3-2001

A Multi-Objective Decision Support Model for the Turkish Armed Forces Personnel Assignment System

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THESIS

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Research

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March 2001

AFIT/GOR/ENS/01M-06

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FOR THE TURKISH ARMED FORCES

PERSONNEL ASSIGNMENT SYSTEM

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Acknowledgements

I would like to express my sincere appreciation to my thesis advisor, Dr. James T. Moore. He enlightened my way throughout this research with his expert advice and precious assistance. I also wish to thank my reader Lt. Col. Smith for his insightful comments and guidance.

I wish to thank my family members for supporting me. They are the most precious things in our lives.

I thank my fellow countrymen, statesmen and Turkish Air Force Personnel. Without them I wouldn't be here and be successful.

I wish to thank all of the instructors and personnel at AFIT for their contributions to the success of this research.

I thank God for everything.

Zubeyir Cimen

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Abstract

The Turkish Armed Forces (TAF) assign more than 25,000 active duty personnel annually. TAF wants to obtain maximum utilization of its personnel by assigning the right person to the right job at the right time. To accomplish this task, decision-makers and personnel assignment staff should consider conflicting multiple objectives that create the widely known problem called "personnel assignment problem".

To assist in this complicated task from a quantitative perspective, a preemptive goal programming approach was used to develop an integer programming (IP) model to capture the multiple objectives flexibly and interactively. A realistic size IP problem with random data was tested for computational efficiency and analysis. The mean solution time for different instances of the problem was reasonably small.

An application of the methodology in an actual assignment decision support system of any large-scale government or non-government organization has a potential to help decision-makers make better use of their personnel.

A MULTI-OBJECTIVE DECISION SUPPORT MODEL FOR THE TURKISH ARMED FORCES PERSONNEL ASSIGNMENT SYSTEM

Chapter 1: Introduction

Background

Manpower allocation (MA) is one of the managerial problems faced by most organizations. The methodology used to solve a MA problem, varies from one organization to another. However, most MA problems boil down to assigning a number of personnel to a number of jobs (Abboud *et. al.* 1998). Personnel assignment (PA) is at the heart of most MA problems and is an important subset of the human resource (HR) system. This research focuses on the PA problem.

In a military organization, there are different professional classifications of personnel (e.g. officers, noncommissioned officers, airmen, civilians, etc.) and many different career paths within these professional classes. These personnel are assigned to different positions along their career paths depending on a number of various objectives. Job filling, job requirements-individual qualifications match, career improvement and changing the environmental climate to increase motivation by decreasing monotony or difficulty of the current job are some of the objectives of a new assignment.

The assignment system is an essential part of an organization. The important question is how well does this system achieve the objectives for which it was created. Although the assignment system is built to satisfy these objectives, in practice some of these objectives may not be met to the expected degree. When the issue is HR, most of the time there is more than one objective when making assignment decisions. The current experience in qualitative sciences (i.e. psychology, sociology, organization theories) on HR provides the basis to consider more than one objective when making decisions.

In a small organization, the task of assigning people to jobs is not difficult. These kinds of organizations have a relatively small number of people whose qualifications can be evaluated and conflicting multi-objectives can be traded off quickly and with a reasonably small effort. Many different schools of thought, rules and techniques have been developed to find the best people for the right positions. However, in large organizations, every year thousands of personnel are assigned to different positions. For example, the United States Marine Corps assigns over 90,000 marines for permanent change of station each year (Tivnan, 1990). The US Air Force makes approximately 110,000 enlisted assignments annually (AFPC, 1999). Hence, the assignment process in large organizations is often a complex, tedious and long process. The following quote emphasizes the significance of PA problems very well:

> "The idea of establishing an Assignment Decision Support System (ADSS) came about because it was evident that Monitors (i.e. assignment officers) need support in their decision-making process due to the vast amount of assignment related information to be considered and the number of assignment alternatives to be weighed. It is anticipated that a truly user-friendly, interactive Decision Support System (DSS) will help Monitors better implement USMC staffing policy, significantly reduce the clerical workload of Monitors, and enhance the match of officers to billets" (NPRDC,1989)

In a historically unstable region, Turkey has always felt the need to maintain a high level of military power to protect herself and contribute to the peace in the region. To support this policy, the Turkish Armed Forces (TAF) employs more than a hundred thousand active duty military personnel (i.e. officers and NCOs) and some hundred thousand recruits (i.e. soldiers). The TAF assigns thousands of active duty personnel annually. For example, the Turkish Air Force (TUAF) assigns over 5000 active duty personnel each year.

Like every large-scale organization, TAF seeks to obtain the maximum utilization of its personnel. This maximum utilization is realized by assigning the right person to the right job at the right time. The decision of "who is the right person for the right job" depends on many rules and conflicting objectives that create a widely known problem called the *assignment problem.*

Although the TAF wants to utilize its manpower effectively and efficiently, it does not employ either any optimization (quantitative) technique or a decision support system (DSS). The assignment system totally depends on certain *rules* and the decision makers' (DM) *intuitive judgement*. Therefore, our research objective is to develop a quantitative decision support model for the TAF. We should point out that even though the concept and the methodology is primarily intended for the TAF, it can be easily extended and adopted by any military or non-military organization.

Problem Statement and Research Questions

Making assignment decisions is a challenging task both quantitatively and qualitatively. Let us illustrate this difficulty by giving an example:

Suppose we have 100 people to assign and 150 positions available. To make assignment decisions for these 100 people, the assignment officials first have to evaluate

100 different position combinations out of 150 positions. Once the specific positions are set, the placement of 100 people for these 100 positions should be determined. So, to make a decision, one should make a computation of (150! / 100!*(150-100)!) times 100!. This is obviously a job that is impossible for man alone to accomplish. Hence, we need the help of a DSS including optimization techniques to accomplish this job quickly and effectively.

The presence of conflicting goals contributes to the complexity of assigning personnel to available jobs as well. Many complex, frequently conflicting and often changing rules and policies influence the assignment process in a military organization. Multi-objective decision making models can be used to assess trade-offs existing among goals and assist in making assignment decisions. Some of these common conflicting objectives can be stated as follows:

1^st^ Objective: Organizational Objective. Assigning personnel to jobs by maximizing the satisfaction of positional requirements, the utilization of skills and filling high priority jobs (a short term, organizational objective).

2^nd^ Objective: Career Development Objective. Maximizing the total personnel career development via assignments (a long-term objective).

3^rd^ Objective: Personal Objective. Decreasing the number of unhappy personnel by assigning them according to one of their "wish list" preferences together with taking the past assignments into consideration (a personal satisfaction, motivational objective).

4^th^ Objective: The total cost of assignments should not exceed an allocated budget if one exists. In addition, the cost can be decreased to lower levels than the budget level.

More objectives can be added to the list above depending on specific organizational requirements. The US Navy, for example, has used 13 objectives in one of its assignment models (Paul, 1990). The four objectives mentioned above were included in that model. We used the first three objectives in our model because we think they are the most important objectives that organizations seek to satisfy when making MA/PA decisions. The US Air Force, for example, seeks to achieve these three objectives when making assignment decisions (AFPC, 1999). The US Air Force Assignment System (AFAS) is mainly a process-based system and not optimization oriented. The AFAS tries to minimize the conflicts between these objectives when assignments are made.

Similar to most military systems, personnel commands in each military branch are responsible for the assignment task in Turkey. In the command headquarters, personnel assignment officers and NCOs work in a sub-branch called *Personnel Assignment Branch* under the Personnel Command. The Personnel Command seeks to assign personnel to positions so that conflicting determinants such as organizational and personal objectives are traded off at a desired level with a reasonable amount of time and work.

Personnel officers and NCOs in the Personnel Command make assignment decisions annually. Before the assignment process starts, personal qualifications and career path positions are obtained for each candidate from their personal records. Based on this information, pools of assignees are formed. In addition to assignment officials, officer and NCO representatives from each career path are employed to assist in the assignment process. These officials function together and with other commands throughout the entire year to prepare for the assignment decision process. After many modifications, the last assignments are made by the Personnel Assignment Branch and approved by the Personnel Command. There is no quantitative optimization technique employed in this system. Therefore, in this research we wish to create a DSS with an optimization model.

→ *The Research Question:*

-Is there any way to build a robust, effective and efficient Decision Support System (DSS) including an optimization model to meet various objectives at the desired levels and help the personnel officials accomplish their tasks?

Some other related questions that cover the topic can be stated as follows:

-Why is there a need to implement such a methodology?

-What are the downsides of the current assignment system?

-Where to start to solve such a complex problem?

-How to integrate the qualitative and quantitative approaches in a model?

-What kind of data is needed for this research? Where should we obtain the data?

-Can the model improve other aspects of the assignment system and the organization?

Data Sources, Research Objectives and Scope

The US Armed Forces Assignment Systems are the role models for the TAF. Since the US Armed Forces especially the Navy have been working on the issue for some time and have large-scale models, we emulate from their studies and strive to build a proper small-scale model for the TAF. With some slight changes in the model, each Turkish military branch can adopt the approach developed in this research.

The data for this research is obtained from experienced personnel, Turkish and US Air Force Personnel Commands, books, thesis studies, internet and various personnel-related military and non-military data sources.

Similar to many other thesis efforts, the aim of this research is to increase the effectiveness and efficiency of an organizational system and/or contribute to a scientific discipline. With the help of a robust optimization model, we would like to increase the efficiency and the productivity of the assignment system. We believe that a model, which is conceptually sound and practical in application, can help assignment officials make quick and accurate decisions. Also, we expect that this model can have a positive impact on the personnel evaluation system as well as the assignment system.

The organizational challenge is to fill each job position with the best-qualified individual. In order to meet this challenge, a good personnel evaluation system should be in place to help HR professionals and DMs. Personnel evaluation can be a delicate process due to its subjective nature. However, it is not impossible to establish a good evaluation system. Quantitative evaluation methods can be employed to make more accurate decisions. We also hope that some unfair assignment decisions can be avoided by using a standard, more objective (which depends less on the DM's subjective judgments) and transparent (the working principals of this model can be learned by all personnel) assignment decision support system.

