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Multi-objective Decision Analysis for Workforce Planning: A Case Study

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Abstract

The United States Department of Defense (DoD) engages in complex decision making on a daily basis, in terms of mission support and workforce management. Decision analysis tools are employed to evaluate and support the best course of action. In particular, multi-objective decision making (MODA) is a robust decision technique that evaluates objectives and measures in terms of value to select from a set of alternatives. This paper examines workforce planning at a DoD Agency through the use of MODA and examines the ratio of government employees (GOV) and contractors (CON) for an engineering related work role. MODA is used to identify influences to the assignment of a GOV or CON to an open position and to determine the appropriate ratio of GOV and CON employees for the work role. Results will be used to provide critical decision support to effectively manage budget and resources while meeting work requirements and agency mission with the best possible skill set.

Keywords
Multiple objective decision analysis, multiple criteria decision analysis, workforce planning, decision analysis, government

1. Background and Problem Statement
Workforce planning is an ongoing problem for every organization. Limited resources such as man hours by skill set and other constraints such as training period and hiring lead time must be balanced against both a changing project landscape and evolving organizational goals. Projects are often time dependent, and typically the permanent workforce's skills and size may not be flexible enough to adapt quickly and appropriately. Such situations include seasonality and new product development and launch. In these and other related situations, organizations bridge the gap with temporary or outsourced workers. These workers are extremely flexible, can be cost efficient, and have specialized skill sets. Balancing the workforce with temporary or contracted workers, who are adaptable to changing requirements and work load, reduces the need for hiring, firing, and cross-training workers, all of which have costs.

In the government, workforce planning takes an additional dimension. The United States federal government employs its own employees (GOV) as well as manages major contracts with private industry to supplement the workforce. These contractor employees (CON) are somewhat temporary and are managed by a contracting company. Their skill set is matched to the work role needs of the government agency, but the time the employees are assigned to a project, or even the agency itself, varies from a few weeks to a few years. These contracts can be terminated or reduced before the planned end date at the convenience of the government but often at a cost. Therefore, even though these CON employees can be viewed as temporary in the traditional workforce planning sense, the planned work term length can be quite lengthy.

The number of government employees is mostly constrained by congressional limitations on the number of employees to hire but also by long lead times in the hiring process. Furthermore, projects constantly evolve, and the required skill set needed to execute the work may not be available in the current government workforce. Due to a lengthy hiring process, a new GOV employee possibly may not be on-boarded quickly enough to complete the work in a timely manner. CON workers can easily fill these needs, as the contracting company typically retains highly skilled and flexible workers and has processes in place to expand more quickly than the government.

This paper addresses workforce planning by examining the preferred mix of GOV and CON employees for a systems engineering work role at a U.S. government agency from a decision analysis perspective. Balancing GOV and CON is not always straightforward, and techniques such as multi-objective decision analysis (MODA) can help the decision maker to discern his/her values and preferences regarding balancing his/her staff. An engineering skill set is clearly needed to fill roles, but agency knowledge, project context, and continuity also factor into planning and project decisions. MODA provides the means for decision makers to quantify their qualitative preferences for these measures, through an expert elicitation process, while analytically determining their preferred mix of GOV and CON employees. Examining such a mix is akin to examining a mix of permanent and temporary workers or a mix of permanent and outsourced workers in an industrial setting.

This paper continues with a discussion of the MODA technique and then follows with details of the unique hierarchy and methodology for the systems engineering work role case study. Multiple organizational leaders were interviewed to elicit their preferences, and a separate MODA was performed for each organization. The individual organizational results were then aggregated into an overall result that is representative of the preferred ratio of GOV and CON employees across the agency for the studied engineering work role. The uniqueness of this approach along with the novel approach to value functions taken in this research, where the alternatives or set of continuous GOV / CON ratios serves as the value elicitation scale, are discussed.

