to weigh technical criteria and utility curves to score those criteria can be used for almost every project, regardless of project cost thresholds and source selection authorities.

## Future Research

While the source selection tool has several potential applications in current Air Force construction contractor selection processes, future research is needed to discover the effectiveness of using this tool. There are multiple potential approaches to accomplishing this research.

First, the effectiveness of the tool could be determined by using past project data. Databases of past DoD projects, like the one built by Stout et al. (2020), can provide a quicker way of applying and analyzing the contractor selection tool's effectiveness on a large set of projects. A future avenue for research could apply the source selection tool to past projects' contractor selection information. Two categories of projects would be created: those where the same contractor was selected while using the tool as the one actually selected and those where a different contractor was selected. By comparing the rates of time, money, or other losses between these two categories, the tool's effectiveness could be determined. The biggest drawback of using past project data is the potential lack of the required in-depth bid evaluation records. This lack of completeness

in the data may prevent the past project data method from being used to test the effectiveness of the contractor selection tool.

A second method future researchers could use to demonstrate effectiveness is to perform current-day case studies using the tool. These studies would allow for user feedback at installations, making it easier to apply the tool to projects, since the appropriate information would be obtained immediately during the bidding process. A drawback of running case studies is the time needed for projects to be completed to grade how well the contractors performed empirically. Multiple projects would need to be included in the case study to build a sample pool for analysis. Multiple projects over multiple years would likely increase the cost of the case study method.

Conclusion

The Air Force's current reliance on using the Lowest Price Technically Acceptable method of project procurement does not optimize the monetary resources it has for completing necessary and required infrastructure construction projects. Data has shown that not selecting the best contractor could lead to cost and schedule overruns. The author conducted a thorough review of the literature to obtain a list of contractor selection criteria. Using these criteria, a Multi-Criteria Decision-Making tool was built that utilizes Analytic Hierarchy Process and Multi-Attribute Utility Theory. The tool is adaptable for any installation and any project type while being simple and straightforward so any Air Force personnel can utilize it. The guidelines set out in FAR Part 15-101-1 regarding the Tradeoff Process are met with this tool, allowing the Air Force, as well as

other DoD and Federal organizations, to make the most of their construction funds and potentially decrease overruns related to poor contractor selection. The aggregation of criteria that came out of the systematic review is also widely applicable for not only future research in the Air Force but also the construction industry as a whole.

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## Appendix 1

| Percent | Count | Selection Criteria |
|---|---|---|
| **69%** | **57** | **Past Experience (Similar Projects)** |
| **60%** | **50** | **Financial Stability (Soundness/Capability)** |
| **47%** | **39** | **Management Capabilities (Ability)** |
| **43%** | **36** | **Bid Price / Tender Sum** |
| **40%** | **33** | **(Past) Performance History** |
| **39%** | **32** | **(Workmanship) Quality** |
| **37%** | **31** | **Technical Resources (Abilities)** |
| **35%** | **29** | **(Occupational) Health and Safety Concerns** |
| **34%** | **28** | **Reputation (Company Image)** |
| **28%** | **23** | **Safety Performance (Record)** |
| **28%** | **23** | **Length of Time in Industry** |
| **27%** | **22** | **Quality Assurance (Management)** |
| **27%** | **22** | **Past Relationship (with client)** |
| **27%** | **22** | **Tech & Equipment (plant & equip)** |
| **27%** | **22** | **(Availability of) Experienced Staff (Personnel)** |
| **24%** | **20** | **Past Failures (in Completed Projects)** |
| **23%** | **19** | **Workload** |
| **23%** | **19** | **Completion of Job within Time** |
| 19% | 16 | Capability and Skill (Knowledge) |
| 18% | 15 | Past Claims and Legal Issues |
| 16% | 13 | Accuracy of Technical Documents (Requirements) |
| 16% | 13 | Local Area Familiarity |
| 16% | 13 | Completion of Job within Budget |
| 16% | 13 | Resources |
| 14% | 12 | Est. Time of Project (Duration) |
| 13% | 11 | Credit Rating |
| 12% | 10 | Banking Arrangements / Bonding |
| 11% | 9 | Firm Background (Organization Chart) |
| 11% | 9 | Size of Past Projects |

| Percent | Count | Selection Criteria |
|---|---|---|
| 11% | 9 | Environmental Management |
| 11% | 9 | Qualifications (of key personnel) |
| 10% | 8 | Facilities and Support Resources (Equipment) |
| 10% | 8 | Type of Past Projects |
| 8% | 7 | Relations with Subs/Suppliers |
| 7% | 6 | Letter of Credit |
| 7% | 6 | Scheduling Plan |
| 7% | 6 | Financial Status (Standing) |
| 6% | 5 | Innovative Capabilities |
| 6% | 5 | Client Satisfaction |
| 6% | 5 | Management Safety Accountability |
| 6% | 5 | Competition |
| 6% | 5 | Flexibility |
| 6% | 5 | Turnover |
| 6% | 5 | Project Management |
| 5% | 4 | Project Size |
| 5% | 4 | Project Type |
| 5% | 4 | Procurement System |
| 4% | 3 | Liquidity |
| 4% | 3 | Firm's Honor and Competence |
| 4% | 3 | Project Complexity |
| 4% | 3 | Location |
| 4% | 3 | Capital Bid |
| 4% | 3 | Maintenance / Repairs (part of bid) |
| 4% | 3 | EMR |
| 4% | 3 | OSHA |
| 4% | 3 | Interview |
| 4% | 3 | Co-operative Outlook |
| 4% | 3 | Debt Ratio |
| 4% | 3 | Number of Staff (Manpower) |