Sequence of Presentation

In Chapter Two, we show how the AFAS works in order to present a practical example of an assignment system. Then we view various studies on HR and systems theory to point out the qualitative perspective of the assignment system. We conclude Chapter Two by bringing together and explaining different quantitative optimization models that can be used to solve MA/PA problems.

In Chapter Three, we establish the methodology to solve the PA problem. In Chapter Four, the methodology is applied to both small and large-scale problems. We illustrate the interactive solution steps of the mathematical program developed in the methodology on a small-scale problem. In addition, we perform some computational efficiency experimentation on a selection of realistic large-scale problems and present the results.

Chapter 2: Literature Review

The United States Air Force Assignment System (AFAS)

In the United States Air Force (USAF), the officer assignment process has gone through several stages over the years. It seems that prior to 1990, even though the officers' preferences were taken into consideration, the focus of the assignment process remained primarily on the requirements of the Air Force. In 1991, the Air Force started implementing new programs to obtain a better balance between the needs of the Air Force (organizational objective), the development needs of the officer (career objective) and the officer's desires (personal preference objective). These new programs gave way to an improved system enabling officers to exercise more control over the timing and the location of their new assignments. In addition to increased officer participation, the commanders were given more hiring authority for assignments, so that they could function more effectively as a bridge between the requirements of the Air Force and the preferences of the officers. In terms of the officer assignment process, the Air Force philosophy centers on the belief that with continuous and progressive improvements to its system and proper coordination among its members, the Air Force will optimize its ability to place the right officers into the right jobs at the right time (AFPC, 1999).

The Air Force Assignment System (AFAS) is established around three key elements:

1) Personnel Requirements Display (PRD): This key component of AFAS is a two part system which functions as an information source providing officers

with available assignment listings around the world. Officers can have access to this system through the AFPC assignment home page on the worldwide web (www.afpc.randolph.af.mil/).

a) Authorizations Listing: All worldwide unclassified officer positions are listed whether they are open or not. This manpower document will be updated monthly to reflect the current manpower file.

b) Requirements Listing: This part of the PRD system is based on the Electronic Bulletin Board concept identifying requirements that are expected to be vacant within a specific time period.

(2) Preference Worksheet (PW)/Air Force Form 4057: This second component, also accessible through the worldwide web, is for the use of officers to state and document their personal assignment preferences.

(3) AFPC Officer Assignment Team (OAT): This team consists of career field representatives who match the available pool of officers with the current requirements.

In general, the assignment process for Air Force officers starts when the gaining commander and the MAJCOM identify and state requirements, which in turn are communicated to AFPC for fill action. The first step in this process is to determine who is moving and subsequently which positions must be filled. The OAT plays a major role in establishing a list of officers projected as vulnerable for reassignment. It is important to note that the purpose of designating an officer vulnerable is to inform the officer that he/she might be matched with an upcoming assignment in the near future. This enables the officer to take the necessary steps to receive assignment counseling and update his/her PW in anticipation of a possible assignment match. After receiving the vulnerability listing, MAJCOMs, working with commanders, study this list and provide feedback to AFPC. Then a final review and validation is performed by OAT and the list is returned to MAJCOMs for notification of the officers. Commanders are expected to identify requirements that need to be met and to coordinate these requirements with their MAJCOMs as they work on vulnerability listings.

The second step in the assignment process is the preparation for the assignment match. Once the officers are validated as vulnerable for reassignment, they are given an Assignment Selection Date (ASD). At this stage, officers are expected to seek assistance from their commanders to help make necessary changes to their PW to mirror the information they would like the OAT to consider when making an assignment match.

The next step is for the OAT to match requirements with the current pool of officers while maintaining the delicate balance of Air Force requirements and commander inputs with officer development needs and officer preferences. This process is normally scheduled around four predetermined time periods. Once requirements are prioritized and validated, OATs review the Preference Worksheets of the eligible officers and make their selections based on those requirements and the information contained in the PWs. Officers not selected in the current time period do remain vulnerable for reassignment. However, there might be duties or locations for which no eligible officer indicates a preference. Since these vacancies still have to be filled, the OATs use certain criteria based on stratifying qualifications and eligibility to maintain an equitable selection process.

Finally, after the completion of a successful match by the OAT, the commander receives official notification of the assignment action, which is then passed on to the officer.

One can see that the assignment process is a tedious and a long process. This is the reason why we wish to make this process work more effectively with the help of proper personnel data processing and optimization techniques. Through the entire process, we want the computers to do most of the tedious work of finding, categorizing, listing, selecting, eliminating and matching the personnel with the jobs in an interactive way with the DM. We can also recognize from the AFAS that all the effort focuses on decreasing the friction between the conflicting objectives. The goal is to create more overlap between different objectives and obtain as high satisfaction of all objectives as possible.

Qualitative Modeling and Analysis Approach to Human Resources

There is a need to analyze the assignment process using both qualitative and quantitative modeling and analysis (M&A) techniques. In our highly competitive world, almost every element of production is subject to efficiency improvement studies. As one element of production, *material* efficiency improvement studies began earlier in the industrial development age with a positive scientific perspective. It can be said that some discoveries on materials started the industrial revolution. Then came the studies on *financial* efficiency improvements through economic theories. Later, scientists and managers began turning their focus toward a relatively untouched area with a positive science perspective, another element of the production process, the human being. After this, many studies were quickly accompished. Hence, as a result of these studies, the HR theory was born followed by other modern organization theories. Today many public and private organizations try to study and implement the results of HR studies to obtain more efficiency and effectiveness in their management of people.

To achieve better efficiency and effectiveness through HR, qualitative M&A methods should be supported by proper quantitative modeling methods. Almost all disciplines of science combine these two separate modeling approaches in one way or another.

In this research, since our focus is on HR, we need to utilize the results of behavioral science studies. Indeed, students and practitioners of management have always been interested in and concerned with the behavior of people in organizations. But fundamental assumptions about the behavior of people at work did not change dramatically from the beginning of mankind's attempts to organize until only a few decades ago. Hugo Munsterberg (1863-1916), the German-born psychologist whose later work at Harvard would earn him the title of the "father" of industrial or applied psychology, pioneered the application of psychological findings from laboratory experiments to practical matters (Shafritz and Ott, 149). He sought to match the abilities of new hires with the company's work demands, to positively influence employee attitudes toward their work and their company, and to understand the impact of psychological conditions on employee productivity. We can say that he combined the quantitative approach to support qualitative theories. Munsterberg's approach characterized how the behavioral sciences tended to be applied in organizations well into the 1950s. During the years following World War II, the armed services in the US were particularly active in conducting and sponsoring research into how the military could *best find and shape people to its needs.* From this perspective it is not surprising that organizations want to utilize the valuable findings of these studies. The following paragraph taken from a Navy Personnel Research and Development Center study in 1989 tells us the importance of personnel psychology perspective when making decisions on personnel.

> " The original effort to develop a DSS for Monitors carried by a contractor in 1979 stressed an optimization approach to assignment and was terminated in the early, concept development stage of life cycle management. A subsequent contractor effort to build OADSS, in 1981, was also terminated in the concept development stage as it also relied too heavily upon optimization and was not sufficiently interactive. Both of these attempts were doomed to failure as the Marine Corps objected to any "black box" approach perceived to automate the assignment process. The goal was to support Monitors in their decision-making, not to make decisions for them. In 1985, a third system development attempt became available at the NPRDC. The project sponsor, Manpower Plans and Policy (MPI), specified that the system design be carried out by personnel research psychologists rather than OR or computer specialists under the assumption that this would avoid yet another optimization-oriented approach to system development (NPRDC, 1989)"

Modern applied behavioral scientists have focused their attention on seeking to answer questions such as how organizations could and should allow and encourage their people to grow and develop. From this perspective, it is *assumed* that organizational creativity, flexibility and prosperity depend on employee growth and development. The essence of the relationship between an organization and its employees is redefined from *dependence* to *codepedence.* People are considered to be as or more important than the organization itself. The organizational behavior methods and techniques of the 1960s, 1970s and 1980s could not have been used in Munterberg's days because *we did not* *believe (assume) that codependence was the right relationship between an organization and its employees* (Shafritz, 1996).

In the 1980s and 1990s, companies looked for other ways to improve productivity and hence gain a competitive advantage in the growing global marketplace. They discovered another element of production, the workforce. Indeed, if properly employed and managed, the human factor in the organization showed its incredible power to carry the organization to a strong competitive level. The studies showed that the productivity input from the employees could be improved greatly with proper HR policies and practices. Recruitment and assignment are one of the most important subsystems that affect productivity of HR. The ways these processes are employed play an important role for the goal of the organization, high productivity (Nash, 1985).

Today, organizations and managers realize the importance of personnel to their organizations and try to take them into consideration when making their strategic and tactical decisions.

In addition to HR theory, we need the approach of systems theory to understand and support the HR system better. The following hierarchical structure represents what we would like to emphasize (Figure 2.1):

Before dealing with the PA problem, we need to understand the place of the assignment process in an organization. What part of the whole organizational process are we considering? Are we dealing with a very small problem or is the problem a really big one? What is the impact of the assignment system on the whole organization? Apart from HR theory, systems theory answers some of these questions.

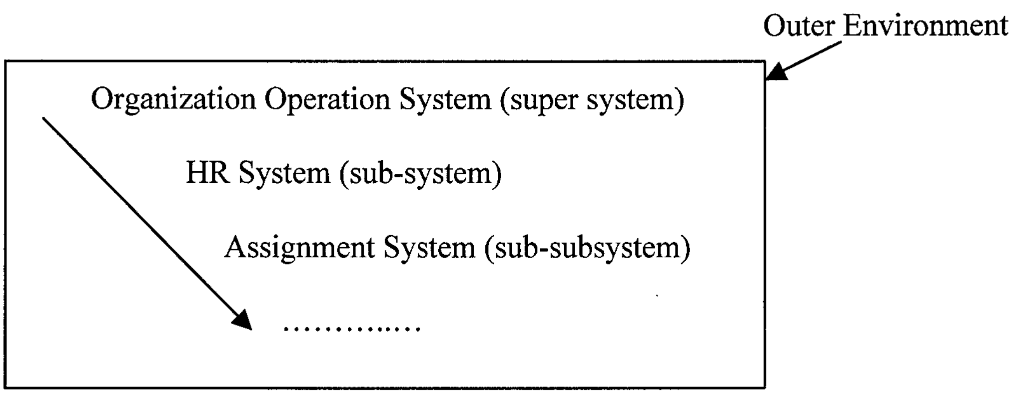

Figure 2.1 A Systematic Look at the Assignment Subsystem

Organizations and individuals are frequently confronted with alternative courses of action. Decisions are part of our life. Each decision has its consequences. Assigning personnel is a decision making process. Since the expected impact of decisions should be viewed in terms of their implications for the organization as a whole, an integrative framework is needed that will afford a broad macro perspective (Cascio, 98). This framework is systems analysis.

