OPTIMIZATION OF RATED OFFICER STAFF ASSIGNMENTS

GRADUATE RESEARCH PROJECT

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Abstract

The United States Air Force matches an average of 1400 rated officers to staff assignments each fiscal year. The primary consideration is the Rated Staff Allocation Plan which details Air Force rated officer entitlements across the Department of Defense. The Operations Staff Assignment Branch, located at Headquarters, Air Force Personnel Center, is responsible for the assignment process. There is currently no method in place to assess or maximize the utility of the assignments made. This research details the development of an assignment matching tool using network flow optimization that, if implemented by the Operations Staff Assignment Branch in future assignment cycles, will make the assignment process more efficient and provide a quantitative assessment of utility that is optimized .

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To my wife and children

Acknowledgments

This project would not have been possible without the love and support of my family. Thanks to my wife for the patience, understanding and constant motivation to complete this research. And to my children who always made sure I kept focused on what is most important in my life.

Thanks to my advisor, Maj. Shane Hall, for his help and guidance as well as his faith when I told him I was not worried. Also thanks to the AFIT faculty, staff and my fellow students for helping me in this endeavor.

Finally, thanks to Maj. Alex Miravite who convinced the Operations Staff Assignments Branch at Air Force Personnel Center to sponsor this research and provided all the necessary information to achieve our goal.

Alexander M. Wylie

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I. Introduction

National security requirements drive the reassignment of military personnel from one duty station to another. In turn, all of the armed services rotate personnel to best meet the needs of that particular service. The task of managing the assignments of more then 340,000 Airmen is a challenge that falls largely on the Air Force Personnel Center (AFPC) at Randolph Air Force Base (AFB), Texas. This research focuses on improving the current process of assigning rated officers to positions on a senior officer's staff, but could be applied to other functional areas as well.

There are numerous improvements that can be made in the current process. They include decrease in time to complete the process, currently 2 to 4 weeks depending on the number of rated officers being matched. The quality of the match is another area that can be improved. This includes creating a method to quantify the quality of a match, optimizing the final result based on that method, and increasing the number of input variables considered.

Terminology and Definitions

The Air Force (AF), like any career field, uses specialized terminology and acronyms that are assumed to be understood by those in the Air Force. This is also true for smaller groups of professionals, such as pilots, who have their own specialized terminology as well. The following definitions are provided to establish the terminology used in this research which may differ from common use. Furthermore, a short list of acronyms and abbreviations is provided in Table 1 and a complete list is provided in the preface.

Rated officer – an individual of the rank Captain to Lieutenant Colonel with an aeronautical rating as a pilot, navigator or air battle manager (ABM). Includes a small number of mission support personnel without an aeronautical rating.

Requirement – a position for a rated officer on a senior officer's staff.

Command – major command (MAJCOM) or higher unit with a requirement.

Entitlement – a command's share of rated officers by aeronautical rating.

Match – a pairing of a rated officer to a particular requirement.

Staff match – a set of matches including all rated officers in a given group.

Assignment cycle – a four month period beginning in January, May or September where a staff match is made.

Assignment process – current process used to develop a staff match.

ABM	Air Battle Manager
AF	Air Force
AFB	Air Force Base
AFPC	Air Force Personnel Center
AFRC	Air Force Reserve Command
AFROTC	Air Force Reserve Officer Training Corps
ANG	Air National Guard
BNR	By name request
C2ISREW	Command and Control, Intelligence, Surveillance and Reconnaissance, and Electronic Warfare
CONUS	Continental United States
CSAF	Chief of Staff of the Air Force
DID	Developmental Identifier
DT	Developmental Team
Ent	Entitlement
FY##	Fiscal Year (##=two digit year; example FY06 is fiscal year 2006)
HAF	Headquarters Air Force
MAJCOM	Major Command
N	Navigator
OSAB	Operations Staff Assignment Branch
P	Pilot
PCS	Permanent Change of Duty Station
PME	Professional Military Education
Req	Requirement
RSAP	Rated Staff Allocation Plan
SAF	Secretary of the Air Force
SO	Special operations
T-ODP	Transitional Officer Development Plan
USAFA	United States Air Force Academy

Table 1. Acronyms and Abbreviations

Operations Staff Assignments

The Air Force matches, on average, more than 1,400 rated officers to requirements each fiscal year. The assignment process is handled by the Headquarters Air Force (HAF) Operations Staff Assignments Branch (OSAB) at AFPC. Each match is made during an assignment cycle with the largest staff match occurring in the assignment cycle beginning in January. The primary consideration in creating a staff match is adhering to the Rated Staff Allocation Plan (RSAP), which specifies the entitlements for each command with a requirement (Chandler, 2006). Secondary considerations are given to other factors such as a rated officer's qualifications to fill a requirement or a by name request (BNR) for a rated officer. The assignment process is discussed in detail in Chapter II.

Problem Statement

The current assignment process for developing a staff match can be improved with the application of both decision analysis and optimization tools. There are three primary areas where the assignment process can be improved. The first is in the time it takes to complete the process. The second is in development of an objective measurement of the quality of a match and then optimizing the value of the staff match. Finally, through the use of automation, a larger number of inputs to the process can be considered resulting in a more robust and higher quality solution. The OSAB desires a tool that will generate an optimal staff match based on the value of each match to the AF, allowing them to develop a higher value staff match in less time. This research applies value-focused thinking to quantify the value of a match to the AF. The subsequent optimization of the staff match is then accomplished using a network flow programming model.

The purpose of this paper is to document the research and detail the accomplishments in improving the assignment process. It is organized in five chapters beginning with this introduction. Chapter II details the assignment process, to include limitations, as well as background in the operations research methods applied to this research. Chapter III provides the problem description and methodology used to solve this specific assignment problem. Chapter

IV will present the results of this research, detail the improvements made to the assignment process and conclude with areas for further study.

II. Background

This chapter provides a detailed description of the assignment process. It addresses all inputs to the assignment process and details limitations that this research attempts to overcome. Also, key operations research methods that apply to this research are explained. In particular, the use of value-focused thinking in development of an objective measurement of quality of a match and the use of network flow and linear programming in solving an assignment problem are discussed.

Assignment Process

The description of the assignment process is based on a two-day visit to AFPC and numerous interviews with the OSAB (Miravite et al., 2007). The primary consideration in developing a staff match is adhering to the RSAP. The RSAP is approved by the Chief of Staff of the Air Force (CSAF) to detail the entitlement for all commands each fiscal year. Entitlements are categorized in terms of a weapon system type (e.g., fighter or bomber), an aeronautical rating (e.g., pilot or navigator) or a combination of the two. An extract from the FY06 RSAP detailing entitlements for Secretary of the Air Force (SAF) and HAF staffs is shown in Figure 1 (Chandler, 2006).

Organization	Category	P Req	P Ent	N Req	N Ent	ABM Req	ABM Ent
SAF/HAF Staff	Totals	238	234	80	124	37	32
Overall Rated %	Fighter	102	57	20	19		
110%	Bomber	23	30	13	21		
Fighter Pilot %	Tanker	8	53	2	22		
56%	Airlift	43	71	2	17		
Overall Pilot %	C2ISREW	7	19	16	39	37	32
98%	Helicopter	4	3	0	0		
Overall Nav %	Trainer	0	0	0	0		
155%	SO	2	1	7	6		
Overall ABM %	Unmanned	1	0	0	0		
86%	Unspecified	48	0	20	0		
Remarks:							

Figure 1. FY06 RSAP Extract

For example, Figure 1 shows total SAF/HAF pilot requirements equal 238 (row 1, column 3) while fighter pilot entitlements equal 57 (row 2, column 4).