| Percent | Count | Selection Criteria |
|---|---|---|
| 4% | 3 | Organization Size |
| 4% | 3 | Formal Training |
| 4% | 3 | Performance Potential |
| 2% | 2 | Cash Credit |
| 2% | 2 | Equity Capital |
| 2% | 2 | Profitability |
| 2% | 2 | Communication |
| 2% | 2 | Organizational Culture |
| 2% | 2 | Amount of Steel, Cement, and Lumber Used |
| 2% | 2 | Range for Reducing Cost |
| 2% | 2 | Comprehensive Evaluation |
| 2% | 2 | Contract Period |
| 2% | 2 | Amount of Subcontract Work |
| 2% | 2 | Human Resources |
| 2% | 2 | Insurance |
| 2% | 2 | Project Specific |
| 2% | 2 | Fraudulent Activity |
| 2% | 2 | Current Ratio |
| 2% | 2 | Company Management |
| 2% | 2 | Financial Management (Planning) |
| 2% | 2 | Liability |
| 2% | 2 | Number of Past Projects |
| 2% | 2 | Work Method |
| 2% | 2 | Uncertainty Level |
| 2% | 2 | Allocation of Risk |
| 2% | 2 | Project Design |
| 2% | 2 | Bank Reference |
| 1% | 1 | Economically Advantageous |
| 1% | 1 | Total Operational Income |
| 1% | 1 | Commitment |

| Percent | Count | Selection Criteria |
|---|---|---|
| 1% | 1 | Credibility |
| 1% | 1 | Marketing Ability |
| 1% | 1 | Labor Plans |
| 1% | 1 | Physical Resources |
| 1% | 1 | Planning Performance |
| 1% | 1 | Change Proposal / Value Engineering |
| 1% | 1 | Advance Payment (part of bid) |
| 1% | 1 | Safety Plan |
| 1% | 1 | Item Bid Prices |
| 1% | 1 | Stability of Firm |
| 1% | 1 | Integrity |
| 1% | 1 | Relationship with Consultant |
| 1% | 1 | Form of Contract |
| 1% | 1 | Specialized Trade |
| 1% | 1 | Tender Variations and Alternatives Offered |
| 1% | 1 | Board of Directors |
| 1% | 1 | Location of Home Office |
| 1% | 1 | Purchasing expertise (material control) |
| 1% | 1 | Accountability |
| 1% | 1 | Asset Turnover Ratio |
| 1% | 1 | Credit Ratio |
| 1% | 1 | Return of Net Worth Ratio |
| 1% | 1 | Ratio of Fix Asset |
| 1% | 1 | Attitude towards Claims |
| 1% | 1 | Contractor Activity over Last Three Years |
| 1% | 1 | Financial Condition |
| 1% | 1 | Financial Guarantee |
| 1% | 1 | Company Assets |
| 1% | 1 | Cash in Hand |
| 1% | 1 | Technical Manpower |

| Percent | Count | Selection Criteria |
| --- | --- | --- |
| 1% | 1 | Cope with Levels of Complexity |
| 1% | 1 | Financial Evaluation of Bid |
| 1% | 1 | Completeness of Bid Documents |
| 1% | 1 | Bid Understanding |
| 1% | 1 | Bid Process |
| 1% | 1 | Market |
| 1% | 1 | Risk |
| 1% | 1 | Supplier Performance |
| 1% | 1 | Transport, Delivery, and Storage |
| 1% | 1 | Offering Letter (Proposal) |
| 1% | 1 | Certificate of Registration as a Service Provider |
| 1% | 1 | Tax Document |
| 1% | 1 | Construction Business License |
| 1% | 1 | Litigation Tendency |
| 1% | 1 | Credit Reference |
| 1% | 1 | Qualification of Owners |
| 1% | 1 | Equity Ratio |
| 1% | 1 | Activity Period |
| 1% | 1 | Disputes Resolution |
| 1% | 1 | Team Efficiency |
| 1% | 1 | Quality of Materials |
| 1% | 1 | Water Management |
| 1% | 1 | Commitment to Sustainability |
| 1% | 1 | Energy Management |
| 1% | 1 | Sustainable Material Management |
| 1% | 1 | Pollution Management |
| 1% | 1 | Labor Well-Being |
| 1% | 1 | Corporate and Social Responsibility |
| 1% | 1 | Progress of Work |
| 1% | 1 | Negotiating Skill |