2. MODA

Multiple Objective Decision Analysis (MODA) is an operations research technique for evaluating a decision under multiple, sometimes conflicting objectives or criteria, based on a set of underlying values belonging to the decision makers. MODA is sometimes also called multiple attribute utility theory (MAUT) or multiple criteria decision analysis (MCDA) [1-3]. Decision problems are characterized by several or many alternatives, none of which is obviously the best because the decision maker tries to balance multiple objectives (e.g., cost, performance, reliability) as well as uncertainty regarding how well each alternative will perform across the objectives. (MODA typically does not explicitly address the uncertainty.) A given alternative might do quite well on one or two objectives but then will be considered moderate to poor on other objectives. There is often an alternative that is moderate across all objectives, providing a possible compromise. In some cases finding a compromise alternative is desirable, but this is not always the case. MODA provides a process that systematically identifies alternatives and the decision maker's objectives (and associated measures) that define a value model. This value model serves as the measuring device for selecting the preferred alternative.

MODA customarily begins with a discussion of both the value model (objectives and measures for which value functions and value swing weights will be defined) and possible, feasible alternatives in the decision space. There is an interplay between the value model and alternatives. New, broader alternatives will often require the development of a broader value model; the value model must be able to distinguish all value differences between the alternatives that the decision maker can sense. Similarly, a clear understanding of the value model often stimulates brainstorming activities that uncover legitimate alternatives that had not been previously defined. Keeney [4] augmented the traditional mathematics and application process of MODA by introducing Value-Focused Thinking (VFT). The VFT process emphasizes the development model at the beginning of the MODA process so that the decision maker's creativity is stimulated to define as many innovative alternatives as possible.

The MODA process is based on several sets of axioms, each of which defines a different mathematical function for integrating the measures and objectives in the value model for the given decision problem [2]. For the purposes of this paper, we assume the strongest set of axioms is appropriate, yielding an additive value function across the value objectives and measures for each alternative. For a detailed discussion on the axioms of the MODA process, see [2].

A general framework for the MODA process implementation is shown in Figure 1. MODA considers all stakeholders in assessing values and requires careful consideration as to whose values should be modeled.

Therefore the first step in the process is obtaining a clear definition of the decision problem and all relevant stakeholders for that problem. Given the problem definition, the stakeholders can be queried about relevant objectives for selecting the preferred alternative. Because there are nearly always several major objectives, some of which have sub-objectives, a value hierarchy is defined as part of step 2. This value hierarchy has an integrating Fundamental Objective at the top and several major fundamental objectives (often called ends objectives to differentiate from means objectives) at the first level below the Fundamental Objective. Each fundamental objective at the first level can be subdivided into more detailed fundamental objectives if there are different aspects or conditions to be considered. This decomposition can proceed one or two more levels. Once the objectives are created in a hierarchy, one or more measures can be defined for each objective at the bottom of this value model. Most decision problems have at least three to five measures for a couple of objectives. More complex decision problems can have 10-15 measures. Very complex decision problems have 20-100 measures.