In recent years, much attention has been given to the concept of systems and the use of systems thinking. The systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than snapshots. It is a set of general principles-distilled over the course of the twentieth century, spanning fields as diverse as physical and social sciences, engineering and management. It is also a specific set of tools and techniques. During the last thirty years, these tools have been applied to understand a wide range of corporate, urban, regional, economic, political, ecological, and even physiological systems. S*ystems* *thinking* is a sensibility for the subtle interconnectedness that gives living systems their unique character (Senge, 1990).

We should think systematically but with the understanding that the system changes dynamically over time. Hence, to obtain a better understanding of the assignment system, we should study it with the principles of systems and HR theory. The assignment process in an organization is a small part of the whole organizational system. It affects other processes in the system and is affected by them. Figure 2.2 shows the place of the assignment system within the 'Human Resource Planning' and 'Business Planning' system in the organization.

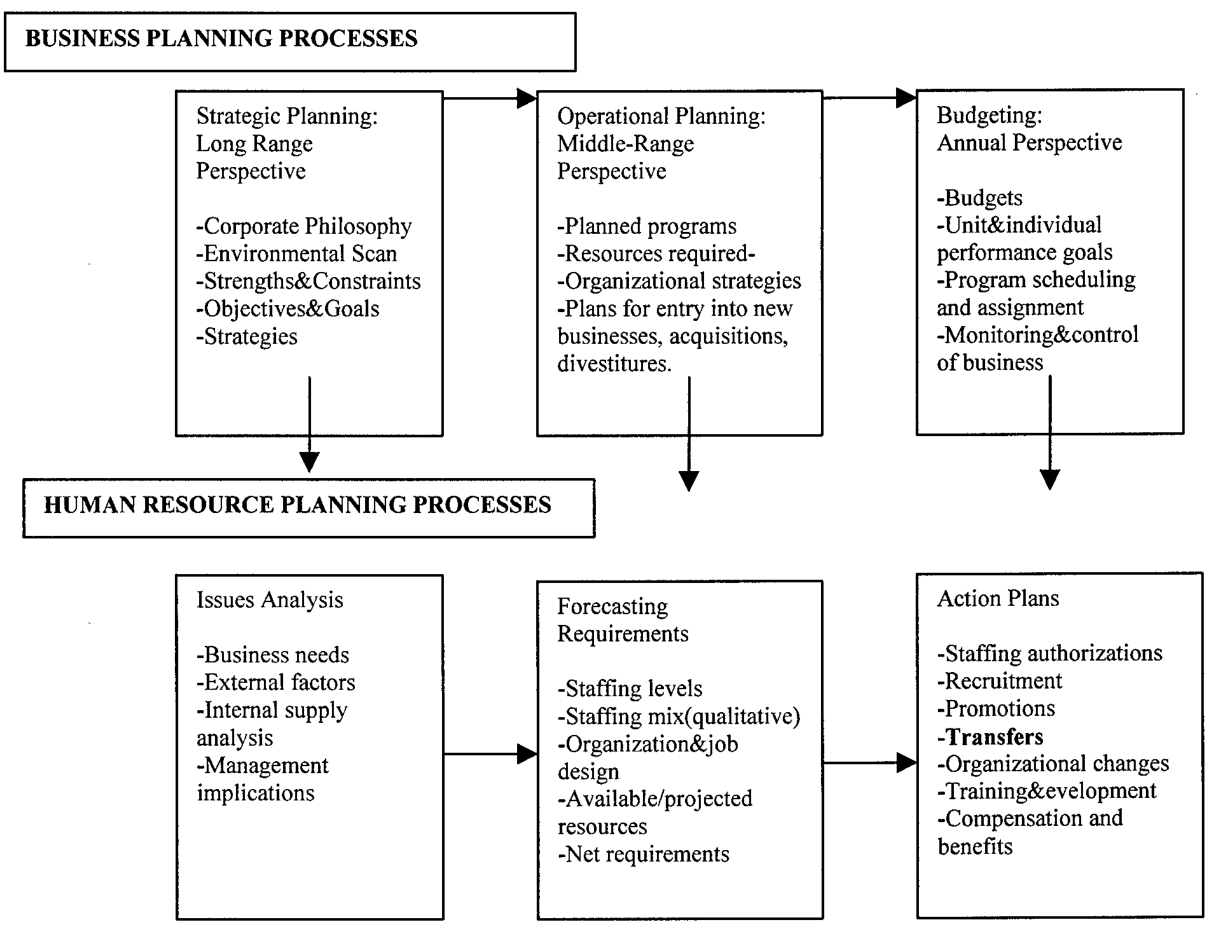

Figure 2.2 The Place of Assignment System in an Organizational System (Cascio, 1998)

The following influence diagram (Figure 2.3) shows the relational structure between different objectives in assignment system.

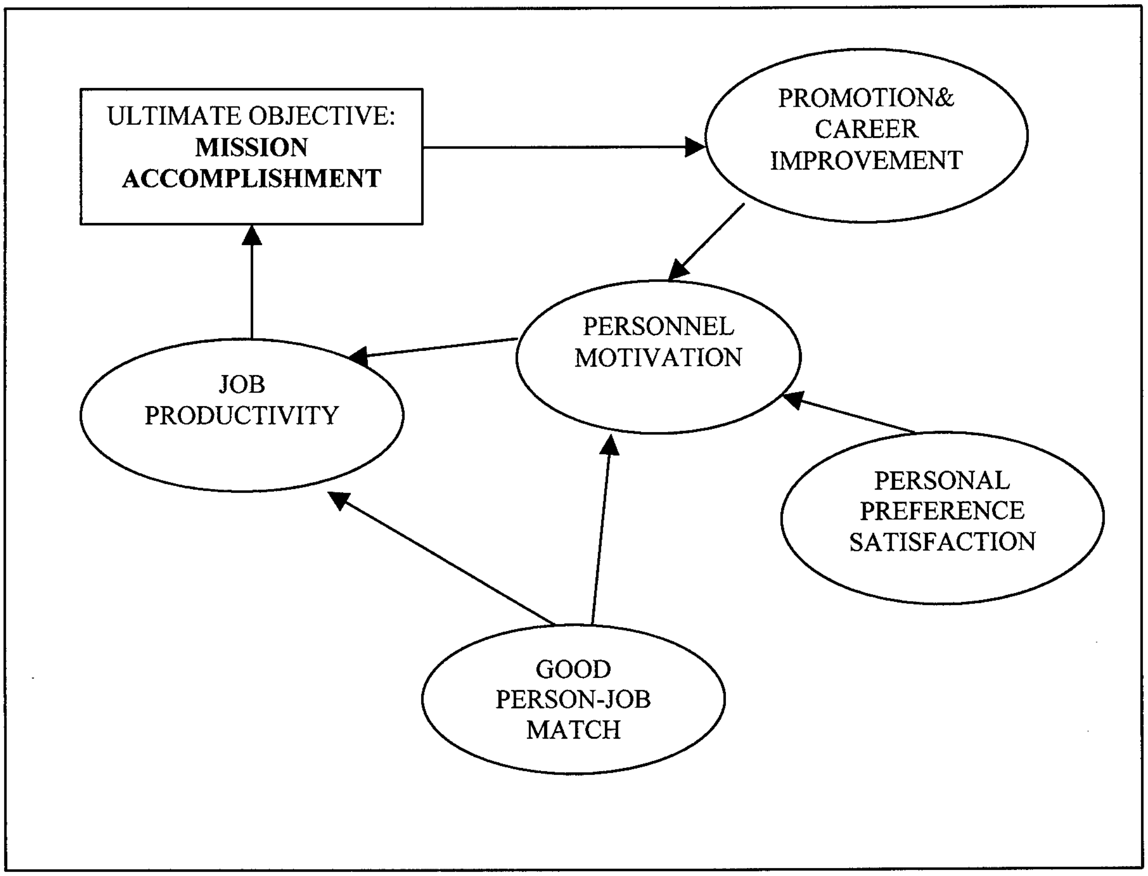

Figure 2.3 Influence Diagram of Goals in Assignment System

Quantitative Modeling and Analysis Approach to Manpower Allocation and Personnel Assignment System

In the military services, terms such as manpower, personnel, training, assignment, and career management and compensation management refer to subsystems or sub processes that are separate organizational functions and management processes by which people are brought together around a specific career or job. Each process and the related models that support it, has its own place in the integrated process of HRM. Two of these subsystem terms are:

-Manpower Planning and Allocation: The process of determining the numbers and types of people necessary to accomplish present and future tasks based on certain past statistical and future forecast analysis data.

-Personnel Assignment: The process of matching personnel to jobs.

The use of operations research (OR) and management science methods (i.e. quantitative management methods) to help in managing HR is, perhaps, the least developed area in this field (Mason and Flamholtz, 1978). It is, undoubtedly, the most difficult to develop. This is because of the *nature of HR*. Many diverse factors are included in HRM. These influencing factors stem from four basic forces or demands as Mason and Flamholtz mention. These are:

1) The organization's demand to have an effective job and role structure that is adequate to produce its goods and services in appropriate quantities and qualities, and on time.

2) The organization's demand for the efficient use of its resources

3) The individual's demand to satisfy basic and self-actualization needs

4) Society's demand for the production and appropriate distribution of goods and services with regard to rights, duties and privileges of citizens.