| Percent | Count | Selection Criteria |
|---|---|---|
| 1% | 1 | Nationality |
| 1% | 1 | Trade Union Record |
| 1% | 1 | Construction Methods |
| 1% | 1 | Technical Solution |
| 1% | 1 | Company Attributes |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Bid Price | | Mission/Technical Capability |
| Bid Price | | Risk |
| Bid Price | | Past Performance |
| Mission/Technical Capability | | Risk |
| Mission/Technical Capability | | Past Performance |
| Risk | | Past Performance |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Past Experience | | Quality (Workmanship) |
| Past Experience | | Technical Resources |
| Past Experience | | Technology and Equipment |
| Past Experience | | Experienced Staff/Personnel |
| Past Experience | | Management Capabilities |
| Past Experience | | Quality Assurance (Management) |
| Quality (Workmanship) | | Technical Resources |
| Quality (Workmanship) | | Technology and Equipment |
| Quality (Workmanship) | | Experienced Staff/Personnel |
| Quality (Workmanship) | | Management Capabilities |
| Quality (Workmanship) | | Quality Assurance (Management) |
| Technical Resources | | Technology and Equipment |
| Technical Resources | | Experienced Staff/Personnel |
| Technical Resources | | Management Capabilities |
| Technical Resources | | Quality Assurance (Management) |
| Technology and Equipment | | Experienced Staff/Personnel |
| Technology and Equipment | | Management Capabilities |
| Technology and Equipment | | Quality Assurance (Management) |
| Experienced Staff/Personnel | | Management Capabilities |
| Experienced Staff/Personnel | | Quality Assurance (Management) |
| Management Capabilities | | Quality Assurance (Management) |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Financial Stability | | Length of Time in Industry |
| Financial Stability | | Health and Safety Concerns |
| Financial Stability | | Workload |
| Length of Time in Industry | | Health and Safety Concerns |
| Length of Time in Industry | | Workload |
| Health and Safety Concerns | | Workload |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Safety Record | | Performance Reports |
| Safety Record | | Past Relationship with Client |
| Safety Record | | Company Reputation |
| Safety Record | | Past Failures |
| Safety Record | | Completion of Job within Time |
| Performance Reports | | Past Relationship with Client |
| Performance Reports | | Company Reputation |
| Performance Reports | | Past Failures |
| Performance Reports | | Completion of Job within Time |
| Past Relationship with Client | | Company Reputation |
| Past Relationship with Client | | Past Failures |
| Past Relationship with Client | | Completion of Job within Time |
| Company Reputation | | Past Failures |
| Company Reputation | | Completion of Job within Time |
| Past Failures | | Completion of Job within Time |

| Score | Linguistic Description |
|---|---|
| 1/9 | Extreme Importance of Criterion 2 over Criterion 1 |
| 1/7 | Very Strong Importance of Criterion 2 over Criterion 1 |
| 1/5 | Strong Importance of Criterion 2 over Criterion 1 |
| 1/3 | Moderate Importance of Criterion 2 over Criterion 1 |
| 1 | Equal Importance between Criteria |
| 3 | Moderate Importance of Criterion 1 over Criterion 2 |
| 5 | Strong Importance of Criterion 1 over Criterion 2 |
| 7 | Very Strong Importance of Criterion 1 over Criterion 2 |
| 9 | Extreme Importance of Criterion 1 over Criterion 2 |

| | Main Criteria | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | Risk | Past Performance | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Bid Price | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! |
| Mission/Technical Capability | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Risk | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Past Performance | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Summation: | | | | | #DIV/0! | #DIV/0! | $\lambda_{max}$ | #DIV/0! |
| | | | | | | | C.I. | #DIV/0! |
| | | | | | | | C.R. | #DIV/0! |

| | Mission/Technical Capability | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Past Experience | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! |
| Quality (Workmanship) | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Technical Resources | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Technology and Equipment | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Experienced Staff/Personnel | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Management Capabilities | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Quality Assurance (Management) | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Summation: | | | | | | | | #DIV/0! | #DIV/0! | $\lambda_{max}$ | #DIV/0! |
| | | | | | | | | | | C.I. | #DIV/0! |
| | | | | | | | | | | C.R. | #DIV/0! |

| | Risk | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Financial Stability | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! |
| Length of Time in Industry | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Health and Safety Concerns | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Workload | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Summation: | | | | | #DIV/0! | #DIV/0! | $\lambda_{max}$ | #DIV/0! |
| | | | | | | | C.I. | #DIV/0! |
| | | | | | | | C.R. | #DIV/0! |

| | Past Performance | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Safety Record | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! |
| Performance Reports | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Past Relationship with Client | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Company Reputation | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Past Failures | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | 0.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Completion of Job within Time | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | 1.0000 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Summation: | | | | | | | #DIV/0! | #DIV/0! | $\lambda_{max}$ | #DIV/0! |
| | | | | | | | | | C.I. | #DIV/0! |
| | | | | | | | | | C.R. | #DIV/0! |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| R.I. | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

| Bid Price | Mission/Technical Capability | Risk | Past Performance |
|---|---|---|---|
| #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| | Past Experience | Financial Stability | Safety Record |
| | #DIV/0! | #DIV/0! | #DIV/0! |
| | Quality (Workmanship) | Length of Time in Industry | Performance Reports |
| | #DIV/0! | #DIV/0! | #DIV/0! |
| | Technical Resources | Health and Safety Concerns | Past Relationship with Client |
| | #DIV/0! | #DIV/0! | #DIV/0! |
| | Technology and Equipment | Workload | Company Reputation |
| | #DIV/0! | #DIV/0! | #DIV/0! |
| | Experienced Staff/Personnel | | Past Failures |
| | #DIV/0! | | #DIV/0! |
| | Management Capabilities | | Completion of Job within Time |
| | #DIV/0! | | #DIV/0! |
| | Quality Assurance (Management) | | |
| | #DIV/0! | | |

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time |
| Contractor #1 | | | | | | | | | | | | | | | | | | |
| Contractor #2 | | | | | | | | | | | | | | | | | | |
| Contractor #3 | | | | | | | | | | | | | | | | | | |
| Contractor #4 | | | | | | | | | | | | | | | | | | |