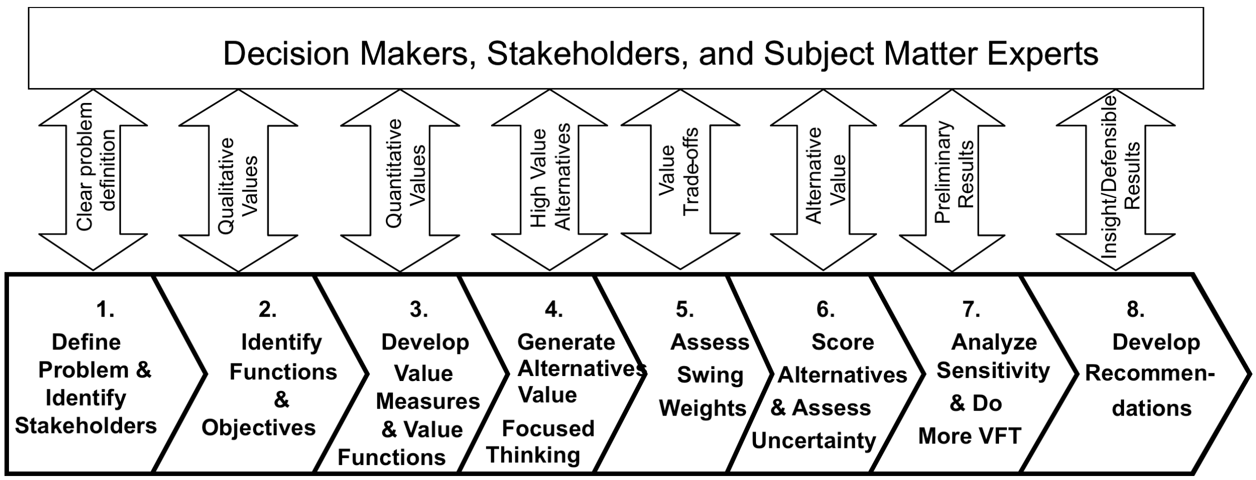

Figure 1: The adaptive MODA process [6]

Once the measures are defined at the bottom of the value hierarchy, value functions can be elicited from the decision maker (a person or a group facing a common decision) [3, 5]. The value function is a continuous or discrete function that maps value from the worst acceptable value on the measure to the best possible value on the measure. The decision maker must be involved in defining the worst and best possible points on each measure. The value function is usually (but not necessarily) a monotonically increasing or decreasing function from the worst to best points on the measure scale. Figure 1 shows step 4 as the definition of the decision alternatives, though discussion about the alternatives is typically ongoing from the very beginning. By step 4 it is important that a well-defined list of alternative be created. The value model is finished in step 5 by the elicitation of value weights across all of the measures at the bottom of the value hierarchy [3, 5]. These weights are often called swing weights because they must capture the value swing from the worst to best measure points on each value function. In step 6, the alternatives can be scored by defining what point on each measure is the best estimate of the alternative's capability. Any alternative that performs worse than the worst acceptable measure point on any measure is usually eliminated from consideration. The total value for each alternative is computed as the weighted average of the values on each measure associated with measure score on those measures. The best alternative achieves the highest value score.

Sensitivity analysis can be performed to the value scores of the alternatives by examining how these value scores change as one or more weights or scores are changed. This enables the decision maker to determine if the selection of the preferred alternative depends on any of the value judgments. If there are important sensitivities, additional discussions on these judgments may be justified before a decision is recommended or made.

3. Methodology

3.1 MODA Hierarchy and Organization Sampling

Because an optimal mix of GOV and CON employees was to be examined across a sample of agency organizations that employ systems engineers, a standardized hierarchy was developed to apply to all organizations. From all possible organizations with systems engineers, a sample of five organizations was taken. This sampling of organizations is considered to be representative of all agency systems engineers and was selected in such a manner to include various aspects of the business, while also respecting resource constraints. Figure 2 depicts the MODA hierarchy, which contained measures of systems engineering functions that are standard across the agency. Table 1 contains descriptions of all included measures.