Furthermore, there has been little research and modeling done to develop robust integrated models that attempt to construct a unified HR system. The processes in a HR system are so multi-faceted in nature that it is difficult to model HR systems. However, small processes in the HR system can be replicated so that the model can be used as a support tool for the DM to accomplish these small processes effectively and efficiently. In order to overcome the difficulties inherent in HR modeling, we need to divide the large processes into smaller processes. The following large-scale network structure shows the entire MA/PA problem of a military organization (Figure 2.4). It is not practical to make assignment decisions for all personnel in one step. Hence, we divide the complete problem into smaller assignment problems.

In the network structure of Figure 2.4, the nodes represent the positions, the arrows represent the possible assignments of personnel from one position to another, the oblong blocks represent the hierarchical career steps. This broad perspective indicates the difficulty of the problem. In practice, this problem is solved by dividing people and positions into smaller groups (i.e. career, rank, specialty). We did the same thing in our model to tackle this large problem.

Quantitative Decision Support Models for MA/PA Problems

1. Integer and Linear Programming
2. Network Optimization Algorithms
3. Heuristic Methods
4. Goal Programming
5. Decision Analysis Models: Analytic Hierarchy Process (AHP)
6. Statistical & Probabilistic Models

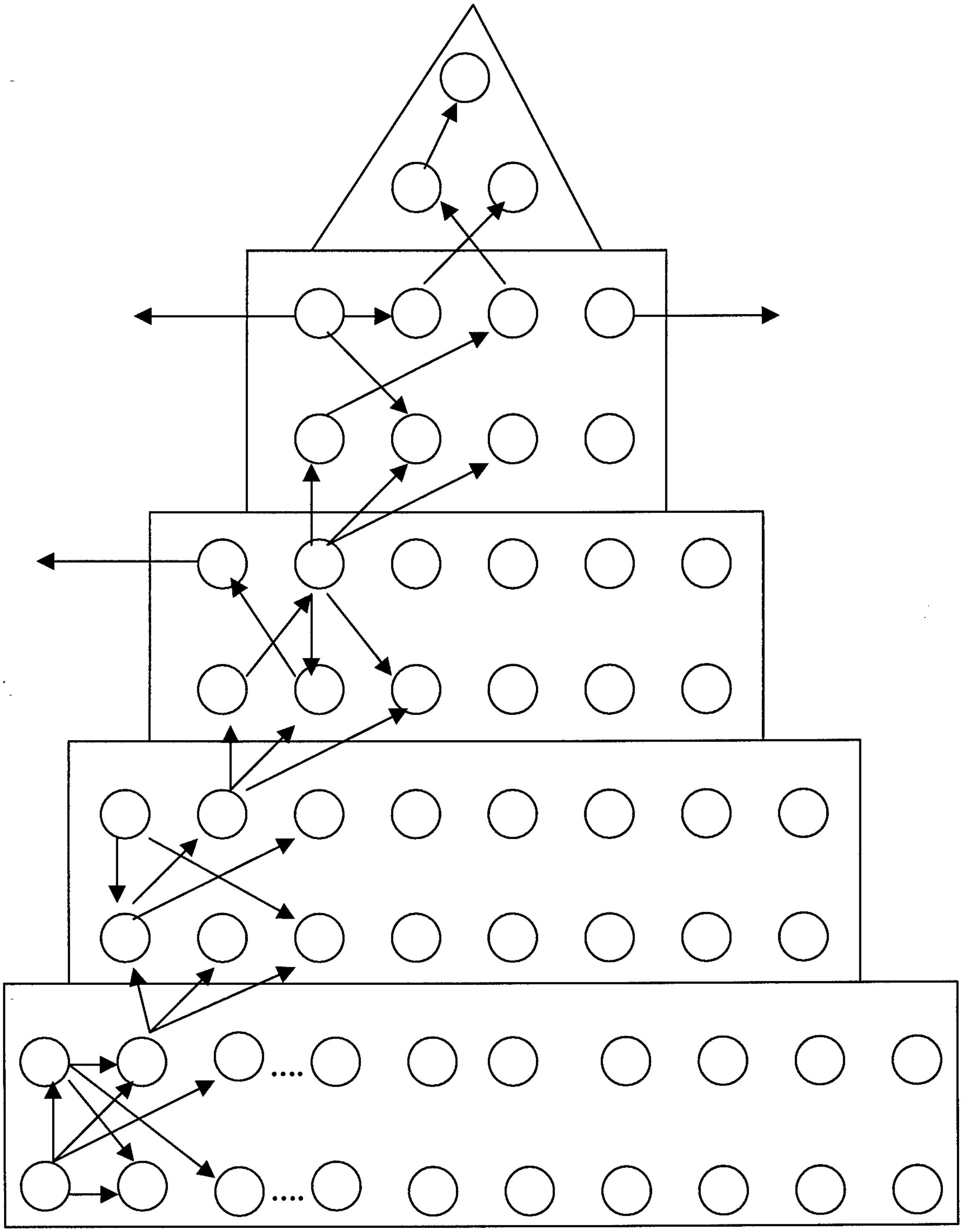

Figure 2.4 The Large-scale Manpower Allocation/Personnel Assignment Problem

Network Structure as a Career Path Pyramid.

Except probabilistic models, the other models are deterministic in nature. All of them fill a gap in the quantitative M&A area and produce solution strategies to different problems. Many robust models integrate these models in one way or other.

1. Integer Programming (IP) and Linear Programming (LP): IP is a robust modeling method to model generalized assignment problems (GAP). Branch and bound (B&B) algorithms are used to solve IP problems. GAP has constraints beside the supply-demand (network flow conservation) constraints. These constraints are usually called *side* or *extra-network* constraints. If there are no side constraints, the problem is a pure assignment problem. Small-scale GAP can be solved by IP models efficiently. Unless the number of assignees in an assignment pool is too high (e.g. thousands), using high-speed processors, enough memory and improved B&B based IP solution techniques can be an efficient method to solve GAP. However, since the complexity of the B&B is exponential in nature, it is inefficient to solve large-scale GAP problems with IP. The number of variables is a good gauge to estimate the solution time. When the scale of the problem is large (e.g. thousands of assignees and positions), the solution time tends to increase significantly.

LP solution techniques can be used to solve pure assignment problems. The PA problem is a 0/1 problem but the special constraint structure (unimodular) of the problem gives us the freedom of relaxing the integer constraints. If the constraints matrix is totally unimodular and the right hand sides of the constraints are integers, then the result of the LP relaxation is also an integer solution. Simplex-based algorithms are efficiently solve LP problems of reasonable size. When the problem size is large, for some problems simplex-based algorithms tend to be inefficient. In addition, the simplex algorithm presents high degeneracy, cycling and potential stalling due to the fact that the right-hand sides of the pure assignment problem constraints are 1. Some techniques have been developed to escape degeneracy, cycling and stalling. But these techniques increase the computational complexity of the simplex algorithm. However, applying cycling prevention rules to network structured linear programs are easy to implement and computationally advantageous (Bazaraa *et. al.* 1990). So, for large-scale pure assignment problems, network simplex and other network algorithms are more attractive than IP/LP methods in terms of computational efficiency. On the other hand, our model is primarily intended to solve more realistic small to medium-scale problems that can be easily handled by assignment officers. In addition, pure network solution algorithms can not solve GAP because of the extra-network constraints. Our solution approach includes an integer assignment problem with extra-network constraints as *objectives to aspire* (Ravindran *et.al*, 1987)

2. Network Optimization Methods: In the operations research literature, the *bipartite weighted matching problem* is known as the assignment problem. The assignment problem is the general name used both in linear/integer programming and network optimization area, but the name bipartite weighted matching problem is used only for network optimization. Assignment problems are a subset of the broader *matching problems* in network optimization (Ahuja *et.al,* 1993). Pure assignment problems have a bipartite network structure that consists of two set of nodes (N_1 and N_2) and directed arcs $(i,j) \in A$, $i \in N_1$ and $j \in N_2$ (Figure 2.5).

There are several network optimization algorithms that can be used to solve a pure assignment problem. These are Hungarian algorithm, successive shortest path algorithm, relaxation algorithm, cost-scaling algorithm, and network simplex algorithm. Except the network simplex algorithm, all other algorithms are shortest path-based algorithms. All of the above algorithms solve the bipartite network structured assignment problem in polynomial time and are very efficient (Ahuja *et.al*, 1993). However these algorithms are used to solve pure assignment problems that have one objective function and flow conservation constraints between supply and demand. Our model is not a pure assignment problem because of the extra network constraints. Therefore we need to apply Lagrangian relaxation (LR) to relax side constraints and make use of the remaining network structure (Martin, 1999). The most efficient appproach is to separate the underlying network portion and the extra network portion of large-scale problems and solve the network portion by using one of the above pure assignment algorithms.