Lieutenant General Carrol H. Chandler, Deputy Chief of Staff for Operations, Plans and Requirements, stated “the intent of the Rated Staff Allocation Plan is to ensure aircrew presence throughout the Air Force reflects AF priorities. CSAF approved this allocation plan based upon the fair share of limited pilot/ABM resources among non-line organizations. Navigators are allocated to unentitled pilot/ABM positions once all navigator entitlements are filled” (Chandler, 2006). The RSAP details for each command the number of requirements and entitlements based on authorized manpower levels. It is important to note that current rated officer manning in the Air Force is below authorized manpower levels, specifically short on pilots and ABMs. Therefore, commands will not receive their full entitlement in the RSAP.

The RSAP applies a fair share method of determining entitlements which spreads rated officer shortfalls, the difference between number of requirements and authorized manning, across command staffs after a 100% fill of higher priority requirements. For example, take two commands with requirements for 5 and 10 ABMs respectively. Due to authorized ABM manning levels, there are only 6 ABM entitlements available to fill command requirements. Each command would get their fair share of the remaining 6 ABM entitlements, 2 and 4 respectively. General Chandler’s memorandum documents the following exceptions to the fair share allocation in development of the RSAP:

1) Certain test fighter pilot entitlements are mandated to be met.

2) 100% fill rate mandated for air liaison officers, above wing-level standardization and evaluation, ANG [Air National Guard]/AFRC [Air Force Reserve Command] unit advisors, organizations with less than 10 pilots or only 1 air battle manager, and a particular test pilot requirement.

3) No more than 33 rated officers can be assigned to AFROTC [Air Force Reserve Officer Training Corps] duty.

4) USAFA [United States Air Force Academy] entitlements are weighted based on inventory levels and current presence of pilots, navigators and ABMs (Chandler, 2006).

According to Air Force Instruction 36-2110, Assignments, dated 20 April 2005, "the primary factor in selection of a member for PCS [permanent change of duty station] is the member's qualifications to fill a valid manpower requirement." This means a rated officer's qualification to fill a requirement is the primary factor in determining their assignment match. These qualifications are numerous and include anything from academic degrees, aeronautical ratings, rank to specialized training courses. They are categorized as mandatory, highly desired or desired. Mandatory qualifications can cause some rated officers to be unqualified for certain requirements. For example, only a navigator can be matched to a navigator requirement. There are many other secondary factors that are considered by the OSAB as well. First, commands often provide a BNR for a requirement, which is a request for a particular rated officer to be matched to a particular requirement. In some cases a single requirement has multiple BNRs. In considering BNRs, the OSAB also uses the rank of the officer submitting the BNR. Second, select groups of senior officers called development teams (DT) provide vectors for the professional development of every officer, not just rated officers, to ensure the right skills and experiences are developed in each career field. These vectors have two parts. The first is a target level that defines where an officer should gain additional experience, such as Air Staff or MAJCOM. The second is a skill pairing which defines what additional experience an officer should get, such as Aerospace Power Employment or Plans and Programs. Each requirement has a specified target level associated with it. Likewise, commands are identifying skill pairings to identify the experience required to satisfy the requirement. This skill pairing can also be used to match a rated officer with a skill pairing vector rather than one who already has that particular experience. Every officer's vector will have a target level, but not all will have a skill pairing. The vectors are based on an officer's record of performance and job preferences as well as their senior rater's inputs. These vectors are not necessarily meant for an officer's next assignment, but maybe a future one. Finally, there is consideration given to an officer's preference in job location. Both an individual's preferences and DT vector are documented on a Transitional Officer Development Plan (T-ODP).

The assignment process is broken down into the following 4 phases:

1) Match Flow

2) Staff Match

3) Reattack

4) Command Approval.

Phase 1 is the only automated phase of the entire process. The OSAB uses a homegrown Microsoft Access database, named The Shield, to maintain a history of each assignment cycle and help manage the current assignment cycle. The Shield includes a module called *Match Flow* that identifies for each command the number of entitlements that will be met that cycle. This considers the number of rated officers to be matched and the current manning at the commands. It ensures that manning shortfalls are shared equally across the commands by maintaining an average percent of entitlements met. For example, Table 2 demonstrates how the *Match Flow* would maintain a projected 66% of entitlements met.

	Command A	Command B
# of Entitlements from RSAP	6	3
Current # of Entitlements met	1	1
Current % of Entitlements met	17%	33%
# of Requirements from Match Flow (4 rated officers available)	3	1
Projected % of Entitlements met	66%	66%

Table 2. Match Flow Example Averaging Shortfalls Across Commands

Phase 2 is the development of the staff match. The first requirements matched are the exceptions to the fair share allocation identified in the RSAP and overseas requirements that have volunteers. The remainder of the staff match is completed in small chunks according to entitlement categories from the RSAP. The command with the lowest current % of entitlements met (e.g., command A in Table 2) gets the first match. That OSAB selects a rated officer and matches them to a requirement from that command. This command's current number and % of entitlements met are then adjusted for subsequent matches. The staff match continues in this fashion until all rated officers or requirements of that entitlement category are matched. The staff match then proceeds to the next entitlement category until all rated officers are matched.

The assignment process of creating a match is another important part of this phase. When the OSAB creates a match for a given command, it matches a rated officer to that command's highest priority requirement first, if the requirements are prioritized in some way. A requirement with a BNR request is automatically prioritized due to the attention it receives from a general officer, and is elevated in proportion to the rank of the officer making the request. If a 3 or 4-star general requests a rated officer, every effort is made to honor that request. If there are no requirements with priorities or BNRs, then the OSAB will match a requirement with a qualified rated officer based on a combination of qualifications, vectors and rated officer preferences that varies depending on the specific personnel officer making the match.

Phase 3 is the reattack. This phase allows for adjustments to the staff match based on any concerns the OSAB might have with the staff match. This phase often involves rated officers being traded between commands to remedy these concerns and overcome limitations in the process, which limitations are discussed below.

In phase 4 the staff match is forwarded to all commands for approval. In some instances, a command rejects a portion of the staff match and the affected rated officers are matched to other requirements during another round of reattack. Every effort is made to match these vacated requirements with a different rated officer; however, it is possible that the rejecting command may have to wait until the next assignment cycle before the vacated requirement is matched again. Another aspect of Phase 4 is the OSAB's defense of the staff match, particularly when a BNR was not honored. The reattack and command approval phases are repeated until the staff match has been approved by all commands. Typically only one additional reattack and command approval are required.

There are limitations to the assignment process that affect the quality of the staff match. The match flow phase is highly efficient in that it determines the number of entitlements by category for each command instantaneously. However, without a complete prioritized list of requirements for each command, the match flow cannot translate those entitlements into a specific list of requirements that will be matched. Some commands provide this prioritized list, but it is not the standard.

The staff match phase presents more limitations. Currently, there is no quantitative measure of how well a rated officer satisfies a particular requirement, that is, there is no mechanism to evaluate the quality of a match. As a result, it is difficult to determine between two rated officers who is a better match to a requirement, but more importantly, it is essentially impossible to compare one possible staff match to another. There is also no method in the assignment process to consider all rated officers and requirements simultaneously, which yields many problems. First, the management by entitlement category means requirements that can be satisfied by multiple entitlement categories are matched to an incomplete pool of qualified rated officers. This occurs when a pilot or navigator can be matched to a particular requirement, but only pilots are considered when that requirement is matched. Second, the sequential process of the staff match based on the command with the lowest percent of entitlements met virtually guarantees the staff match will not be optimal, even if the most qualified rated officer is selected at each step. In fact, the most qualified rated officer for the current requirement being matched may be the only qualified rated officer for the next requirement. There are also the volumes of unorganized qualifications for each requirement. This includes many qualifications that the OSAB does not have information available on the rated officers, such as writing abilities or the capability to run 3 miles. Due to the amount of data and the way it is organized, it is impossible for the OSAB to consider it all. Finally, there is subjectivity involved by the OSAB due to the sequential process of the staff match. It is not uncommon to pass on matching a particular rated officer to a requirement in hopes of matching that rated officer to a lower priority requirement.