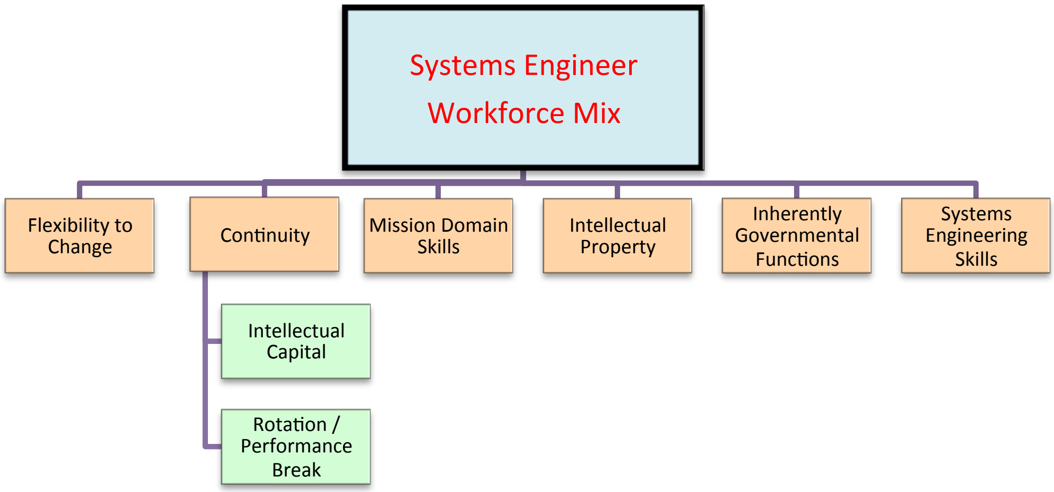

Figure 2: MODA hierarchy and measures

Table 1: Definitions of measures on MODA hierarchy

Measure	**Definition**
Flexibility to Change	Ability to make workforce adjustments due to project scope, funding, etc.
Continuity	Break in a project due to change in contract, promotions, etc.
Intellectual Capital	Ability to maintain project details and knowledge through employee transition
Rotation / Performance Break	Ability to continue to deliver results as employees transition
Mission Domain Skills	Skills that are closely held and support the activities that the agency does
Intellectual Property	Skills that support how the agency carries out mission
Inherently Governmental Functions	Work functions that only government employees may complete
Systems Engineering Skills	Processes, analytics, and skills that are traditional to the systems engineering body of knowledge

These functions encompass the systems engineering work role; systems engineers are employed in a variety of capacities, supporting projects and programs with budgets of varying size. In some settings, the focus of the system engineering tasks is in support of enterprise-wide processes and functions. In others, the focus is on the architecture and implementation of a complex engineering system vital to an organization's mission or goal. And still in others, the focus is on the integration of many complex engineering systems across the entire enterprise. These areas are classified as Enterprise, Mission, and Program, respectively. Regardless of area, there is a need for a balance among the following skill areas: academic systems engineering skills (i.e. skills taught in degree granting programs), traditional engineering skills in a physical science realm, and agency domain specific systems engineering skills (i.e. skills that can only be "learned on the job").

Overall, this set of measures for the MODA value hierarchy are common to all systems engineering work roles and yet independent of an organization's specific focus or mission. This is in line with best MODA modeling practices, which prescribe collectively exhaustive and mutually independent measures. The measures were elicited in a top-down manner from the chief systems engineer and deputy chief systems engineer of the entire agency to whom many of the systems engineers at the agency are in some sense subordinate. This ensured that individual MODA models for all sub-organizations which employ systems engineers would share the same set of measures.

3.1 Interview Protocol and Value Functions

The chief of each organization that was sampled was interviewed to elicit MODA value functions for each relevant measure on the hierarchy. Although the measures identified by leadership are representative of the systems engineering work role, each measure may not be a function of all organizations across the agency, depending on organization mission. Therefore, the leadership subject matter experts (SMEs) that were interviewed were first asked to identify the relevant measures to his/her organization, and then for every remaining measure, define a value function for the ratio preference of GOV systems engineers.

All measures were evaluated on the same scale. Figure 3 shows the elicited value function for the Intellectual Property Knowledge measure from organization A. Note that the most preferred ratio of GOV/CON systems engineers occurs between 10 and 50 percent government employees. That is, the leadership of organization A would be most happy with a GOV workforce anywhere between ten and fifty percent and is indifferent to any value within that range, as all are most preferred. Leadership is least happy with either zero percent or 100 percent GOV employees. All value functions for all measures and organizations were elicited in this manner, but not all functions take this shape.