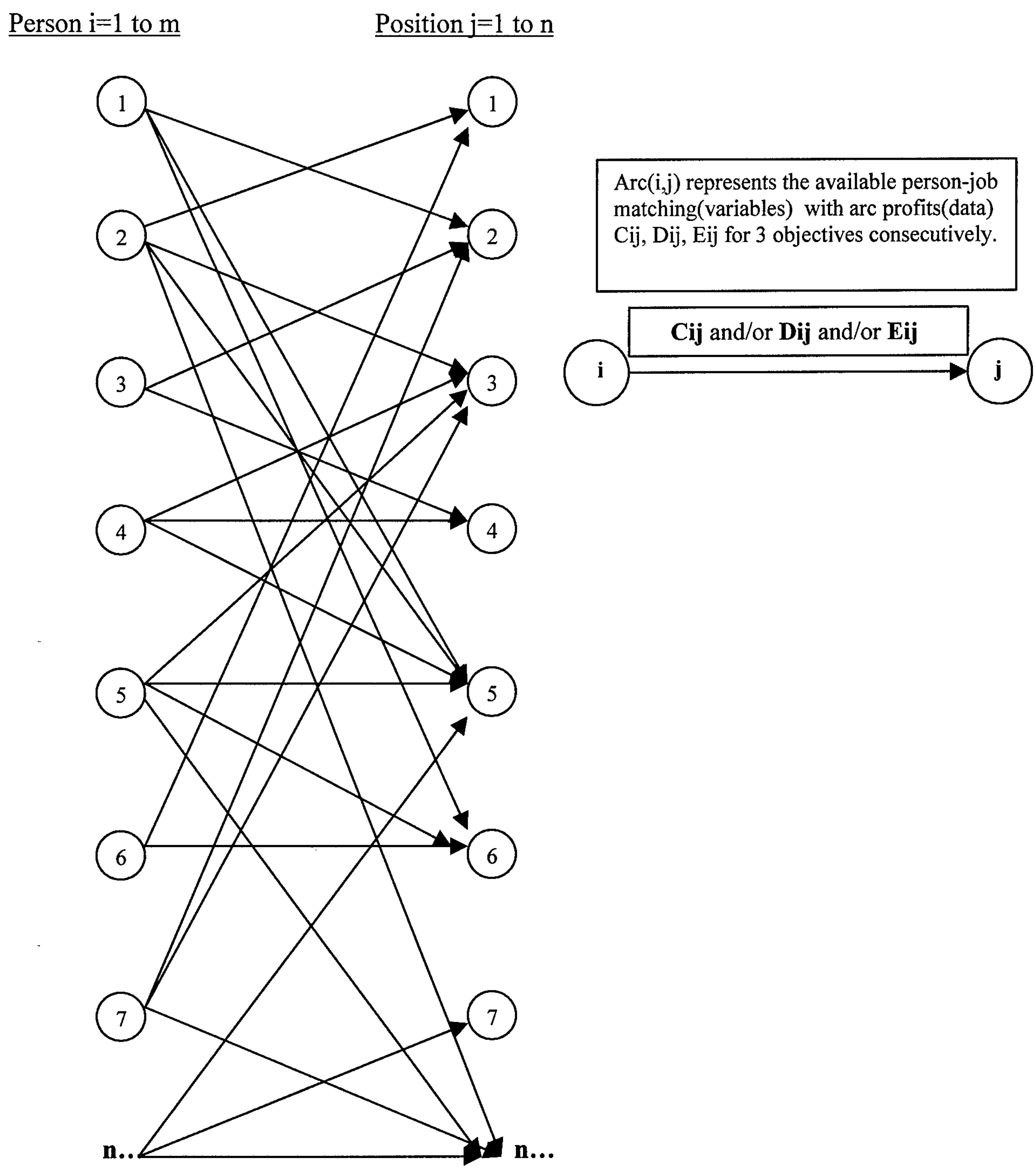

Figure 2.5 The Bipartite Network Structure of Assignment Problems

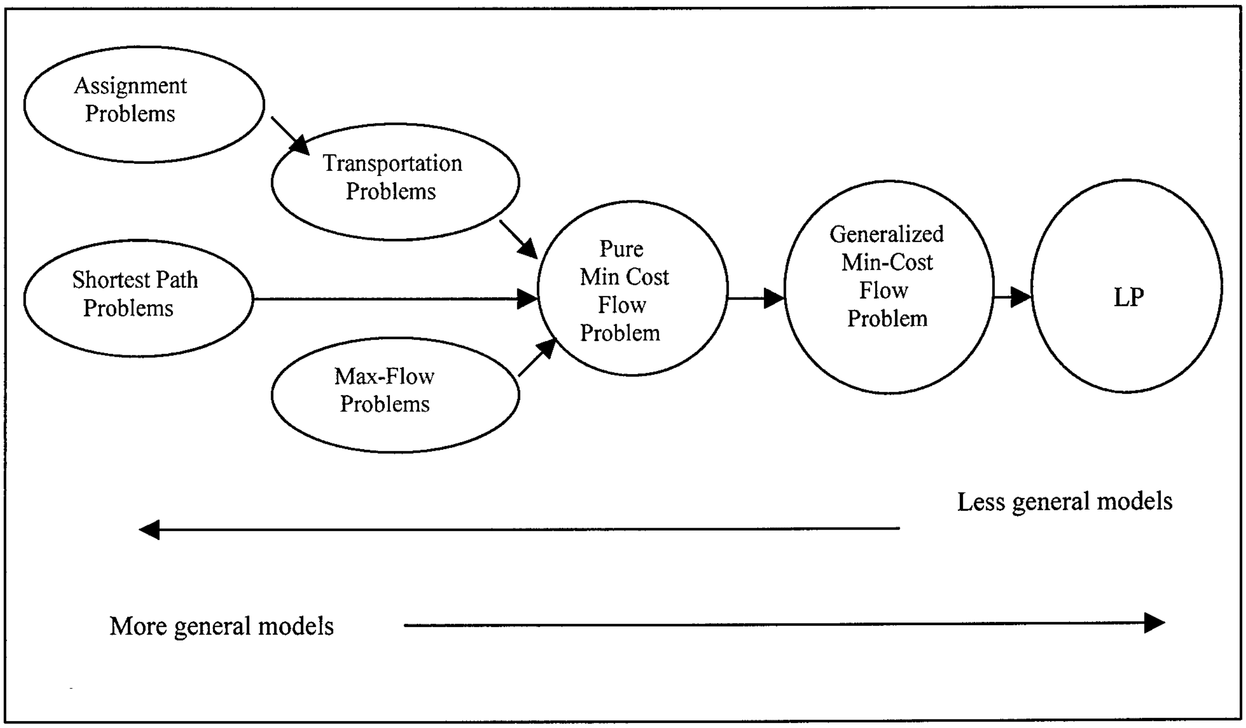

Figure 2.6 Assignment Problems within the Broader Class of Network Problems

3. Heuristics Methods: Heuristic methods are used when the problem size is too large and/or the problem is too complex to solve by exact solution algorithms within a reasonable amount time. In addition, heuristic methods are embedded in exact solution algorithms to improve solution time quality. There is another argument in favor of using heuristics: What we are actually solving is a model of a real-world problem. There is no guarantee that the best solution to the model is also the best solution to the underlying real-world problem. To put it another way, should we prefer an exact solution of an approximate model, or an approximate solution of an exact model? (Reeves, 1995) There is no guarantee of the availability of an exact model of the real-world problem. Heuristics are usually more flexible and are capable of coping with more complicated and

more realistic objective functions and/or constraints than exact algorithms. On the other hand, if the solution time of an exact algorithm (e.g. partitioning algorithms) is acceptable, we prefer to use it rather than using heuristic procedures. Since we assume that an average assignment problem in the TAF will not be too large (it is unlikely to have a group consisting of thousands of assignees) or complicated, a heuristic procedure was not chosen as a solution methodology.

As a modern example of a heuristic implementation to a PA/MA model, Abboud *et.al.* applied a genetic annealing (Gan) metaheuristic to a salesman allocation problem. The problem is to distribute the sales force over the branches of a company satisfying several objectives as well as considering the salesmen's abilities, satisfactions, and preferences. They obtained lower solution times than many other heuristic and optimization methods.

4. Goal Programming: Goal programming (GP) gained popularity in the 1960s and 1970s. GP is now an important area of multiple objective optimization (MOP). MOP is one of the two general approaches to multiple objective decision-making (MODM). The other general approach is multi-attribute decision analysis or simply decision analysis (DA). MOP is the prescriptive version of MODM while DA is a descriptive version. DA is a "process-oriented" approach, which seeks to answer the question "how" whereas MOP is an "outcome-oriented" approach which seeks to answer the questions "what and when" (Paulsen, 1988). DA has been most applicable to resolving problems with a smaller number of alternatives in the presence of uncertainty such as those involving public policy decisions (where to build a nuclear power plant, an airport, factory, etc.) MOP is more useful when applied to less controversial

deterministic problems in which the number of feasible alternatives is large such as PA problem.

The idea of GP is to establish a goal level achievement for each objective. GP is ideal for criteria with respect to which *target* (or threshold) values of achievement are of significance. The GP is distinguished from LP by:

1. The conceptualization of objectives as goals.
2. The assignment of *priorities* and/or *weights* to the goals.
3. The presence of *deviational* variables d_i^+ and d_i^- to measure overachievement and *underachievement* of target (or threshold) levels t_i.
4. The minimization of weighted-sums of deviational variables to find solutions that best satisfy the goals.

A point that optimizes all the goals usually does not exist. Thus we try to find some trade-offs that satisfy our objectives *as much as possible*. The way in which such points are found using priority and/or weighting structures defines GP. (Steuer, 1986)

A multi-objective problem may have four types of goal criteria.

1. Greater than or equal to (>=t_i)
2. Less than or equal to (<=t_i)
3. Equality (=t_i)
5. Range (a<=t_i<=b)

One way of treating multiple competing objectives is to select one objective as primary and the remaining objectives as secondary. The primary objective is then used as an optimization performance measure while the secondary objectives are assigned acceptable minimum or maximum values (right-hand side (rhs) values) and are treated as problem constraints. However, if careful considerations are not given while selecting the acceptable levels, a feasible design that satisfies all the constraints may not exist. This problem is overcome by a technique called *goal programming.* In GP, there are different math programming techniques to formulate the multi-objective problem. Different techniques can be applied to different problems.

Finding good rhs (see the definition of rhs values in the optimization phase) for the constraints is an issue to deal with when solving the multi-objective problem. Finding upper and lower bounds for each objective can give an idea of the feasible region. Then, by assigning initial rough weights based on our perception of the hierarchical importance of the objectives, a local search can be done. It is relatively easier to find good feasible solutions for problems with fewer objectives. The complexity of assigning rhs values that permit finding a feasible solution increases as the number of constraints (objectives) increase.

In GP, all the objectives are assigned target levels for achievement and a relative priority on achieving these levels is established. GP treats these targets as *goals to aspire for* and not absolute constraints. These constraints are called *goal constraints (*Ravindran *et.al., 1987).* The other constraints are absolute restrictions on the decision variables while the goals are conditions one would like to achieve but are absolute. GP then attempts to find an optimal solution that comes as close as possible to the targets in order of specified priorities.