This might be done if there are multiple BNRs for the same rated officer or the rated officer is best matched to a lower priority requirement.

Ideally, the reattack phase solves all the problems from the staff match and results in an optimal staff match. In reality, that is highly unlikely. Problems with an unqualified rated officer matched to a requirement will at least be identified, if not solved. However, if all requirements are matched to qualified rated officers and the constraints of the RSAP are met, then little effort is made toward increasing the quality of the staff match since there is no mechanism to assess or measure this quality.

There are also problems that occur in the command approval phase. First, is when a match is rejected. The best way to eliminate, or minimize, this problem is to ensure the best possible staff match was forwarded for approval. The second is the inevitable questioning that occurs when a BNR is not honored. This could happen for various reasons. The requested rated officer may not be the most qualified, or qualified at all, for that requirement. Or, the requirement may not be high enough priority to warrant a match, for instance a command could have three requirements with BNRs, but only two entitlements.

These are limitations with the assignment process that can be improved upon with the application of operations research methods. The OSAB wants a tool that evaluates the quality of a match and produces an optimal staff match considering all requirements and rated officers at once while still meeting the constraints of the RSAP. The quality of a match will be determined through the use of a value function developed using a decision analysis technique called value-focused thinking. The results from value-focused thinking will provide necessary information to determine an optimal staff match using network flow programming techniques.

Value-Focused Thinking

Keeney (1992) provides an approach to decision-making that is focused on a decision maker's values rather than the choice of alternatives available. "We should spend more of our decision-making time concentrating on what is important: articulating and understanding our values and using these values to select meaningful decisions to ponder, to create better alternatives than those already identified, and to evaluate more carefully the desirability of the alternatives" (Keeney, 1992). This focus on a decision maker's values results in a strategic approach to decision making and is broken down into 5 steps by Kirkwood (1997). The 5 steps are:

1. Specify objectives and evaluation criteria with respect to the objectives.
2. Develop alternatives that potentially might achieve the objectives.
3. Determine how well each alternative achieves each objective.
4. Consider tradeoffs among the objectives.
5. Select the alternative that, on balance, best achieves the objectives.

There are numerous benefits to this approach, but the one that is particularly important to this research is the process of quantifying the value of alternatives.

A value hierarchy is a graphic representation of the objectives and evaluation criteria for a decision. A value hierarchy can take many forms and an example is given in Figure 2 (Kirkwood, 1997). The decision in this example is to choose a job among several alternatives and the objective is to select the best job. The decision maker has identified four values with respect to the objective and they are shown as the first tier in Figure 2 (i.e., to the right of the objective). Values in the first tier are then decomposed into evaluation criteria that are used to measure the value of the alternative to the decision maker. The value hierarchy is not only useful in organizing key inputs in the decision making process, but is a tool in the development of a value function that quantifies the value of an alternative to the decision maker.

Kirkwood (1997) describes five desirable properties of a value hierarchy, which are completeness, nonredundancy, decomposability, operability, and small size, and are now described in detail. Completeness implies there are no values or evaluation criteria missing from the hierarchy. Missing items from the hierarchy could result in two alternatives with the same value (according to the other evaluation criteria) to the decision maker when in fact one is a better choice. For example, assume *Travel requirements* is a value of the decision maker but is missing from the hierarchy in Figure 2. There are two alternatives with the same value (according to the other evaluation criteria), one with a 15 minute commute and the other a 2 hour commute. The incomplete value hierarchy would evaluate these alternatives as equal in value, when in reality one is better than the other.

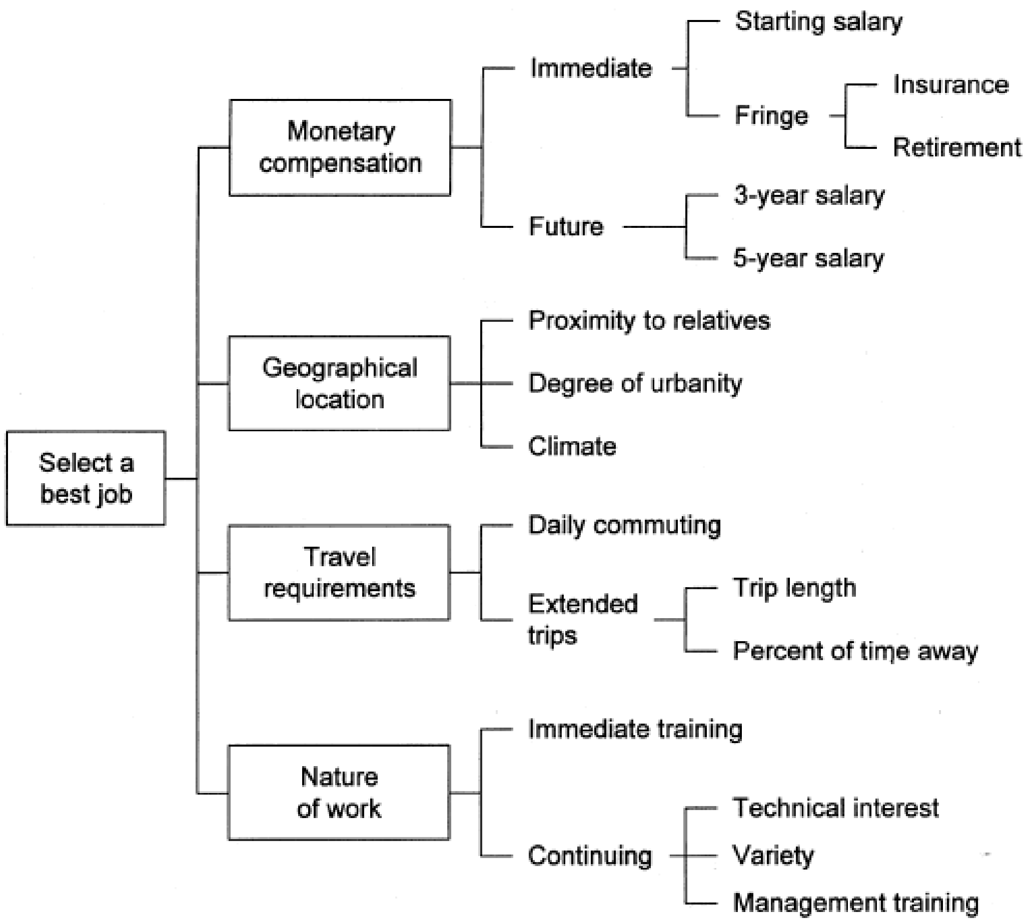

Figure 2. Value Hierarchy for Selecting the Best Job

Nonredundancy implies that evaluation criteria do not overlap or repeat in the hierarchy. For example, assume *Daily commuting* is also an evaluation criterion for *Geographical location* in Figure 2. In the process of creating a value function for the overall objective, *Daily commuting* would be counted twice, since it is an evaluation criteria for *Travel Requirements*, and as a result be given an over inflated weight.