Typically in MODA, decision makers are asked to identify measures, then identify scales for each measure, and finally identify values associated with each entry on the scale. However, in this study, the end goal was to determine a ratio of systems engineers across GOV and CON employees, and leadership was asked to define value in terms of ratio. This is a unique approach, as most MODA analyses do not use the range of alternatives as value measure scales. However, doing so in this instance ensures consistency across each leader interviewed. Leaders must approach the measures in the same fashion, so the potential for bias in assessing value and/or misunderstanding of the measure is reduced. Furthermore, the MODA process is simplified, because each organizational leader only has to determine value, eliminating the requirement to define scale as well. Therefore, in addition to consistency, this approach streamlines the process, reducing the time commitment from leadership.

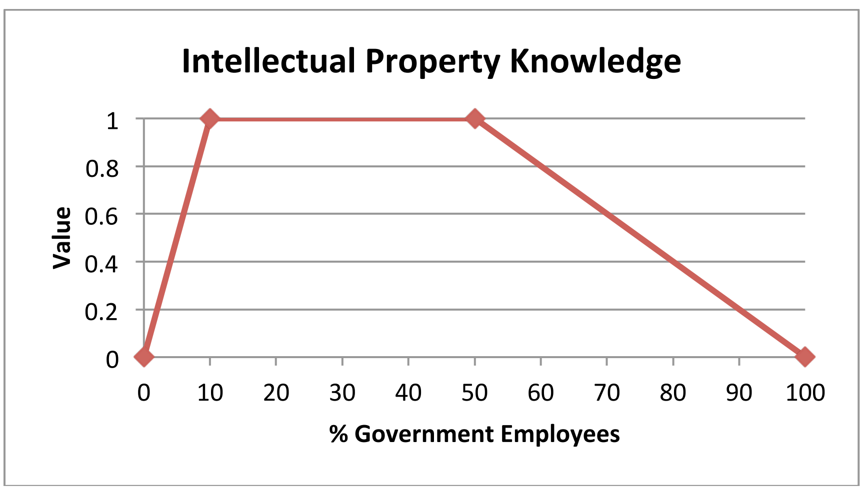

Figure 3: Example value function

Thus, in this study, the value function scale for most of the measures (except Inherently Governmental Functions) was a continuous scale indicating the percentage of government employees with respect to the organization's total number of employees. Inherently Governmental Functions was elicited as a whole number of government employees but then converted to a percentage scale to conform to the other measures. The conversion was based on the number of employees in the organization; thus, the number required to perform inherently governmental functions was converted to a percent of the total current engineers in the organization. This scale and approach allowed the final answer to be reported in terms of percentage.

Because each organization evaluated the hierarchy individually, a separate MODA value curve was developed for each organization. The next section details these results along with the aggregation procedure across the organizations.

3. Results

Figure 4 depicts the MODA value curve for organization B and Figure 5 depicts the MODA value curve for organization C. The measures included in each organization's MODA are shown below the figure, along with the value contribution of each measure at various alternatives. The measures were weighted by one of two methods, depending on the SME. If the SME was comfortable providing weights for the measures, then those weights were elicited and normalized. Otherwise, a rank order of the measures was elicited, and MODA's rank order centroid method was used to calculate the weights. The unnormalized rank order centroid weight for the measure of rank k (of K measures) is the sum of $1/k$ through $1/K$, divided by K. For a detailed description of the rank order centroid method, see [5, 7, 8]. Organizations B and C provided weights for the measures that were then normalized.