Preemptive Goal Programming: Our modeling approach to the multi-objective assignment problem is a preemptive GP. The reason we apply a preemptive goal programming approach is that it allows us to consider prioritized objectives. In most military organizations, the objectives can be ordered in decreasing order of importance. In our problem, we applied the following assumption: "The first objective is definitely accepted as more important than the remaining objectives, the second objective is more important than the remaining objectives, the third objective is more important than the remaining and so on...(Shrage, 1999)"

The priorities of objectives in our approach are ordered in a decreasing order of importance as described below. The priority (or weight) of the 1st objective is larger than the priority for the 2nd and the priority for the 2nd objective is larger than the 3rd objective and so on...(Winston, 1994)

$$\mathbf{F_1(\underline{x}) >>> F_2(\underline{x}) >>> F_3(\underline{x}) >>> \ldots\ldots}$$

The search space with its upper and lower bounds is shown as follows for a 3-objective preemptive GP (Figure 2.7).

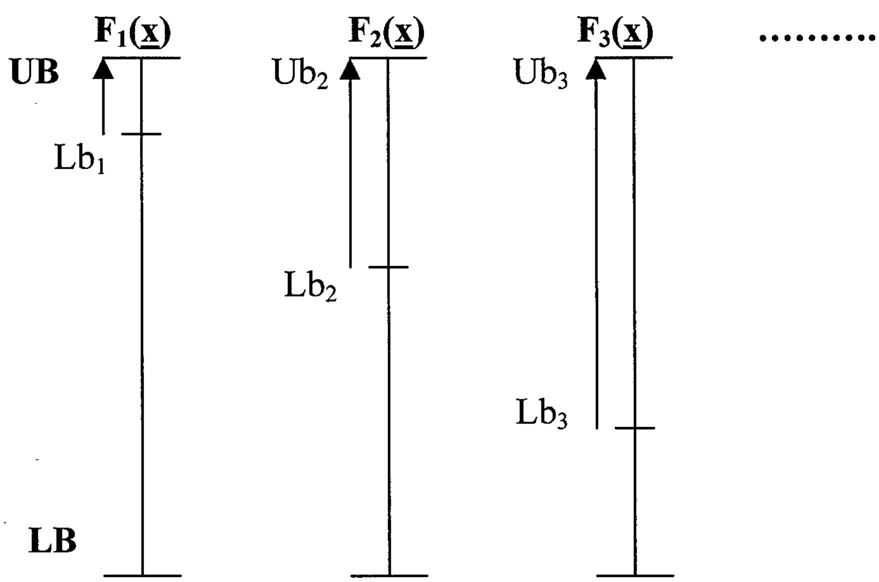

Figure 2.7 The Search Space for the 3-Objective Preemptive Goal Programming

5. Decision Analysis Models- Analytic Hierarchy Process: When multiple objectives are important to a DM, it may be difficult to choose between alternatives. The DM requires a rated list of alternatives, which are assigned priority score. AHP is such a tool, which does prioritization of alternatives according to the DM's judgement. Pairwise comparison of objectives and alternatives is the heart of AHP (Winston, 1994). By comparing each objective pairwise, weights are obtained for each objective.

6. Statistical and Probabilistic Models: The models presented up to this point can be classified as deterministic models because the input data to the model are not stochastically determined. Statistics is definitely one of the most widely used M&A tool in the area of HR because it has the ability to help DM interpret and make sense of large, complicated sets of HR data. Statistics is flexible enough to be able to capture very small HR processes as well as very large ones. Other than statistics, there are stochastic models created to model HR. These models basically search for the answer to this question: "Given a work force described by class descriptors at the beginning of a period, what is the composition of the force at the end of the planning period?" These models are usually called transition state models and use Markov Chains in general. There are other statistical and stochastic methods (e.g. forecasting) to help DMs solve MA problems. Since our problem is deterministic, we did not apply these models. These models serve different purposes in HR processes and are used especially for manpower and career planning purposes. In the next chapter, the research methodology is presented. A goal programming approach is used.

Chapter 3: The Methodology

Introduction

In this chapter we present our mathematical model and solution approach to the PA problem phase by phase. The solution approach is preemptive goal programming. First, the assumptions that we make for the methodology are presented. Then, personnel evaluation phase is handled in an illustrative example by using analytical hierarchy process-based Expert Choice decision support software (Winston, 1994). After this phase, the preprocessing phase is demonstrated by an illustrative example using Visual Basic for Excel. Then the mathematical model (IP) is presented. This is the optimization and decision-making phase where assignment decisions are made. In our methodology, we tried to integrate different sub processes (phases) in an assignment system by using quantitative modeling, analysis, optimization and decision-making tools. The validity of any model depends on the degree of representation. Hence, integrated models represent systems for which they are built better than non-integrated models.

Assumptions

1. We assume that the whole organizational assignment process starts from the highest available rank to the lowest rank. Within each career, the pools of assignees are formed. The positions that are vacant after each assignment step constitute the available candidate positions for the following assignment process. All of the available positions must be vacant at the time of assignment.

2. We assume that at least one position within a person's assignment domain is in another person's domain. There is an intersection among the assignees' assignment position domain in an assignment pool.
3. Any person desiring an assignment to any position outside the career path or any person desired by the higher command for such positions is handled on an individual case by case basis. Career broadening assignments are handled separately too.
4. Exceptional assignments such as positions that require highly specialized and/or skilled personnel, classified assignments are handled separately.
5. The person-job match degrees, career development degrees and personal preference degrees should be reasonably quantifiable.
6. Since real data cannot be used because of the privacy of personnel data, random numbers are used to represent the actual data. We assume that the computational complexity test results obtained by using these random data are not significantly different from the actual case. We assume that the data for personnel and positions are correctly stated, i.e. there is no significant data validity problem.

Data Obtaining Phase

Variable coefficients for the multiple objectives and any side constraints should be obtained for the mathematical model. Position-filling priorities (fill criteria), personnel-position match degrees (requirement-qualification fit criteria), personal preference match degrees should all be obtained. A lot of effort is needed to determine future career needs of organizations. Each organization uses different personnel evaluation system. Performance appraisal methods, ability tests, screening and capturing special interests of personnel and many other kinds of *personnel evaluation* methods should be used in order to obtain valid personnel match data (see Cascio, 1998). On the other hand all jobs starting from the prioritized ones should be analyzed by proper *job analysis* methods. Many statistical and forecasting studies should be made to predict future personnel qualification needs through *career planning*. Personnel psychologists and HR professionals should play key roles in all these data obtaining and preparation phase. This process should be a continuous process through time. Improved, user-friendly personnel database and other resources should be utilized to search, screen, sort, group, *preprocess* and prioritize personnel and positions. Personal privacy issues also contribute to the difficulty of this problem area data retrieval. This data retrieval effort should be done with a proper planned system. So, there is a need for strategic planing, systems analysis and feasibility studies on this area too. The costs of all these efforts should be considered as well. Although it seems very difficult to fulfill all these tasks, it is not impossible. We believe that the most important asset of an organization is its HR. It's worth all these efforts.

Personnel Evaluation: This phase is the subject of much research. Personnel evaluation is an interdisciplinary research and application area. There are different personnel evaluation models as many as the number of organizations. To evaluate the personnel, who are eligible for assignment, some decision support methods can be employed to determine the match degrees of personnel to available positions. *Expert Choice* 2000 (EC2000) decision support software is an example of a tool that orders alternatives (assignees) according to their match degrees for a particular position. Under each position, we need the ordered set of available assignees for that specific position. The match degrees determine the level of organizational need for each available person-job match. A sample problem is presented to illustrate the application of the EC2000 software (Tables 3.1, 3.2 and 3.3).

Table 3.1 The Pairwise Comparison Matrix of the Objective Criteria

Compare the relative importance with respect to the **objective**: Select the Best Assignee for an R&D Position					
	Discipline	Experience	Educational Level	Specialty Area	Job Performance
Discipline	1	0.3000003	0.230769408	0.176470484	0.374999531
Experience		1	0.769230769	0.588235294	1.25
Educational Level			1	0.742859265	1.73333
Specialty Area				1	1.6
Job performance	Incon: 0.00				1

The values are determined so that the inconsistency of the criteria evaluation is 0. The inconsistency value is a measure of the irregularity of the DM's pairwise comparisons. Then the alternatives (assignees) are determined and their qualifications are evaluated one by one with respect to the each criterion.

After selecting the candidates (in bold) among these alternatives and applying the analytical hierarchy process (AHP) to these candidates, the overall degrees of priority are determined.

Table 3.2 The Alternatives (assignees) and Their Evaluation Degrees

Distributive mode					
-	DIRECT	DIRECT	DIRECT	DIRECT	DIRECT
Alternatives (Assignees)	Discipline (L: .059)	Experience (L: .197)	Educational Level(L: .258)	Specialty Area(L: .320)	Job Performance (L: .166)
P1	0.85	0.67	0.69	0.88	0.83
P2	0.77	0.93	0.61	0.71	0.71
P3	0.91	0.6	0.81	0.89	0.53
P4	0.77	0.81	0.59	0.72	0.9
P5	0.77	0.79	0.9	0.85	0.65
P6	0.74	0.7	0.79	0.54	0.83
P7	0.95	0.79	0.62	0.83	0.81
P8	0.79	0.91	0.91	0.68	0.93
P9	0.76	0.57	0.69	0.19	0.88
P10	0.83	0.46	0.68	0.72	0.87
P11	0.9	0.87	0.15	0.75	0.79
P12	0.77	0.74	0.69	0.26	0.87
P13	0.22	0.48	0.6	0.91	0.82
P14	0.42	0.74	0.76	0.49	0.69
P15	0.81	0.67	0.58	0.83	0.78
P16	0.87	0.81	0.77	0.88	0.91
P17	0.76	0.63	0.27	0.44	0.86
P18	0.85	0.72	0.78	0.68	0.78
P19	0.88	0.78	0.87	0.83	0.88
P20	0.55	0.88	0.85	0.87	0.75

Table 3-3. The Overall Evaluation of the Candidate Assignees

Alternative	Priority
P2	0.096631
P5	0.107711
P6	0.091995
P7	0.102119
P8	0.110007
P13	0.090808
P14	0.084173
P15	0.095822
P19	0.111364
P20	0.10937

Likewise the overall evaluation degrees, i.e. the objective function coefficients for the decision variables in the first objective function can be obtained. There is no need to repeat the process for the positions having the same characteristic. Here one important point is the additivity of coefficients in each objective function. The coefficient for one position should be additive with the coefficient for another position.