Decomposability is concerned with the independence of evaluation criteria. Consider evaluation criteria of *Annual salary* and *Pension plan*. A decision maker may value a starting salary of $100,000 much more if there is no pension plan than if there is a generous pension plan. The dependence of evaluation criteria can cause significant problems when determining a value function. There are ways to compensate for this dependence, but are beyond the scope of this research.

Operability is synonymous with understandable. Those using the hierarchy must be able to understand it. For example, using *Annual worth* as an evaluation criterion of a future bonus is not operable to someone who does not know what annual worth means.

Small size refers to maintaining a balance between detail and time to complete the analysis. In general, the more detailed the hierarchy, the longer it will take to evaluate alternatives. However, the hierarchy must be detailed enough to provide meaningful results to the decision maker.

Value-focused thinking is used in this research to quantify how well an alternative, in this case a match, meets the overall objective, to maximize value. There are two steps in developing a value function used to evaluate alternatives. First, each evaluation criteria must have a measurement scale. Second, the weight of each value and evaluation criteria to the overall value function must be determined.

Some evaluation criteria have natural measurement scales, for instance *Annual salary* can be measured in dollars. A constructed measurement scale may be required if a natural measurement scale does not exist or is not appropriate. For example in Figure 2, *Degree of urbanity* does not have a natural measurement scale and would require a constructed one, such as high, medium or low with respect to big city amenities.

Once all the measurement scales are set, the decision maker must determine how much weight should be given to each value and evaluation criteria within a tier of the value hierarchy. This is not as simple as stating *Annual salary* is twice as important as a *Pension plan*. See Kirkwood (1997) for various methods for determining these weights. The resulting overall value function is then used to quantify the extent to which an alternative satisfies the values of the decision maker.

Network Flow and Linear Programming

Jensen and Bard (2003) state, “the branch of operations research that deals with the optimal allocation of scarce resources among competing activities is known as mathematical programming, of which linear programming is a special case.” This statement clearly applies to this research in which rated officers are the scarce resource and the requirements are the competing activities. A linear program is a mathematical formulation of a problem where all the functions involved are linear.

A network is defined as a set of nodes connected by a set of arcs, much like cities connected by highways (Jensen and Bard, 2003). Many problems can be modeled by a network, such as moving goods from warehouses to vendors (transportation problem) or assigning rated officers to requirements (assignment problem). Network flow programming, also called minimum-cost flow, is concerned with optimizing (minimizing) the cost of flow across arcs in a network. Figure 3 (Jensen and Bard, 2003) provides an example of a network flow programming model of a transportation problem with 6 nodes (denoted by circles) and 7 arcs (denoted by arrows depicting single direction flow).

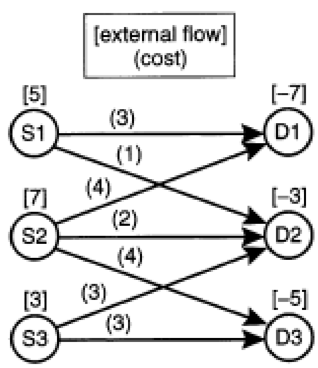

Figure 3. Network Flow Programming Model

External flow indicates the supply of goods on hand at a warehouse (positive) or demand by a vendor (negative). Cost is for transporting a single unit of goods from a particular warehouse to a particular vendor. For example, S1 is a warehouse with a supply of 5 and it costs $3 to transport a unit from warehouse S1 to vendor D1.

All network flow programming problems can be modeled using linear programming. In fact, as seen in Figure 4 (Jensen and Bard, 2003), the assignment problem is a less general case of a network flow programming (minimum-cost flow) problem which is a less general case of a linear programming problem. The significance of this is that any method used to optimize a more general problem can be used to solve the less general case. Specifically, an assignment problem can be optimized using the same methods used to optimize any linear program.

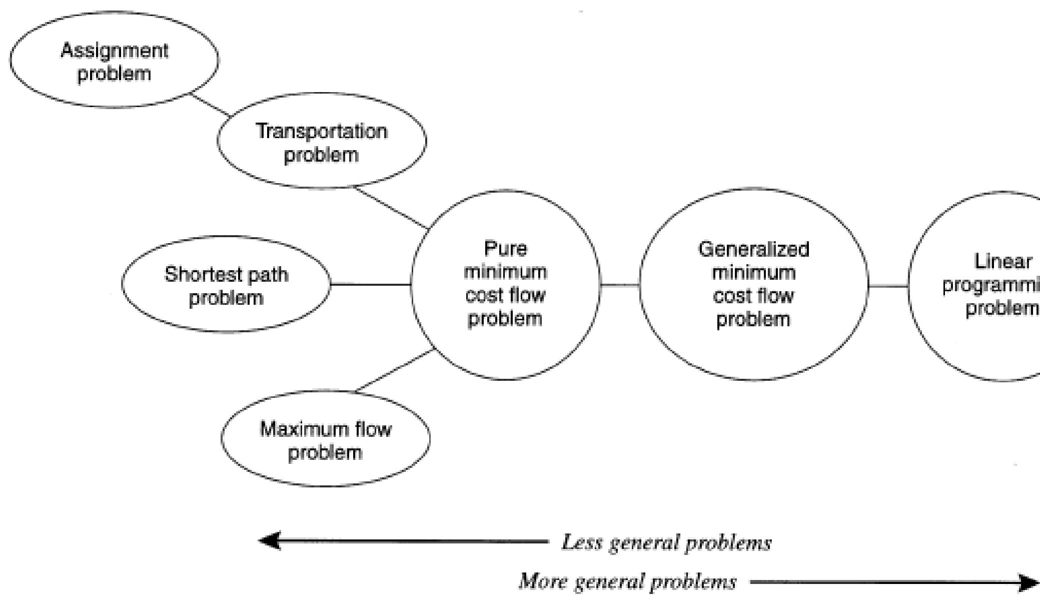

Figure 4. Relationships Between Linear Programming Problems

The assignment problem can be modeled using a network flow program. The classic formulation has n workers being assigned to n jobs. Each worker and job is represented by a node in the network. An arc represents a possible match between a worker and a job and each match has an associated cost. If a match is not allowed, there is no arc between the two nodes. The object is to minimize the cost involved in assigning all the workers to a job and leaving no job unfilled. An example network for an assignment problem is given in Figure 5 (Jensen and Bard, 2003).

The cost of an assignment, arc, is not displayed for clarity. Note this network is bipartite, meaning the nodes can be divided into two distinct sets with all flow moving between the two distinct sets and none within each distinct set. Also, there is no arc between worker W1 and job J1, meaning the assignment of worker W1 to job J1 is not allowed.

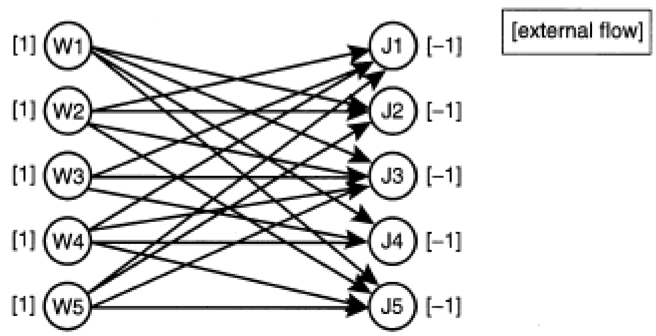

Figure 5. Network Example for an Assignment Problem

The same network can easily be displayed in matrix form as seen in Figure 6 (Jensen and Bard, 2003). In this form, a non-existent arc is given a large cost (denoted by *M*).