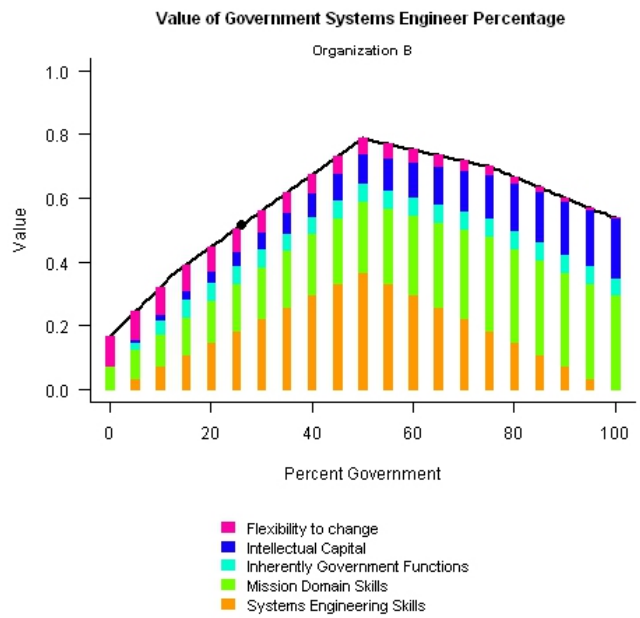

Figure 4: MODA value curve for organization B

Value functions for each measure considered in an organization's respective value hierarchy yield a range of mixes reflecting high value. In some cases, this range is consistent across all measures yielding a similar overall optimal range of mixes with respect to an organization's value hierarchy; organization B (Figure 4) is an example of this. In other cases, mixes reflecting high value differ significantly across the measures, yielding "flatter" optimal ranges; organization C (Figure 5) is an example. Organizations with flat optimal ranges are relatively indifferent between government and contractor employees, and issues not considered in our particular case study (e.g. fiscal and budgetary issues) are more likely to be drivers of decisions impacting the workforce than the measures considered in our models.

In addition to finding the optimal ranges of mixes for each organization's value model, distance from the preferred range can also be determined. That is, given an organization's current mix of government and contractor employees, where it currently falls on its own value curve and how far is that from the preferred range. The organization's current mix of employees is represented by the black dot on the max value curve. As evident from Figures 4 and 5, organization C is currently near its preferred mix while organization B has a current mix that is below preferred.

In order to provide a general value curve that is representative of all organizations at the agency, the organizational value curves were aggregated into one curve by weighting each organization by the number of employees currently performing systems engineering functions. Figure 6 shows the overall value curve across all five organizations;

recall we are assuming these organizations are representative of all organizations at the agency. Given this weighted value function, we extract the 98th percentile mixes, i.e. the percentages of government employees that yield value within 2% of the maximum value of the weighted value function. Thus, a preferred range of GOV systems engineers at the agency falls between 82 and 94 percent.