Preprocessing Phase

The purpose of pre-processing is twofold. The first purpose is to decrease the number of variables in the mathematical model and hence reduce computational difficulty. The second purpose is to apply the assignment rules and policies that determine a person's available assignment positions among all of the positions. The DM should determine the *policies or rules* to eliminate some candidates from consideration. For example, previous assignment data, geographic location, or elimination of personnel from some positions whose match degree is below a lower bound or above an upper bound can be used in the pre-processing phase. Actually, assignment officials accomplish this phase by cross-checking the person-job availability depending on predetermined assignment policies or rules. In addition to the mathematical optimization phase, the automation of this phase can help the assignment officials prepare the data (i.e. person-job availability variables) for the optimization phase. The automation of this phase should have enough flexibility to accommodate changes in policies and regulations. A robust personnel database can be utilized to reach the desired level of automation. Human interaction should be included to handle the highly changeable nature of HR systems. Currently, both in the current US and Turkish Armed Forces assignment systems, the assignment officials or teams determine the available assignees for a specific position by looking at predetermined rules and policies. For example, the following policies can be employed to decrease the number of variables (see optimization phase for the definition of variables):

-Exclude some personnel or positions from the list, if the person-job match degree is very high, above some upper limit, which can be computed by some statistical computations.

-Exclude some variables (person-job availability) by establishing a lower bound for the match degree of personnel.

-Exclude some variables due to geographical considerations, (e.g. do not assign personnel at a sea task to another sea task.)

Likewise any rule can be incorporated into this automation with the support of a robust personnel database. The current US Navy personnel assignment model includes both an optimization algorithm and a preprocessing phase.

Optimization Phase (Mathematical Model)

The officer assignment problem can be modeled as a mathematical program with multiple objectives. We utilize a preemptive goal programming approach to solve the multi-objective mathematical program.

Indices

i : personnel

j : positions (billets)

Decision Varibles

$\mathbf{X_{ij}}$ = 1, if personnel i is assigned to position j

= 0, otherwise

Explanations: X_{ij} is a binary variable. The pure assignment problem with integer right-hand side values has a totally unimodular constraint matrix. Making use of this property, we can solve the LP relaxation of a pure assignment problem with one objective function and flow conservation constraints. Any dummy personnel or positions can be added to achieve a balanced assignment problem if the number of personnel and positions are not equal (Winston, 1994).

Data(variable coefficients)

$\mathbf{C_{ij}}$ **:** Personnel-position match degree. This is a measure of organizational needs satisfied by assigning personnel i to position j.

$\mathbf{D_{ij}}$ **:** Career development degree. This is the degree of career development expected to be gained by assigning personnel i to position j.

$\mathbf{E_{ij}}$ **:** Personal preference match degree. This is the satisfaction degree when a person i is assigned to a position j.

Objectives in Decreasing Order of Importance

MAX $\sum_i \sum_j C_{ij} * X_{ij}$

MAX $\sum_i \sum_j D_{ij} * X_{ij}$

MAX $\sum_i \sum_j E_{ij} * X_{ij}$

Explanations:

1st **Objective**: The first objective is the organizational objective, i.e. fill the jobs with the people having the highest total match degree. This objective focuses more on the short-term interests of the organization than the long-term interests.

2nd **Objective**: The second objective is the career objective. This objective is both an organizational and personal objective and meets the career needs of both organization and personnel. The organization should think about not only filling the current jobs but also about the future education and experience level of its personnel. The personnel should be given on the job training (experience) by assigning them to challenging jobs (i.e. not only to their best match position) during their career. From the personal point of interest, most people are highly concerned about their career in the future. The organization should meet the career expectations of its personnel. To get a positive impact on the motivation of personnel, the organization should consider person's future career.

3rd **Objective**: The third objective is the personal preference objective. Its goal is to satisfy, to highest level possible, the sum of the personal preferences. Military personnel fill out a preference form when they are vulnerable to assignment. They base their preferences on a wide variety of reasons, such as geographical location, income, family, career opportunity, job requirements etc. This objective is also a *motivational* objective. Job performance studies show that if a person is assigned to a place he or she prefers, the job performance is higher on the average than otherwise.

Constraints

Supply Constraints:

$\sum_j X_{ij}$ **= 1 for i=1…n** (Each person is assigned to only one position)

Demand Constraints:

$\sum_i X_{ij}$ **= 1 for j=1…n** (Each position can be filled with only one person)

$X_{ij} \in \{0,1\}$ **for i=1...n ; j=1…n**

Explanations: If the number of personnel and positions are not equal which is the usual case, then we create a balanced assignment model by adding dummy personnel or dummy positions. We assumed a balanced case in our sample problems. In the following, the ub and lb notations mean upper bound and lower bound, respectively.

Subproblem 1

$Z_1^{ub} = \text{MAX} \sum\sum C_{ij} * X_{ij}$

S.T. $\sum_j X_{ij}$ **= 1 for i=1…n**

$\sum_i X_{ij}$ **= 1 for j=1…n**

$X_{ij} >= 0$ **for all i and j** (LP relaxation)

Subproblem 2

$Z_2^{ub} = \text{MAX} \sum\sum D_{ij} * X_{ij}$

S.T. $\sum_j X_{ij}$ **= 1 for i=1…n**

$\sum_i X_{ij}$ **= 1 for j=1…n**

$X_{ij} >= 0$ **for all i and j** (LP relaxation)

<u>Subproblem 3</u>

$$Z_3^{ub} = \text{MAX} \sum\sum E_{ij} * X_{ij}$$

$$\text{S.T.} \sum_j X_{ij} = 1 \text{ for } i=1\ldots n$$

$$\sum_i X_{ij} = 1 \text{ for } j=1\ldots n$$

$$X_{ij} >= 0 \text{ for all } i \text{ and } j \text{ (LP relaxation)}$$

First, we obtained upper bounds on the three objective function values by solving the subproblems, which are in the form of pure assignment problem, respectively. We formed a 3x3 objective function value matrix by solving subproblems (see Table 4.2). Then we obtained an idea of the upper and lower bounds on each objective function. This is a preparation step to get initial right-hand side value guesses (***w2**** Z_2^{ub} and ***w3****Z_3^{ub}) for the side constraints in the main problem which will be explained below. Here w2 and w3 are degradation factors for the 2nd and 3rd objective function upper bounds, Z_2^{ub} and Z_3^{ub}. Simply by decreasing the upper bounds of the 2nd and 3rd objective functions we wanted to increase the most important objective function value, Z_1^*. Z_1^{ub} is the upper bound for the 1st objective function and we tried to reach that value by ensuring that the 2nd and 3rd objective function values are restricted by a lower bound, hence obtaining the desired level of trade-off among the multiple objectives.

Main Problem

$Z_1^* = \textbf{MAX} \ \sum\sum \mathbf{C_{ij} * X_{ij}}$

$$\textbf{S.T.} \ \sum_j \mathbf{X_{ij}} = \mathbf{1} \textbf{ for } \mathbf{i=1 \dots n}$$

$$\sum_i \mathbf{X_{ij}} = \mathbf{1} \textbf{ for } \mathbf{j=1 \dots n}$$

$$\sum\sum D_{ij} * X_{ij} >= w_2 * Z_2^{ub} \text{ (side constraint 1)}$$

$$\sum\sum E_{ij} * X_{ij} >= w_3 * Z_3^{ub} \text{ (side constraint 2)}$$

$$\mathbf{X_{ij} \in \{0,1\}} \textbf{ for all i and j}$$

The parameters w_2 and w_3 are degradation coefficients for the 2nd and 3rd objective function as they are treated as side constraints in the main problem. These factors are carefully selected to make sure the hierarchical (decreasing order of importance) structure is protected among the objectives.

After setting up the math model, we apply the model to problems having different input data. We present the application, testing, results and analysis in the following chapter.

Chapter 4: Application and Analysis

The Determination of Input Data

Because of the privacy of actual personnel information, we were not able to analyze the actual data. Instead, we created notional random data to represent the actual data. Each organization can input its own data to our model.

The notional random data:

1. Personnel-Position Match Degree, Cij

We use Expert Choice's overall evaluation numbers that it computes for each alternative (i.e. personnel-position match). However, organizations have their own personnel evaluation systems, so the person-job match degrees are changeable from one organization to another. Indeed, the area of personnel evaluation and the validity of this data is beyond the scope of this research. However, we have to state that the accuracy of this data is crucial for this model. If the organization is going to implement a PA model, then first, it has to have a good personnel evaluation system. For this reason, a PA model can obviously have a positive impact on the personnel evaluation system. We used data values close to the following notional data for each objective function.

-Excellent Match	:(95-100)
-Very Good Match	:(85-94)
-Good Match	:(75-84)
-Average Match	:(65-74)

-Under Average Match :(50-64)

-Poor Match :(10-49)

-No Match :0 (-1000, to prevent pivoting for these variables)

2. Career Development Degree, Dij

Career need level of the position for the specific person can be determined as:

-The position is critically important for the career :(5)

-The position is very good for the career :(4)

-The position is good for the career :(3)

-The position is fair for the career :(2)

-The position is not good for career development :(1)

We assigned random numbers for the 5 career match degrees for each available position.

3. Personal Preference Match Degree, (Eij)

-1st Preference position :3+p

-2nd preference position :2+p

-3rd preference position :1+p

-Out-of-preference position :0

We want to use past assignments to give a value for the preference coefficients. We think that a person's employment history is as important as his or her future one. An individual who has never been assigned to one of his or her preferences is not the same as an individual who was assigned to one; likewise a person who has never been assigned to his or her 1st preference position should not be evaluated the same as a person who has been assigned to one. Therefore we generated a small model to deal with this problem (Table 4.1).

According to the table, the personnel who will be assigned the first time will have a *p* value of zero. Here p value is the *past assignment coefficient.* The computation of this value is given in the table below.