| Weights: | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | | |
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Total |
| Contractor #1 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Contractor #2 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Contractor #3 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |
| Contractor #4 | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! | #DIV/0! |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Bid Price | 1/9 | Mission/Technical Capability |
| Bid Price | 1/3 | Risk |
| Bid Price | 1/3 | Past Performance |
| Mission/Technical Capability | 5 | Risk |
| Mission/Technical Capability | 5 | Past Performance |
| Risk | 3 | Past Performance |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Past Experience | 3 | Quality (Workmanship) |
| Past Experience | 5 | Technical Resources |
| Past Experience | 5 | Technology and Equipment |
| Past Experience | 7 | Experienced Staff/Personnel |
| Past Experience | 9 | Management Capabilities |
| Past Experience | 7 | Quality Assurance (Management) |
| Quality (Workmanship) | 3 | Technical Resources |
| Quality (Workmanship) | 3 | Technology and Equipment |
| Quality (Workmanship) | 5 | Experienced Staff/Personnel |
| Quality (Workmanship) | 7 | Management Capabilities |
| Quality (Workmanship) | 5 | Quality Assurance (Management) |
| Technical Resources | 1 | Technology and Equipment |
| Technical Resources | 3 | Experienced Staff/Personnel |
| Technical Resources | 5 | Management Capabilities |
| Technical Resources | 3 | Quality Assurance (Management) |
| Technology and Equipment | 3 | Experienced Staff/Personnel |
| Technology and Equipment | 5 | Management Capabilities |
| Technology and Equipment | 3 | Quality Assurance (Management) |
| Experienced Staff/Personnel | 3 | Management Capabilities |
| Experienced Staff/Personnel | 1 | Quality Assurance (Management) |
| Management Capabilities | 1/3 | Quality Assurance (Management) |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Financial Stability | 1/5 | Length of Time in Industry |
| Financial Stability | 3 | Health and Safety Concerns |
| Financial Stability | 1/3 | Workload |
| Length of Time in Industry | 7 | Health and Safety Concerns |
| Length of Time in Industry | 3 | Workload |
| Health and Safety Concerns | 1/5 | Workload |

| Criterion 1 | Preference? | Criterion 2 |
|---|---|---|
| Safety Record | 3 | Performance Reports |
| Safety Record | 5 | Past Relationship with Client |
| Safety Record | 7 | Company Reputation |
| Safety Record | 1/3 | Past Failures |
| Safety Record | 9 | Completion of Job within Time |
| Performance Reports | 3 | Past Relationship with Client |
| Performance Reports | 5 | Company Reputation |
| Performance Reports | 1/5 | Past Failures |
| Performance Reports | 7 | Completion of Job within Time |
| Past Relationship with Client | 3 | Company Reputation |
| Past Relationship with Client | 1/5 | Past Failures |
| Past Relationship with Client | 5 | Completion of Job within Time |
| Company Reputation | 1/7 | Past Failures |
| Company Reputation | 3 | Completion of Job within Time |
| Past Failures | 9 | Completion of Job within Time |

| Score | Linguistic Description |
|---|---|
| 1/9 | Extreme Importance of Criteria 2 over Criteria 1 |
| 1/7 | Very Strong Importance of Criteria 2 over Criteria 1 |
| 1/5 | Strong Importance of Criteria 2 over Criteria 1 |
| 1/3 | Moderate Importance of Criteria 2 over Criteria 1 |
| 1 | Equal Importance between Criterion |
| 3 | Moderate Importance of Criteria 1 over Criteria 2 |
| 5 | Strong Importance of Criteria 1 over Criteria 2 |
| 7 | Very Strong Importance of Criteria 1 over Criteria 2 |
| 9 | Extreme Importance of Criteria 1 over Criteria 2 |

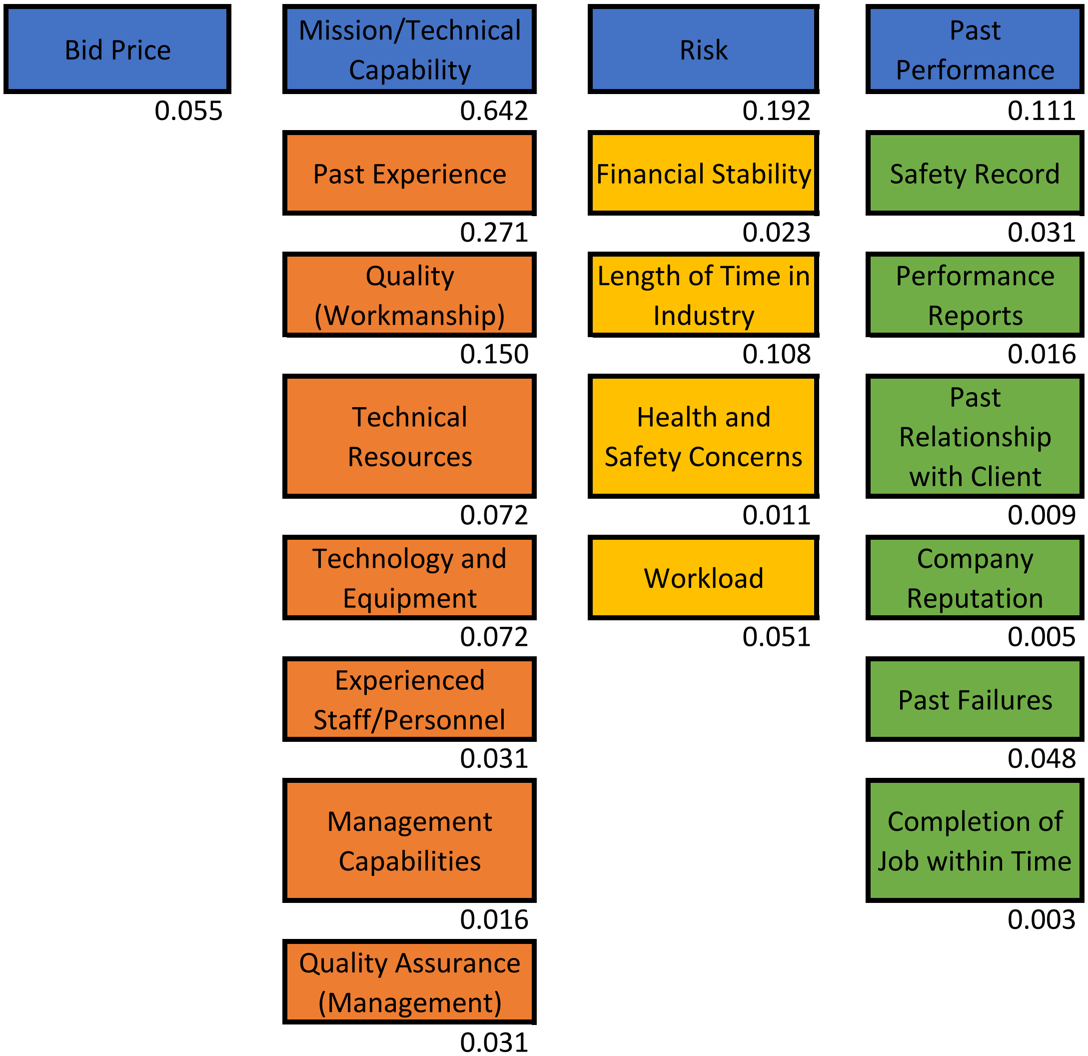
| Main Criteria | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | Risk | Past Performance | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Bid Price | 1.0000 | 0.1111 | 0.3333 | 0.3333 | 0.3333 | 0.0552 | 0.2275 | 4.1180 |
| Mission/Technical Capability | 9.0000 | 1.0000 | 5.0000 | 5.0000 | 3.8730 | 0.6419 | 2.6533 | 4.1333 |
| Risk | 3.0000 | 0.2000 | 1.0000 | 3.0000 | 1.1583 | 0.1920 | 0.8186 | 4.2641 |
| Past Performance | 3.0000 | 0.2000 | 0.3333 | 1.0000 | 0.6687 | 0.1108 | 0.4690 | 4.2310 |
| Summation: | | | | | 6.0333 | 1.0000 | $\lambda_{max}$ | 4.1866 |
| | | | | | | | C.I. | 0.0622 |
| | | | | | | | C.R. | 0.0691 |