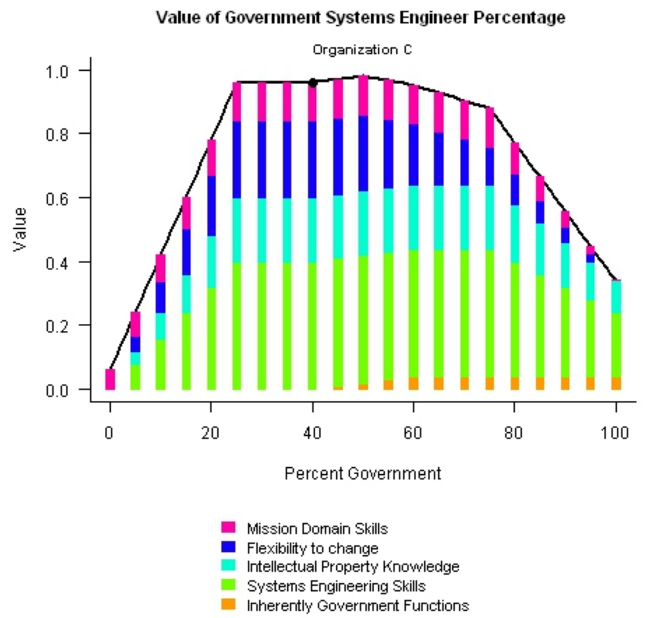

Figure 5: MODA value curve for organization C

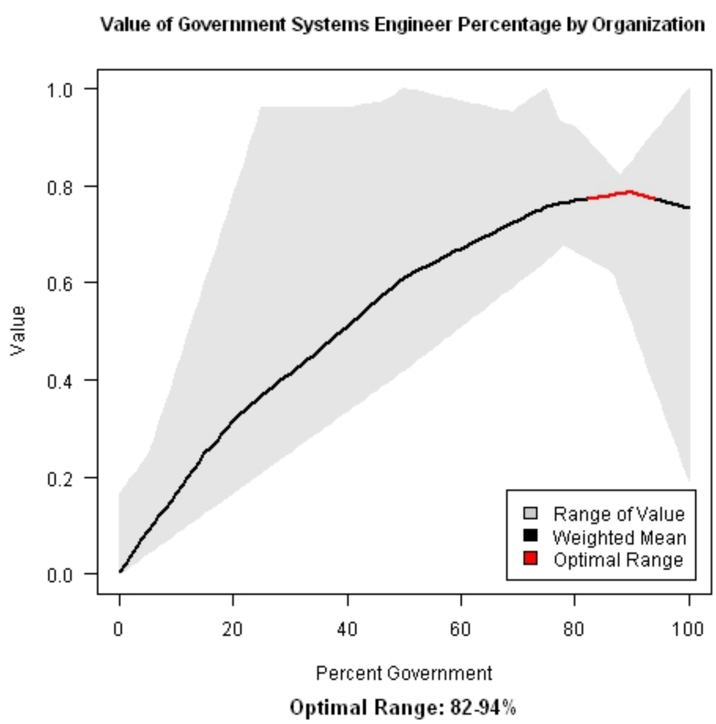

Figure 6: MODA value curve for all agency systems engineers

3.1 Sensitivity Analysis
To explore the sensitivity of the weighting scheme, a Monte Carlo simulation was developed to allow the weights to vary plus or minus 50%. These weights were selected from a uniform distribution and normalized to sum to 1 for every simulation run. Table 2 shows the weight range for every organization. This yielded a distribution over the 98th percentile mix and allowed us to compute the percentage of time that a given percentage of GOV employees was in the 98th percentile. Figure 7 shows the simulation results for percentage of GOV employees in the 70-100% range. In these results, if the number of employees in the organization would vary, then the desired percent ratio of GOV systems engineers would be approximately 72%, with 86% also closely preferred. This suggests that if the distribution of systems engineers across the organization's activities could fluctuate significantly over time, the overall preferred agency percentage may be lower than calculated from the aggregate MODA value curve.

Table 2: Organizational weight ranges in Monte Carlo simulation

Organization	Original Weight	Weight Range
A (Enterprise)	22%	11.0 – 33.0%
B (Enterprise)	3%	1.5 - 4.3%
C (Program)	1%	0.6 - 1.9%
D (Enterprise)	12%	6.0 – 19.0%
E (Mission)	62%	31.0 – 92.0%

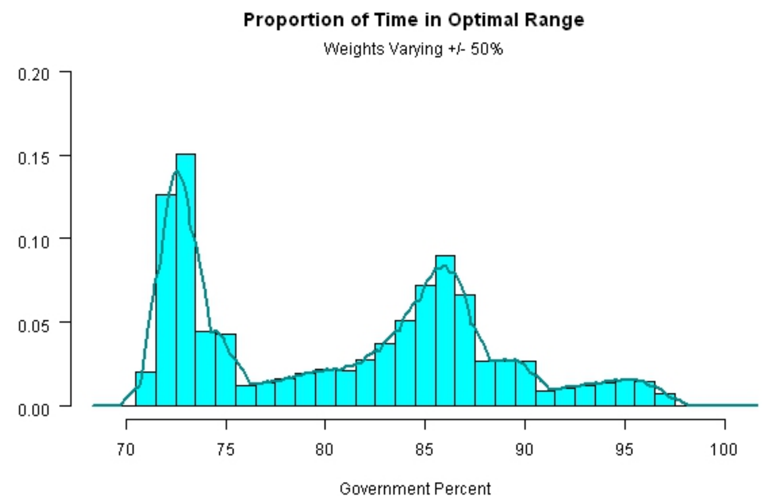

Figure 7: Monte Carlo simulation results

6. Conclusions and Future Work
Overall, this paper presents an examination of workforce planning for an engineering work role from a decision analysis perspective. Multiple organizations were surveyed, and leadership defined value functions for measures related to the work role. MODA value curves were calculated for each organization and then aggregated into an overall function weighted by the number of employees currently in the organization. Results showed a high preference for GOV systems engineers at the agency.