	J1	J2	J3	J4	J5
W1	*M*	8	6	12	1
W2	15	12	7	*M*	10
W3	10	*M*	5	14	*M*
W4	12	*M*	12	16	15
W5	18	17	14	*M*	13

Figure 6. Example Assignment Problem in Matrix Form

The linear programming model for the assignment problem requires the definition of the following variables and parameters:

Z – objective function to be optimized.

c_{ij} – cost associated with assigning worker i to job j.

n – number of workers/jobs.

$$x_{ij} = \begin{cases} 1 & \text{if worker } i \text{ is assigned to job } j; \quad i, j = 1, 2, ..., n \\ 0 & \text{otherwise} \end{cases}$$

The linear programming model is below:

$$\text{Minimize} \qquad Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$$

$$\text{Subject to} \qquad \sum_{j=1}^{n} x_{ij} = 1, \qquad i = 1, 2, \ldots, n$$

$$\sum_{i=1}^{n} x_{ij} = 1, \qquad j = 1, 2, \ldots, n$$

$$x_{ij} \geq 0, \qquad \text{for all } i \text{ and } j.$$

The objective function minimizes the total cost of all job assignments. The first constraint ensures each worker is assigned to only one job. The second ensures each job is assigned only one worker, while the last constraint ensures the decision variables are nonnegative.

The assignment problem is guaranteed to have a feasible, and consequently an optimal solution, since the feasibility property holds because the number of workers equals the number of jobs (Jensen and Bard, 2003). Note that in the linear programming model the decision variables are not required to be binary. The constraints of the assignment problem force the decision variables to take on values between 0 and 1. Furthermore, the unimodularity of the coefficient matrix (see Figure 7) ensures the decision variables are binary (Hillier and Lieberman, 1990).

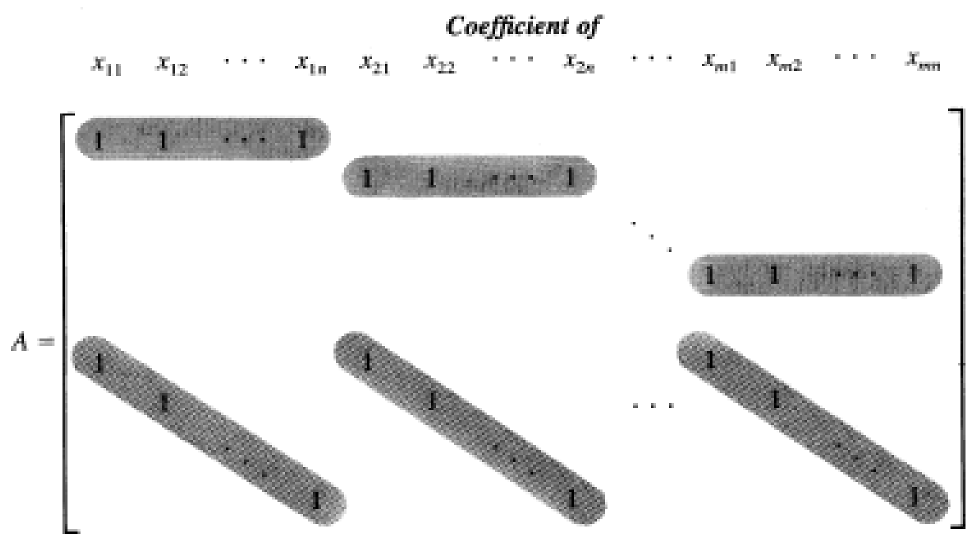

Figure 7. Constraint Coefficient Matrix for the Assignment Problem ($n = m$)

A matrix is totally unimodular if every square submatrix has determinant +1, -1 or 0, which holds for the assignment problem (Bazaraa et al., 1990). The Unimodularity Theorem states for an integer matrix $\boldsymbol{A}$ with linearly independent rows, the following three conditions are equivalent:

(a) $\boldsymbol{A}$ is unimodular.

(b) Every basic feasible solution defined by the constraints $\boldsymbol{Ax} = \boldsymbol{b}, x \geq 0$, is integer for any integer vector $\boldsymbol{b}$.

(c) Every basis matrix $\boldsymbol{B}$ of $\boldsymbol{A}$ has an integer inverse $\boldsymbol{B}^{-1}$ (Ahuja et al., 1993).

The constraints of the assignment problem, in matrix notation, are defined as in part (b) of the Unimodularity Theorem, therefore since the coefficient matrix $\boldsymbol{A}$ is unimodular, every basic feasible solution to the assignment problem is integer. This result allows the binary constraint to be dropped from the math programming model yielding the previous linear programming model.

As stated earlier, the assignment problem can be optimized using any method used to optimize a linear program. However, several more efficient algorithms have been created to take advantage of the assignment problem's special structure (Jensen and Bard, 2003). These algorithms include a specialization of the network simplex method, multiple variants of successive shortest path algorithms, an adaptation of the cost scaling algorithm and the Hungarian algorithm (Ahuja et al., 1993). See Bazara et al. (1990) for a detailed description of the Hungarian algorithm. However, large assignment problems are still solved primarily through the use of network simplex codes (Jensen and Bard, 2003).

III. Methodology

This chapter provides a detailed description of the methodology used to optimize the assignment of rated officers to requirements. First, the specific inputs to the value hierarchy are discussed, and the value hierarchies and constructed measures provided by the OSAB are presented. Next the linear programming model for the OSAB assignment problem is presented. Finally, a description of the assignment tool used to optimize the staff match is detailed.

Value Hierarchy

Factors influencing a match in the assignment process were presented in the Assignment Process section of Chapter II. Other than the explicit weighting of factors to assess the quality of the match, most of the factors influencing a match have not changed. However, it is necessary to discuss how the specific qualifications of a requirement are considered in this new process.

As stated in Chapter II, qualifications for a requirement are unorganized and overwhelming in number. This makes it impossible in the current assignment process to consider all qualifications in creating a match. Fortunately the DT is instituting developmental identifiers (DIDs) for every officer. These DIDs match the skill pairings used to describe experiences needed in a requirement as well as skill pairing vectors given to officers. DIDs identify experience that an officer has, but is not a measure of their performance in achieving that DID. For example, a rated officer may have an Aerospace Employment DID from a previous assignment, but it says nothing about their performance in that assignment which could have been superior or poor. The OSAB uses DIDs as the primary means to determine the qualification of a rated officer to be matched to a requirement, but does not use DIDs in determining the overall quality of the match. Furthermore, there are still a small number of specific qualifications that the OSAB wants to consider in addition to the DIDs. Some of these specific qualifications include: rank of rated officer (exact or one rank above or below), advanced school graduate, security clearance, language, instructor, evaluator, Weapons School graduate, safety experience, academic degree (field and level), weapon system (e.g., B-52), entitlement category, aeronautical rating or test experience. Many of these qualifications are mandatory, but are often waived. The only mandatory qualifications that are currently not often waived are that a pilot requirement can only be matched to a pilot or navigator, a navigator requirement can only be matched to a navigator, and an ABM requirement can only be matched to an ABM or a navigator. Generally, the mandatory qualifications that cannot be waived come directly from the RSAP. There are three additional highly desired qualifications the OSAB considers, which are graduated commanders, professional military education (PME) graduates (appropriate school for the rated officer's rank) and previous staff experience (Miravite et al., 2007). These three qualifications are handled differently in determining the value of a match.