| Mission/Technical Capability | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Past Experience | 1.0000 | 3.0000 | 5.0000 | 5.0000 | 7.0000 | 9.0000 | 7.0000 | 4.4222 | 0.421455 | 3.1412 | 7.4532 |
| Quality (Workmanship) | 0.3333 | 1.0000 | 3.0000 | 3.0000 | 5.0000 | 7.0000 | 5.0000 | 2.4468 | 0.233186 | 1.7031 | 7.3037 |
| Technical Resources | 0.2000 | 0.3333 | 1.0000 | 1.0000 | 3.0000 | 5.0000 | 3.0000 | 1.1699 | 0.111498 | 0.8008 | 7.1817 |
| Technology and Equipment | 0.2000 | 0.3333 | 1.0000 | 1.0000 | 3.0000 | 5.0000 | 3.0000 | 1.1699 | 0.111498 | 0.8008 | 7.1817 |
| Experienced Staff/Personnel | 0.1429 | 0.2000 | 0.3333 | 0.3333 | 1.0000 | 3.0000 | 1.0000 | 0.5143 | 0.049019 | 0.3522 | 7.1847 |
| Management Capabilities | 0.1111 | 0.1429 | 0.2000 | 0.2000 | 0.3333 | 1.0000 | 0.3333 | 0.2552 | 0.024324 | 0.1817 | 7.4718 |
| Quality Assurance (Management) | 0.1429 | 0.2000 | 0.3333 | 0.3333 | 1.0000 | 3.0000 | 1.0000 | 0.5143 | 0.049019 | 0.3522 | 7.1847 |
| Summation: | | | | | | | | 10.4928 | 1 | $\lambda_{max}$ | 7.2802 |
| | | | | | | | | | | C.I. | 0.0467 |
| | | | | | | | | | | C.R. | 0.0354 |

| Risk | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Financial Stability | 1.0000 | 0.2000 | 3.0000 | 0.3333 | 0.6687 | 0.1178 | 0.4834 | 4.1041 |
| Length of Time in Industry | 5.0000 | 1.0000 | 7.0000 | 3.0000 | 3.2011 | 0.5638 | 2.3280 | 4.1291 |
| Health and Safety Concerns | 0.3333 | 0.1429 | 1.0000 | 0.2000 | 0.3124 | 0.0550 | 0.2275 | 4.1348 |
| Workload | 3.0000 | 0.3333 | 5.0000 | 1.0000 | 1.4953 | 0.2634 | 1.0798 | 4.0998 |
| Summation: | | | | | 5.6776 | 1.0000 | $\lambda_{max}$ | 4.1169 |
| | | | | | | | C.I. | 0.0390 |
| | | | | | | | C.R. | 0.0433 |

| Past Performance | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Safety Record | 1.0000 | 3.0000 | 5.0000 | 7.0000 | 0.3333 | 9.0000 | 2.6085 | 0.275336 | 1.7667 | 6.4165 |
| Performance Reports | 0.3333 | 1.0000 | 3.0000 | 5.0000 | 0.2000 | 7.0000 | 1.3831 | 0.145991 | 0.9409 | 6.4452 |
| Past Relationship with Client | 0.2000 | 0.3333 | 1.0000 | 3.0000 | 0.2000 | 5.0000 | 0.7647 | 0.08072 | 0.5143 | 6.3718 |
| Company Reputation | 0.1429 | 0.2000 | 0.3333 | 1.0000 | 0.1429 | 3.0000 | 0.3998 | 0.042197 | 0.2695 | 6.3866 |
| Past Failures | 3.0000 | 5.0000 | 5.0000 | 7.0000 | 1.0000 | 9.0000 | 4.0964 | 0.432392 | 2.8976 | 6.7013 |
| Completion of Job within Time | 0.1111 | 0.1429 | 0.2000 | 0.3333 | 0.1111 | 1.0000 | 0.2213 | 0.023363 | 0.1531 | 6.5516 |
| Summation: | | | | | | | 9.4738 | 1 | $\lambda_{max}$ | 6.4788 |
| | | | | | | | | | C.I. | 0.0958 |
| | | | | | | | | | C.R. | 0.0772 |