The approach taken in this research is novel, as typically one MODA analysis is performed in a decision analysis problem. However, multiple leaders had to provide input, and those leaders supported organizations ranging a variety of areas, including Enterprise, Mission, and Program. Each functional area of the business has unique goals, and leader perspectives will vary in support of those goals. Capturing all relevant perspectives in terms of both value functions and weights of measures is crucial to both the analysis and the assumption that the sample is representative of the entire agency. Thus, to prevent bias and ensure all preferences are accurately elicited, each SME was interviewed separately. Weighting the results by number of employees ensures the spread of employees across the Enterprise, Mission, and Program areas is accurately represented in the model.

This applied research effort takes a unique approach to MODA value functions by using the continuous range of alternatives as the scale for the value functions. We found the organization chiefs were able to relate to the elicitation questions very quickly and were quite confident in the elicited results. As expected, the value curves for a given measure varied quite significantly across organizations due their differing missions and needs. This provides consistency to the model, but future research will examine this problem from a traditional MODA perspective, where SMEs define both scales and values for each measure. Introducing the opportunity for unique scales for every measure across the organizations may contribute more detail to the analysis and deeper understanding of the preferred mix of employees for all organizations. Furthermore, increasing the sample size of organizations will provide further insight into the overall agency preferred mix. Upon the analysis of additional organizations, the results may show that preferred mix may vary by the Enterprise, Mission, and Program areas, with an overall agency mix that is the aggregate of each functional area mix.

Future research will also consider other strategies for calculating the preferred range. For instance, suppose an organization's current mix is less than their optimal range, i.e. the current number of government employees is too small. The organization might hire government employees while holding the number of contractors constant. Or, the organization may need to hold the number of total employees constant, in which case the proper course of action is to reduce the number of contractors. The inclusion of other constraints may also yield optimization formulations with respect to an organization's value function (a linear combination of piece-wise, linear functions). Furthermore, weighting the individual MODA value curves via alternative methods may also reduce the range around the preferred mix while improving the bi-modal simulation results.

In general, the workforce mix model presented in this paper quantifies the subjective nature of preference while remaining adaptable and flexible to changing work requirements. It is suitable for workforce planning and has been highly received by the agency.

Acknowledgments

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References

1. Parnell, G.S., 2006, "Chapter 19: Value-Focused Thinking using Multiple Objective Decision Analysis," appears in Methods for Conducting Military Operational Analysis, Loerch, A.G. and Rainey, L.B. (eds.), Military Operations Research Society, Alexandria, Virginia.
2. Keeney, R.L., and Raiffa, H., 1976, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, Wiley, New York.
3. Kirkwood, C.W., 1997, Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets, Duxbury Press, Belmont, California.
4. Keeney, R.L., 1992, Value-Focused Thinking: A Path to Creative Decisionmaking, Harvard University Press, Cambridge, Massachusetts.
5. Buede, D.M., 2009, The Engineering Design of Systems: Models and Methods, Wiley, New York.
6. Dillon-Merrill, R.L., Parnell, G.S., Buckshaw, D.L., Hensley, W.R., and Caswell, D.J., 2008, "Avoiding Common Pitfalls in Decision Support Frameworks for Department of Defense Analyses," Military Operations Research, 13(2), 19-31.
7. Barron, F.H., 1992, "Selecting a Best Multiattribute Alternative with Partial Information About Attribute Weights," Acta Psychologica, 80(1-3), 91-103.
8. Barron, F.H., and Barrett, B.E., 1996, "Decision Quality Using Ranked Attribute Weights," Management Science, 42(11), 1515-1523.