There are two value hierarchies used in the new process to determine the quality of a match, and are now presented. The first is for overseas requirements and the second is for continental United States (CONUS) requirements. This allows a higher weighting of individual preferences for overseas requirements. The OSAB currently employs an operations research analyst that performed an analysis of the value hierarchies. Therefore the value hierarchies approved by the OSAB are presented in Figures 8 and 9, and the desired properties discussed in Chapter II are assumed to hold.

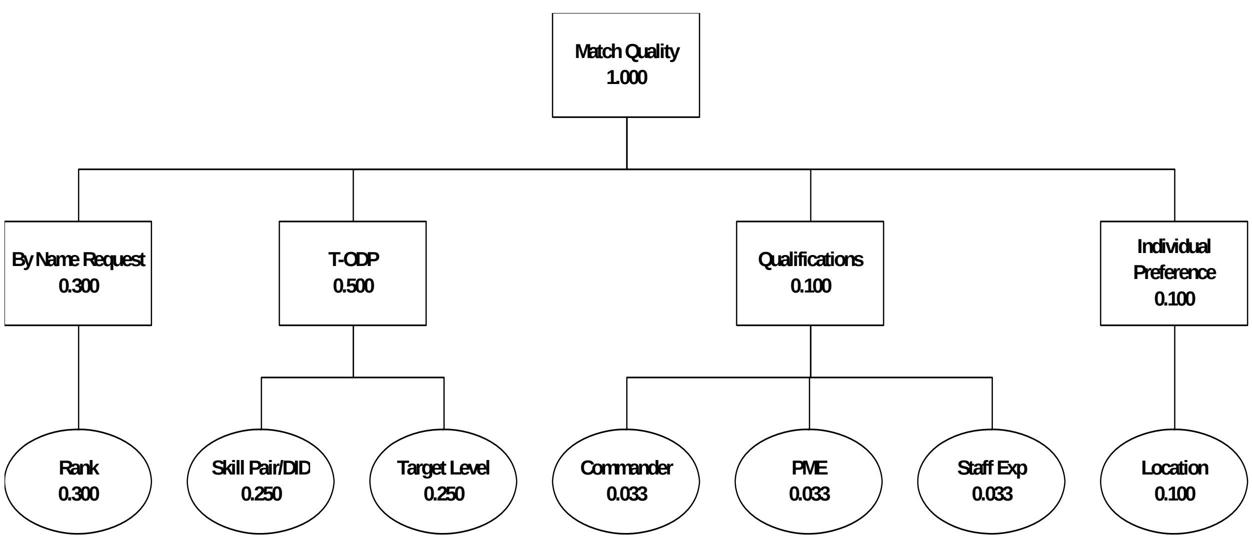

Figure 8. CONUS Requirements Value Hierarchy

The weights given for each value and evaluation criteria are depicted (e.g., the weight of the value *By Name Request* is 0.3). The weights for each tier of the hierarchy must also sum to one. See Kirkwood (1997) for a detailed description of the development of weights for values and evaluation criteria.

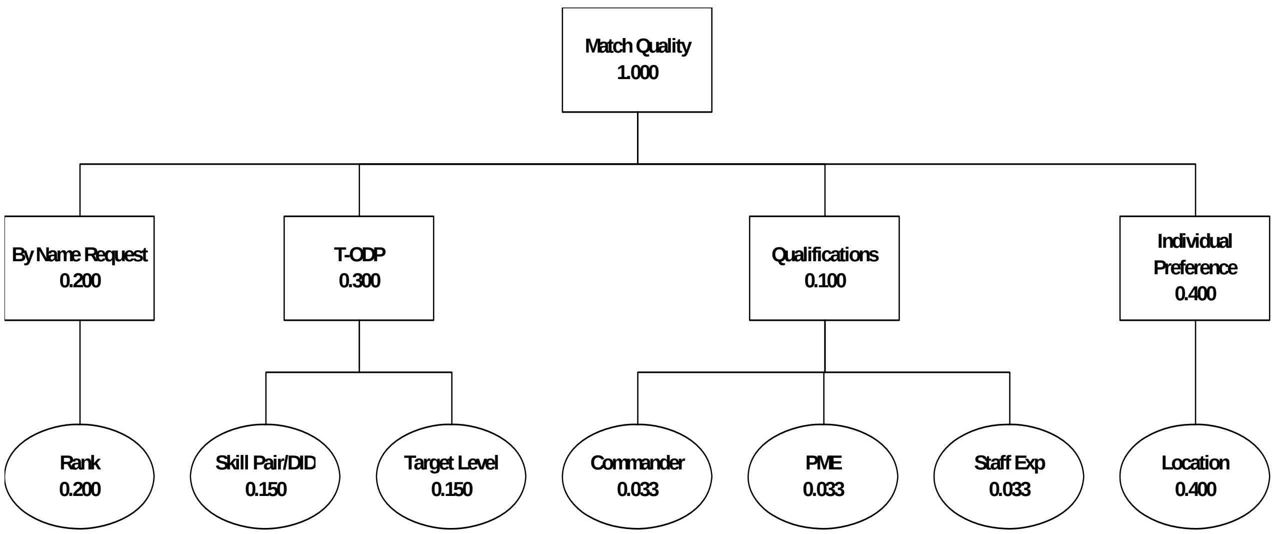

Figure 9. Overseas Requirements Value Hierarchy

Notice the difference in the two value hierarchies is in the weight of the *Individual Preference* which is increased from 0.1 in the CONUS value hierarchy in Figure 8 to 0.4 in the overseas value hierarchy in Figure 9. This is accompanied by decreases in the weights of *By Name Request*, from 0.3 to 0.2, and *T-ODP*, from 0.5 to 0.3, respectively. The value of matches between all rated officers who volunteered for either an overseas short tour (an unaccompanied 1-year assignment), or an overseas long tour (a 2 to 3-year accompanied tour), and all overseas requirements are the only ones evaluated using the overseas value hierarchy in Figure 9.

The evaluation criteria are identical for the two value hierarchies in Figures 8 and 9. All evaluation criteria have constructed measurement scales, and were developed in cooperation with the OSAB. The constructed measurement scale for the evaluation criterion *Rank* (Figure 10) is based on the rank of the senior officer that submitted the BNR for that particular requirement. The constructed measurement scales for evaluation criteria *Skill Pair/DID* and *Target Level* are provided in Figure 11.

Rank of Requesting Official	Scale
General	1
Lieutenant General	0.8
Major General	0.6
Brigadier General	0.4
Colonel	0.2
Lieutenant Colonel	0.1
No BNR	0

Figure 10. Constructed Measurement Scale for *Rank*

Skill Pairing / DID	Scale
Primary Skill or DID Match	1
Secondary Skill Match	0.5
None	0

Target Level	Scale
Primary Match	1
Secondary Match	0.5
None	0

Figure 11. Constructed Measurement Scales for *Skill Pair/DID* and *Target Level*

The *Skill Pair/DID* evaluation criterion is based on either the rated officer's skill pairing vectors or DIDs matching the skill pairing of the associated requirement. The *Target Level* evaluation criterion is based on the rated officer's target level vector matching the level of the requirement. The *Commander*, *PME* and *Staff Exp* evaluation criteria in Figure 12 are defined based on whether a rated officer has the particular qualification or not. The *Location* evaluation criterion in Figure 13 is based on the rated officer's preferences in location of their next assignment.