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |


Bid Price
0.055
Mission/Technical Capability
0.642
Risk
0.192
Past Performance
0.111
Past Experience
0.271
Quality (Workmanship)
0.150
Technical Resources
0.072
Technology and Equipment
0.072
Experienced Staff/Personnel
0.031
Management Capabilities
0.016
Quality Assurance (Management)
0.031
Financial Stability
0.023
Length of Time in Industry
0.108
Health and Safety Concerns
0.011
Workload
0.051
Safety Record
0.031
Performance Reports
0.016
Past Relationship with Client
0.009
Company Reputation
0.005
Past Failures
0.048
Completion of Job within Time
0.003

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time |
| Contractor #1 | 1.0 | 0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.2 | 0.3 | 0.0 | 0.4 | 0.2 | 0.3 | 0.4 | 0.2 | 0.4 | 0.6 | 0.5 |
| Contractor #2 | 0.7 | 0.1 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | 0.5 | 0.8 | 1.0 | 0.9 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 |
| Contractor #3 | 0.1 | 1.0 | 0.8 | 0.9 | 0.9 | 0.8 | 1.0 | 0.8 | 0.5 | 0.5 | 0.7 | 0.4 | 0.7 | 0.6 | 0.4 | 0.7 | 0.9 | 0.7 |
| Contractor #4 | 0.9 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

| Weights: | 0.055 | 0.271 | 0.150 | 0.072 | 0.072 | 0.031 | 0.016 | 0.031 | 0.023 | 0.108 | 0.011 | 0.051 | 0.031 | 0.016 | 0.009 | 0.005 | 0.048 | 0.003 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | | |
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Total |
| Contractor #1 | 0.055 | 0.027 | 0.030 | 0.021 | 0.014 | 0.013 | 0.006 | 0.006 | 0.007 | 0.000 | 0.004 | 0.010 | 0.009 | 0.006 | 0.002 | 0.002 | 0.029 | 0.001 | 0.244 |
| Contractor #2 | 0.039 | 0.027 | 0.090 | 0.043 | 0.036 | 0.019 | 0.009 | 0.016 | 0.018 | 0.108 | 0.010 | 0.040 | 0.024 | 0.015 | 0.009 | 0.004 | 0.043 | 0.002 | 0.552 |
| Contractor #3 | 0.006 | 0.271 | 0.120 | 0.064 | 0.064 | 0.025 | 0.016 | 0.025 | 0.011 | 0.054 | 0.007 | 0.020 | 0.021 | 0.010 | 0.004 | 0.003 | 0.043 | 0.002 | 0.767 |
| Contractor #4 | 0.050 | 0.135 | 0.075 | 0.036 | 0.036 | 0.016 | 0.008 | 0.016 | 0.011 | 0.054 | 0.005 | 0.025 | 0.015 | 0.008 | 0.004 | 0.002 | 0.024 | 0.001 | 0.522 |

| Criteria 1 | Preference? | Criteria 2 |
|---|---|---|
| Bid Price | 3 | Mission/Technical Capability |
| Bid Price | 5 | Risk |
| Bid Price | 5 | Past Performance |
| Mission/Technical Capability | 3 | Risk |
| Mission/Technical Capability | 3 | Past Performance |
| Risk | 3 | Past Performance |

| Criteria 1 | Preference? | Criteria 2 |
|---|---|---|
| Past Experience | 3 | Quality (Workmanship) |
| Past Experience | 5 | Technical Resources |
| Past Experience | 5 | Technology and Equipment |
| Past Experience | 7 | Experienced Staff/Personnel |
| Past Experience | 9 | Management Capabilities |
| Past Experience | 7 | Quality Assurance (Management) |
| Quality (Workmanship) | 3 | Technical Resources |
| Quality (Workmanship) | 3 | Technology and Equipment |
| Quality (Workmanship) | 5 | Experienced Staff/Personnel |
| Quality (Workmanship) | 7 | Management Capabilities |
| Quality (Workmanship) | 5 | Quality Assurance (Management) |
| Technical Resources | 1 | Technology and Equipment |
| Technical Resources | 3 | Experienced Staff/Personnel |
| Technical Resources | 5 | Management Capabilities |
| Technical Resources | 3 | Quality Assurance (Management) |
| Technology and Equipment | 3 | Experienced Staff/Personnel |
| Technology and Equipment | 5 | Management Capabilities |
| Technology and Equipment | 3 | Quality Assurance (Management) |
| Experienced Staff/Personnel | 3 | Management Capabilities |
| Experienced Staff/Personnel | 1 | Quality Assurance (Management) |
| Management Capabilities | 1/3 | Quality Assurance (Management) |

| Criteria 1 | Preference? | Criteria 2 |
|---|---|---|
| Financial Stability | 1/5 | Length of Time in Industry |
| Financial Stability | 3 | Health and Safety Concerns |
| Financial Stability | 1/3 | Workload |
| Length of Time in Industry | 7 | Health and Safety Concerns |
| Length of Time in Industry | 3 | Workload |
| Health and Safety Concerns | 1/5 | Workload |

| Criteria 1 | Preference? | Criteria 2 |
|---|---|---|
| Safety Record | 3 | Performance Reports |
| Safety Record | 5 | Past Relationship with Client |
| Safety Record | 7 | Company Reputation |
| Safety Record | 1/3 | Past Failures |
| Safety Record | 9 | Completion of Job within Time |
| Performance Reports | 3 | Past Relationship with Client |
| Performance Reports | 5 | Company Reputation |
| Performance Reports | 1/5 | Past Failures |
| Performance Reports | 7 | Completion of Job within Time |
| Past Relationship with Client | 3 | Company Reputation |
| Past Relationship with Client | 1/5 | Past Failures |
| Past Relationship with Client | 5 | Completion of Job within Time |
| Company Reputation | 1/7 | Past Failures |
| Company Reputation | 3 | Completion of Job within Time |
| Past Failures | 9 | Completion of Job within Time |

| Score | Linguistic Description |
|---|---|
| 1/9 | Extreme Importance of Criteria 2 over Criteria 1 |
| 1/7 | Very Strong Importance of Criteria 2 over Criteria 1 |
| 1/5 | Strong Importance of Criteria 2 over Criteria 1 |
| 1/3 | Moderate Importance of Criteria 2 over Criteria 1 |
| 1 | Equal Importance between Criterion |
| 3 | Moderate Importance of Criteria 1 over Criteria 2 |
| 5 | Strong Importance of Criteria 1 over Criteria 2 |
| 7 | Very Strong Importance of Criteria 1 over Criteria 2 |
| 9 | Extreme Importance of Criteria 1 over Criteria 2 |

| Main Criteria | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | Risk | Past Performance | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Bid Price | 1.0000 | 3.0000 | 5.0000 | 5.0000 | 2.9428 | 0.5538 | 2.2894 | 4.1339 |
| Mission/Technical Capability | 0.3333 | 1.0000 | 3.0000 | 3.0000 | 1.3161 | 0.2477 | 1.0278 | 4.1499 |
| Risk | 0.2000 | 0.3333 | 1.0000 | 3.0000 | 0.6687 | 0.1259 | 0.5372 | 4.2682 |
| Past Performance | 0.2000 | 0.3333 | 0.3333 | 1.0000 | 0.3861 | 0.0727 | 0.3079 | 4.2380 |
| Summation: | | | | | 5.3137 | 1.0000 | λ max | 4.1975 |
| | | | | | | | C.I. | 0.0658 |
| | | | | | | | C.R. | 0.0731 |

| Mission/Technical Capability | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Past Experience | 1.0000 | 3.0000 | 5.0000 | 5.0000 | 7.0000 | 9.0000 | 7.0000 | 4.4222 | 0.421455 | 3.1412 | 7.4532 |
| Quality (Workmanship) | 0.3333 | 1.0000 | 3.0000 | 3.0000 | 5.0000 | 7.0000 | 5.0000 | 2.4468 | 0.233186 | 1.7031 | 7.3037 |
| Technical Resources | 0.2000 | 0.3333 | 1.0000 | 1.0000 | 3.0000 | 5.0000 | 3.0000 | 1.1699 | 0.111498 | 0.8008 | 7.1817 |
| Technology and Equipment | 0.2000 | 0.3333 | 1.0000 | 1.0000 | 3.0000 | 5.0000 | 3.0000 | 1.1699 | 0.111498 | 0.8008 | 7.1817 |
| Experienced Staff/Personnel | 0.1429 | 0.2000 | 0.3333 | 0.3333 | 1.0000 | 3.0000 | 1.0000 | 0.5143 | 0.049019 | 0.3522 | 7.1847 |
| Management Capabilities | 0.1111 | 0.1429 | 0.2000 | 0.2000 | 0.3333 | 1.0000 | 0.3333 | 0.2552 | 0.024324 | 0.1817 | 7.4718 |
| Quality Assurance (Management) | 0.1429 | 0.2000 | 0.3333 | 0.3333 | 1.0000 | 3.0000 | 1.0000 | 0.5143 | 0.049019 | 0.3522 | 7.1847 |
| Summation: | | | | | | | | 10.4928 | 1 | λ max | 7.2802 |
| | | | | | | | | | | C.I. | 0.0467 |
| | | | | | | | | | | C.R. | 0.0354 |

| Risk | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Financial Stability | 1.0000 | 0.2000 | 3.0000 | 0.3333 | 0.6687 | 0.1178 | 0.4834 | 4.1041 |
| Length of Time in Industry | 5.0000 | 1.0000 | 7.0000 | 3.0000 | 3.2011 | 0.5638 | 2.3280 | 4.1291 |
| Health and Safety Concerns | 0.3333 | 0.1429 | 1.0000 | 0.2000 | 0.3124 | 0.0550 | 0.2275 | 4.1348 |
| Workload | 3.0000 | 0.3333 | 5.0000 | 1.0000 | 1.4953 | 0.2634 | 1.0798 | 4.0998 |
| Summation: | | | | | 5.6776 | 1.0000 | λ max | 4.1169 |
| | | | | | | | C.I. | 0.0390 |
| | | | | | | | C.R. | 0.0433 |