Command	Scale
Yes	1
No	0

PME Graduate	Scale
Yes	1
No	0

Staff Experience	Scale
Yes	1
No	0

Figure 12. Constructed Measurement Scales for *Command*, *PME* and *Staff Exp*

Location Preference	Scale
#1 Choice	1
#2 Choice	0.9
#3 Choice	0.8
#4 Choice	0.7
#5 Choice	0.6
#6 Choice	0.5
#7 Choice	0.4
#8 Choice	0.3
#9 Choice	0.2
#10 Choice	0.1
None	0

Figure 13. Constructed Measurement Scale for *Location*

Linear Programming Model

The linear programming model for the OSAB's assignment problem is similar to the assignment problem discussed in Chapter II except the goal is to maximize value and there are four additional side constraints. The following sets, parameters, and variables are required to define the OSAB assignment problem.

O - set of rated officers

$O_A \subseteq O$ - set of ABMs

$O_N \subseteq O$ - set of navigators

$O_P \subseteq O$ - set of pilots

R - set of requirements

$R_A \subseteq R$ - set of ABM requirements

$R_N \subseteq R$ - set of navigator requirements

$R_P \subseteq R$ - set of pilot requirements

C - set of commands

$C_A \subseteq C$ - set of commands with ABM entitlement

$C_N \subseteq C$ - set of commands with navigator entitlement

$C_P \subseteq C$ - set of commands with pilot entitlement

$R_{Ac} \subseteq R_A$ - set of ABM requirements for command $c \in C$

$R_{Nc} \subseteq R_N$ - set of navigator requirements for command $c \in C$

$R_{Pc} \subseteq R_P$ - set of pilot requirements for command $c \in C$

$\boldsymbol{A} = (A_1, A_2, ..., A_{|C_A|})$, where A_c is the ABM Match Flow output for $c \in C_A$

$\boldsymbol{N} = (N_1, N_2, ..., N_{|C_N|})$, where N_c is the navigator Match Flow output for $c \in C_N$

$\boldsymbol{P} = (P_1, P_2, ..., P_{|C_P|})$, where P_c is the pilot Match Flow output for $c \in C_P$

$\boldsymbol{X} = (X_1, X_2, ..., X_{|C_N|})$, where X_c is the RSAP navigator entitlement for $c \in C_N$

$$x_{or} = \begin{cases} 1 & \text{if rated officer } o \in O \text{ is matched to requirement } r \in R \\ 0 & \text{otherwise} \end{cases}$$

v_{or} - value of rated officer $o \in O$ matched to requirement $r \in R$

For example, assume requirement $r \in R_A$ is an Air staff requirement at the Pentagon with a skill pairing of Aerospace employment and no BNR. The highly desired qualifications are for a graduated commander, PME graduate and prior staff experience. Assume rated officer $o \in O_A$ has an Aerospace employment DID, primary target level vector of Air staff, and is a PME graduate. The rated officer is not a graduated commander and has no prior staff experience. The Pentagon is the rated officer's second choice for location preference. Therefore, using the evaluation criteria weights from the value hierarchy in Figure 8, the value of this match, v_{or}, is:

$$v_{or} = (0.3*0) + (0.25*(1+1)) + (0.033*(0+1+0)) + (0.1*0.9) = 0.623.$$

The linear programming model for OSAB's rated officer matching problem (denoted by ROMP) is now presented:

ROMP: Maximize

$$Z = \sum_{o \in O} \sum_{r \in R} v_{or} x_{or} \qquad (1)$$

Subject to

$$\sum_{o \in O} x_{or} \le 1 \qquad \text{For each } r \in R \qquad (2)$$

$$\sum_{r \in R} x_{or} = 1 \qquad \text{For each } o \in O \qquad (3)$$

$$0 \le x_{or} \le 1 \qquad \text{For each } o \in O,\ r \in R \qquad (4)$$

$$\sum_{o \in O_A} \sum_{r \in R_{Ac}} x_{or} \le A_c \qquad \text{For each } c \in C_A \qquad (5)$$

$$\sum_{o \in O_N} \sum_{r \in R_{Nc}} x_{or} \le N_c \qquad \text{For each } c \in C_N \qquad (6)$$

$$\sum_{o \in O_P} \sum_{r \in R_{Pc}} x_{or} \le P_c \qquad \text{For each } c \in C_P \qquad (7)$$

$$\sum_{o \in O_N} \sum_{r \in R_{Ac} \bigcup R_{Pc}} x_{or} \le \max\{0, N_c - X_c\} \qquad \text{For each } c \in C_N \qquad (8)$$

Objective function (1) maximizes the sum of the values v_{or} for each rated officer $o \in O$ matched to requirement $r \in R$. Constraint (2) limits one rated officer per requirement. Constraint (3) forces one requirement per rated officer (i.e., every rated officer must be matched to a requirement), which assumes $|O| \le |R|$. Constraint (4) bounds each decision variable between 0 and 1. Constraints (5), (6) and (7) limit the number of ABM, navigator and pilot requirements, respectively, per command to the number of entitlements output from the *Match Flow* module of

The Shield. Constraint (8) limits the number of navigators matched to ABM or pilot requirements per command to the difference in the *Match Flow* module output and the RSAP navigator entitlement, or zero, whichever is greater. This means that a navigator cannot be matched to a pilot or ABM requirement unless command $c \in C_N$ is receiving more navigators than its entitlement from the RSAP.

Rated Officer Match Optimizer

The rated officer match optimizer, denoted by ROMO, uses Microsoft Excel and SAS software to optimize ROMP. These software packages were selected because they are already in use at AFPC. Most of the data needed to accomplish the staff match is already available to the OSAB via simple database queries using The Shield or accessing the AFPC personnel database using SAS software. ROMO requires all rated officer data be included in a single Microsoft Excel spreadsheet. Similarly, all requirements data must also be in a single spreadsheet. The output from the *Match Flow* module is included in a third spreadsheet. ROMO has two stages. The first stage uses Microsoft Excel macros to assess the value of all matches as input data for SAS, i.e., the first stage determines v_{or} for each rated officer $o \in O$ and requirement $r \in R$. The second stage optimizes ROMP using a built-in SAS procedure, called *Netflow*, which solves network flow models and allows the definition of additional side constraints, such as constraints (5) - (8) in ROMP.

The new assignment process proposed here is accomplished in three phases. Phase 1 matches rated officers who volunteered for overseas short tours to overseas short tour requirements using the overseas value hierarchy in Figure 9. The second phase matches rated officers who volunteered for overseas long tours to overseas long tour requirements also using the overseas value hierarchy in Figure 9. Finally, all remaining rated officers, including the overseas volunteers not yet matched, are matched to remaining requirements, both CONUS and overseas. The final phase uses the CONUS value hierarchy in Figure 8.

As described above, the first step in each phase is to determine the value of every possible match using the appropriate value hierarchy (i.e., determine v_{or} for each rated officer $o \in O$ and requirement $r \in R$). Matches that do not satisfy any mandatory qualification from the list that can be waived are given a value of -1. For example, if rated officer $o \in O$ is an F-16 pilot and the requirement $r \in R$ has a mandatory qualification for an F-15C pilot, then $v_{or} = -1$. Likewise, any match that violates the mandatory qualification that cannot be waived is given a value of -2. For example, if rated officer $o \in O_P$ and the requirement $r \in R_N$, then $v_{or} = -2$. These penalties force ROMP to minimize the number of matches that require a waiver, while maintaining feasibility, since all possible matches are considered. Additionally, prioritized requirements are given additional value equal to the inverse of the priority. For example, if a match between a rated officer $o \in O$ and a requirement $r \in R$ has a value $v_{or} = 0.5$, but r is the fifth highest priority for command $c \in C$, then $v_{or} = 0.5 + (1/5) = 0.7$. The second step, once the Excel processing is complete, is to import the data into SAS and optimize ROMP using the *Netflow* procedure. The SAS output then provides the optimal matches from that phase. The rated officers and requirements that are not matched in phase 1 or 2 are matched in phase 3, resulting in an optimal staff match.