| Past Performance | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Column Vector | [W] | Weighted Sum | Eigenvalue (λ) |
| Safety Record | 1.0000 | 3.0000 | 5.0000 | 7.0000 | 0.3333 | 9.0000 | 2.6085 | 0.275336 | 1.7667 | 6.4165 |
| Performance Reports | 0.3333 | 1.0000 | 3.0000 | 5.0000 | 0.2000 | 7.0000 | 1.3831 | 0.145991 | 0.9409 | 6.4452 |
| Past Relationship with Client | 0.2000 | 0.3333 | 1.0000 | 3.0000 | 0.2000 | 5.0000 | 0.7647 | 0.08072 | 0.5143 | 6.3718 |
| Company Reputation | 0.1429 | 0.2000 | 0.3333 | 1.0000 | 0.1429 | 3.0000 | 0.3998 | 0.042197 | 0.2695 | 6.3866 |
| Past Failures | 3.0000 | 5.0000 | 5.0000 | 7.0000 | 1.0000 | 9.0000 | 4.0964 | 0.432392 | 2.8976 | 6.7013 |
| Completion of Job within Time | 0.1111 | 0.1429 | 0.2000 | 0.3333 | 0.1111 | 1.0000 | 0.2213 | 0.023363 | 0.1531 | 6.5516 |
| Summation: | | | | | | | 9.4738 | 1 | λ max | 6.4788 |
| | | | | | | | | | C.I. | 0.0958 |
| | | | | | | | | | C.R. | 0.0772 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| R.I. | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

| Bid Price | Mission/Technical Capability | Risk | Past Performance |
|---|---|---|---|
| 0.554 | 0.248 | 0.126 | 0.073 |
| | Past Experience 0.104 | Financial Stability 0.015 | Safety Record 0.020 |
| | Quality (Workmanship) 0.058 | Length of Time in Industry 0.071 | Performance Reports 0.011 |
| | Technical Resources 0.028 | Health and Safety Concerns 0.007 | Past Relationship with Client 0.006 |
| | Technology and Equipment 0.028 | Workload 0.033 | Company Reputation 0.003 |
| | Experienced Staff/Personnel 0.012 | | Past Failures 0.031 |
| | Management Capabilities 0.006 | | Completion of Job within Time 0.002 |
| | Quality Assurance (Management) 0.012 | | |

| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time |
| Contractor #1 | 1.0 | 0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 0.4 | 0.2 | 0.3 | 0.0 | 0.4 | 0.2 | 0.3 | 0.4 | 0.2 | 0.4 | 0.6 | 0.5 |
| Contractor #2 | 0.7 | 0.1 | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 | 0.5 | 0.8 | 1.0 | 0.9 | 0.8 | 0.8 | 0.9 | 1.0 | 0.9 | 0.9 | 0.8 |
| Contractor #3 | 0.1 | 1.0 | 0.8 | 0.9 | 0.9 | 0.8 | 1.0 | 0.8 | 0.5 | 0.5 | 0.7 | 0.4 | 0.7 | 0.6 | 0.4 | 0.7 | 0.9 | 0.7 |
| Contractor #4 | 0.9 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

| Weights: | 0.554 | 0.104 | 0.058 | 0.028 | 0.028 | 0.012 | 0.006 | 0.012 | 0.015 | 0.071 | 0.007 | 0.033 | 0.020 | 0.011 | 0.006 | 0.003 | 0.031 | 0.002 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bid Price | Mission/Technical Capability | | | | | | | Risk | | | | Past Performance | | | | | | |
| | Bid Price | Past Experience | Quality (Workmanship) | Technical Resources | Technology and Equipment | Experienced Staff/Personnel | Management Capabilities | Quality Assurance (Management) | Financial Stability | Length of Time in Industry | Health and Safety Concerns | Workload | Safety Record | Performance Reports | Past Relationship with Client | Company Reputation | Past Failures | Completion of Job within Time | Total |
| Contractor #1 | 0.554 | 0.010 | 0.012 | 0.008 | 0.006 | 0.005 | 0.002 | 0.002 | 0.004 | 0.000 | 0.003 | 0.007 | 0.006 | 0.004 | 0.001 | 0.001 | 0.019 | 0.001 | 0.645 |
| Contractor #2 | 0.388 | 0.010 | 0.035 | 0.017 | 0.014 | 0.007 | 0.004 | 0.006 | 0.012 | 0.071 | 0.006 | 0.027 | 0.016 | 0.010 | 0.006 | 0.003 | 0.028 | 0.001 | 0.659 |
| Contractor #3 | 0.055 | 0.104 | 0.046 | 0.025 | 0.025 | 0.010 | 0.006 | 0.010 | 0.007 | 0.035 | 0.005 | 0.013 | 0.014 | 0.006 | 0.002 | 0.002 | 0.028 | 0.001 | 0.396 |
| Contractor #4 | 0.498 | 0.052 | 0.029 | 0.014 | 0.014 | 0.006 | 0.003 | 0.006 | 0.007 | 0.035 | 0.003 | 0.017 | 0.010 | 0.005 | 0.003 | 0.002 | 0.016 | 0.001 | 0.722 |

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**14. ABSTRACT**

Currently, there is no Air Force-wide best practice or standard for using an other-than lowest price source selection process for construction projects. Installations often award contracts using Lowest Price Technically Acceptable (LPTA) because of perceived cost and time savings. However, a heavy reliance on LPTA often leads to long-term decreases in quality and value. To allow the Air Force to receive the best value for its construction funding, a simple and adaptable tool was developed that allows installations to pursue contractor selection for construction projects by other-than lowest price methods. This research conducted a systematic literature review to obtain a list of the most frequently used contractor selection criteria from research. Using the PRISMA Process guidelines, a research question was developed to identify evaluation criteria that could be used to assess and select construction contractors and subcontractors from those bidding on a construction project. Using these criteria, a Multi-Criteria Decision-Making tool was built that uses the Analytic Hierarchy Process to weigh each criterion. Multi-Attribute Utility Theory is then used to score contractor data for each criterion. The final Performance Index shows the most qualified contractor based on the inputs to the source selection tool. This source selection tool will allow the Air Force to maximize the value of its construction funds within federal guidelines and the aggregated list of most frequently used criteria may benefit other construction contractor selection research.

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