IV. Results and Conclusion

This chapter presents the results of this research, details the improvements made to the assignment process and concludes with areas for further research. There is no baseline or historical data available to use for quality comparison. The benefits of this research are in the use of objective measures to assess the quality of the staff match, the use of optimization techniques in creating an optimal staff match and the time savings earned by use of ROMO.

Results

ROMO was verified through multiple runs on smaller data sets to ensure each individual input was evaluated properly in determining $v_{or},\ o \in O,\ r \in R,$ and that data was in the format required by the SAS procedure *Netflow*. Note that ROMP is the exact type of network problem that the SAS *Netflow* procedure was designed, verified, and validated to optimize. Furthermore the *Netflow* procedure ensures the decision variables are binary.

Actual data from the 2006 summer and fall assignment cycles was used in the development of ROMO. Most of the required data was available via a simple database query at AFPC, however it was necessary to fabricate certain data that is not yet available, such as DIDs for rated officers and skill pairings for requirements. Requirement qualifications were also fabricated to overcome the present lack of organization in that data. There was also some data manipulation required due to inconsistencies between the requirements and rated officer datasets. For example, the datasets did not use the same abbreviations for locations. These data issues, while minor, must be corrected before the OSAB can implement ROMO. Additionally, the Excel macro code requires the rated officer and requirements spreadsheets to contain the necessary data in a particular format. This format is based on the initial data formats provided by the OSAB.

Trials were run on two groups of rated officers to simulate the sizes typically matched in the assignment process. The first group included 269 rated officers and 415 requirements, which represents the size of a fall or spring assignment cycle. The second group included 907 rated officers and 1399 requirements, which represents the size of a summer assignment cycle. The current assignment process requires an average of 10 minutes per match and is completed over a 2 to 4 week period. ROMO produced far superior results with respect to processing time as seen in Table 3.

	269 Matches	**907 Matches**
AFPC	44.8 hours	151.2 hours
Microsoft Excel	0.04 hours	0.40 hours
SAS	0.02 hours	0.03 hours
ROMO Total	0.06 hours	0.43 hours

Table 3. Processing Time Results

ROMO clearly outperformed the current assignment process by more then two orders of magnitude.

The use of objective criteria to assess the value of a match and the subsequent optimization of the staff match are other areas of improvement from the current process. ROMO quantifies the value an individual match has to the Air Force and allows for an objective comparison between matches (i.e., which of two officers when matched to the same requirement yields the highest value to the Air Force). Quantifying the value of a match makes optimization of the staff match possible and allows easy identification of which matches require a waiver (i.e., the matches with $v_{or} = -1$). ROMO also provides an increased capability to consider a greater number of inputs to the assignment process, including the vast amount of requirement qualifications. Finally, ROMO is easy to use and flexible enough to allow adjustments in weights or the addition of objectives and evaluation criteria to the value hierarchies.

Areas for Additional Research

There are a few areas that would benefit from additional research. Sensitivity analysis of the value and evaluation criterion weights may yield insights that could improve the resulting value of a staff match. For example, the weight given the *By Name Request* value in the overseas value hierarchy in Figure 9 was 0.2 and in the CONUS value hierarchy in Figure 8 was 0.3. In the larger trial, only 1 of 208 BNRs was honored. The one honored BNR was matched using the CONUS value hierarchy in Figure 8. Note that the highest weighted evaluation criterion in the CONUS value hierarchy was *Rank* (of the officer providing the BNR). *Rank* was the second highest weighted evaluation criterion in the overseas value hierarchy in Figure 9. The result indicates that, assuming these value hierarchies accurately reflect the OSAB's values, ROMO provides a higher quality solution than the current assignment process, which attempts to honor BNRs first if entitlements allow. The OSAB plans to do additional sensitivity analysis on the value hierarchies to help determine the value and evaluation criterion weights that best meet Air Force needs. Second, the time savings from ROMO could be increased with improvements in the code for the Excel macros. ROMO could be programmed to use SAS exclusively, but that would require significant effort by a skilled SAS programmer and SAS knowledge by the user. However, this modification could yield even more time savings. Finally, further study can be done on the unimodularity of the constraint matrix corresponding to ROMP. Preserving unimodularity is particularly important if additional side constraints are added to ROMP. Otherwise it may require significantly more computing time to optimize ROMP. Other followon topics include applying to different career fields in the Air Force and considering different objective functions (i.e., including PCS cost in the objective function).

Conclusions

The Air Force matches more than 1,400 rated officers to requirements each year. The assignment process currently takes 2-4 weeks to complete a staff match depending on the number of rated officers being matched. Until this research, there was no method to quantify the quality of a match. This meant it was impossible to optimize the staff match. The research described here detailed the development of ROMO for the OSAB at AFPC. ROMO makes significant improvements in time to complete the staff match and makes it possible to evaluate the quality of the staff match.

Specifically, this research applied decision analysis and optimization methods to increase the efficiency and quality of the assignment process. The value of a match, and subsequently the staff match, can now be evaluated using a value model approved by the OSAB. This evaluation is done through the use of Microsoft Excel macros. ROMP was then optimized using a network flow procedure in SAS. ROMO produced a staff match in less than an hour, as opposed to weeks, with quantifiable value to the Air Force. This time savings will allow the OSAB to focus energies on higher impact tasks rather than being consumed with the important, yet tedious task of creating the staff match. ROMO is scheduled to be implemented by the OSAB in the fall during the next assignment cycle, and with minor modifications, could be applied to any career field in the Air Force. This research, if implemented, will provide significant time savings to the OSAB while maximizing the value of rated staff assignments to the Air Force for years to come.

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Vita

Major Alexander M. Wylie was born at Camp Lejune, North Carolina. He was commissioned in 1994 after earning a Bachelor of Science degree in Mathematical Sciences from the United States Air Force Academy. Following completion of a Master of Science degree in Applied Mathematics and Statistics from the University of Nebraska-Lincoln, he was assigned as the B-2 Flight Test Data Analyst at Whiteman AFB Missouri. Major Wylie next completed Undergraduate Navigator Training at Naval Air Station Pensacola Florida and was later qualified in the B-52H and assigned to the 23d Bomb Squadron, 5th Operations Group, 5th Bomb Wing, Minot AFB North Dakota. He held various positions at Minot AFB including flight commander and Chief of Standardization and Evaluation (Stan/Eval) of the 23d Bomb Squadron, Deputy Chief of Stan/Eval of the 5th Operations Group and 5th Bomb Wing Executive Officer.

Major Wylie is a senior navigator with nearly 2,200 flying hours, including 288 combat hours. He has deployed in support of Operations ENDURING FREEDOM and IRAQI FREEDOM (OIF) and earned the General Ira C. Eaker Award for Outstanding Airmanship during OIF.

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14. ABSTRACT
The United States Air Force matches an average of 1400 rated officers to staff assignments each fiscal year. The primary consideration is the Rated Staff Allocation Plan which details Air Force rated officer entitlements across the Department of Defense. The Operations Staff Assignment Branch, located at Headquarters, Air Force Personnel Center, is responsible for the assignment process. There is currently no method in place to assess or maximize the utility of the assignments made. This research details the development of an assignment matching tool using network flow optimization that, if implemented by the Operations Staff Assignment Branch in future assignment cycles, will make the assignment process more efficient and provide a quantitative assessment of utility that is optimized .

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