Table 4.1 A Past Assignments Evaluation Model

	Past Assignments Realized According to a Person's Preference			
Person(I);Total Number of Assignments(∑Nj)	1st Preference Assignment Number	2nd or 3rd Preference Assignment Number*1	Non-preference Assignment Number*2	**Row Sum (p value)**
1;1	0	0*1	1*2	**2**
2;2	0	0*1	2*2	**4**
3;2	0	1*1	1*2	**3**
4;4	0	0*1	4*2	**8**
.....	....	....	....	....
(n); (∑Nj)	N1*0	N2*1	N3*2	**P**

In the table above, the columns represent a person's past assignments, which are grouped into three columns. The 1st column represents the number of assignments (N1) made according to a person's 1st preference. In the second column is the number of assignments made according to the 2nd and 3rd preferences. These two types of assignments are weighted the same because we assume they are almost equivalent. In the actual sense, a person's 1st preference is usually much more important than their 2nd or 3rd preferences. Also, if there are more preferences, the columns can be easily extended. We created notional data. This approach can be adapted by different organizations for their own specific organizational climate.

To explain the above table more clearly: person 3 has been assigned 2 times ($\sum N$). She has been assigned to her 2nd or 3rd preference position once and once to a non-preferred position. Then her p value is computed as 3 by adding the 3rd row values. Person 4 has been assigned 4 times and he has never been assigned according to his three preferences, so he will get the highest p value. The p values are incorporated into the 3rd objective function.

Results and Analysis

Small-Scale Application

The results of the application of our mathematical program to a small-scale sample problem (20x20 size) is shown for illustrative purposes:

Table 4.2 Solutions to the Subproblems and Upper/Lower Bounds on the Objective Function Values

	Z_1	**Z_2**	**Z_3**
Subproblem 1 MAX 1st Obj. only:	**1645(Z_1^{ub})**	15(Z_2^{lb})	43(Z_3^{lb})
Subproblem 2 MAX 2nd Obj. only:	813	**86(Z_2^{ub})**	53
Subproblem 3 MAX 3rd Obj. only:	510(Z_1^{lb})	37	**134(Z_3^{ub})**

Table 4.3 Searching the Solution Space for the Three Objectives (Interactively with DM)

				Assigned Rhs Combinations	
	Z_1	Z_2	Z_3	$Z_2 >= w_2 * Z_2^{ub}$	$Z_3 >= w_3 * Z_3^{ub}$
UB	**1645**	**86**	**134**	-	-
	Inf.			78	110
	Inf.			70	110
	940	**65**	100	65	100
	680	**66**	**101**	66	101
	1400	**60**	**90**	60	90
	1415	**59**	**88**	58	88
	1470	**59**	**80**	59	80
	1370	**66**	**80**	66	80
	1425	**63**	***81***	*63*	*75*
VeryGood	**1500**	**60**	**74**	**60**	**74**
Good	**1475**	**61**	**75**	61	75
Good	**1400**	**65**	**78**	65	75
Good	**1560**	**50**	**70**	50	40
	1600	**42**	**72**	40	40
	1620	**31**	**56**	30	40
	1645	**22**	**63**	20	30
	1645	**20**	**61**	10	10
LB	**813**	**15**	**43**	-	-

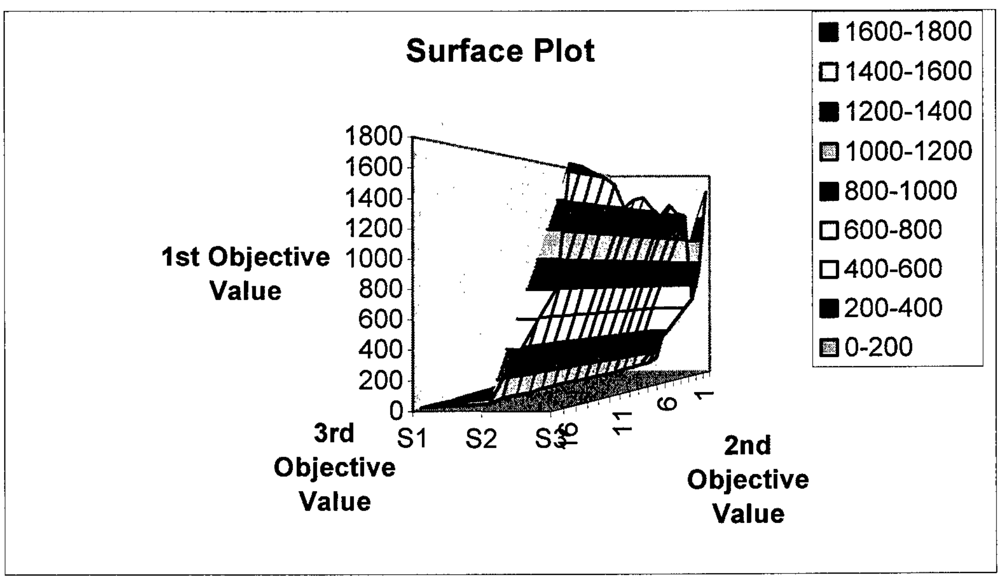

Figure 4.1 Surface Plot of the Multi-objectives Solution Space

Table 4.3 shows us that the desired level of objectives can be obtained through searching the solution space for the three objectives. The rhs values for the side constraints (2^{nd} and 3^{rd} objectives) are determined by the DM or by some predetermined policy. This way, the model incorporates the DM into the decision process interactively. The analyst should present not only the objective function values but also the profile of personnel assigned. The profile of the assigned personnel is for example, the percentage of personnel assigned to their 1^{st}, 2^{nd} or 3^{rd} preference positions, the percentage of personnel assigned to excellent match positions or the percentage of personnel assigned to positions critically important for their career. This profile of assigned personnel gives firm base of attained objectives comparisons to DM and analysts. Hence, the objective function values should not be the only factor monitored when looking for "very good" solutions. The term "very good" is used as an example to show that the 1^{st} objective should be maximized as much as possible subject to the side constraint rhs values that are within an acceptable range. The DM should be given a set of solutions for the decision.

Large-scale Testing and Experimentation

We tested our model on large-scale problems of different sizes to see how long it takes to solve the main problem with Extended LINGO's IP algorithm. We created a LINGO model that can easily handle models having different numbers of variables. At each problem size level (100*100, 200*200, 400*400,500*500), we ran the main model for a number of times, each time with different uniform random numbers for the coefficients of the three objective functions. We used the Lingo program with the uniform random data generator in Appendix B. The generator generates C_{ij}, D_{ij} and E_{ij}

values and the resulting generated data represents a completely dense network structure. Hence, we can say that the efficiency test results indicate a kind of *worse case* bound for our model. At each problem size level, we obtained the mean value of the elapsed times. We then plotted the problem size (number of variables) vs. solution time (elapsed time) on a diagram (Figure 4.2). The LINGO settings we used are shown below:

Extended LINGO integer solver settings:

Constraint Cuts	Tolerances
Application: *Solver Decides*	Hurdle: *None*
Mixed Cuts: *None*	Optimality: *0.05*
0/1 Cuts: *Knapsack&Gub*	Relative Integrality: $8*10^{-5}$
Storage: *Solver Decides*	Probing: *Solver Decides*
Limit: *None*	Perform Heuristics: *Yes*

General Solver Settings: Generator Memory Limit: *300 Mb.*

Dual Computations: *None*

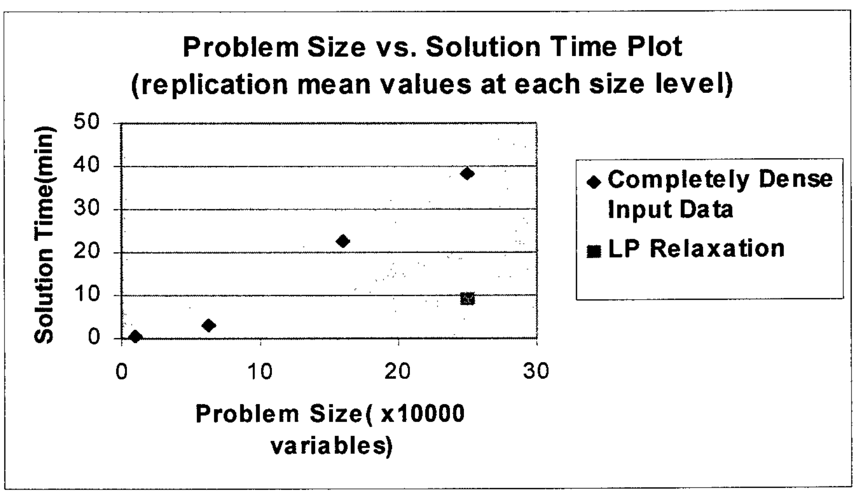

Figure 4.2. Problem Size vs. Solution Time Plot

We did experimental runs on a pc with a 500 Mhz processor and 96 Mb Ram and Windows 98 OS. For many large-scale problems, the ram size is an important determinant of the solution time. The LINGO software's company ran a 500*500 sized sample model on a 600 Mhz processor with 1 Gb ram and it took 2 minutes to get an optimum solution with a completely dense network data structure. It took about 38 minutes on the average to solve the same size problem on our 96 Gb ram/500 Mhz machine. The difference in the solution time can easily be explained by the difference in the ram size. Because of the small ram, windows operating system has to swap data to the ram and hence, it takes much longer to solve. For models having a 500*500 size and more we need at least some hundred Mb ram. Much of the memory is needed by the model generation (e.g. 300 Mb). Some additional memory (e.g. 50 Mb) is also needed for the solver workspace and the operating system.

We then searched for other factors that can significantly effect the solution time. We observed that when the right-hand sides of the side constraints (2^{nd} and 3^{rd} objective functions) approach their upper bound, the solution time increases significantly. We did the runs for this test by using 250*250 size problems with 100% dense data structure (Figure 4.3)

We also wanted to make a computational efficiency comparison between two problems, one having a 100% dense uniformly distributed network data structure and one having a 35% dense uniformly distributed network data structure. We used a problem size of 250*250 variables and tested each problem 5 times. The results corresponded to our expectations that it would take more time to solve a problem with dense data than the problem with sparse data The results are as follows (Figure 4.4).

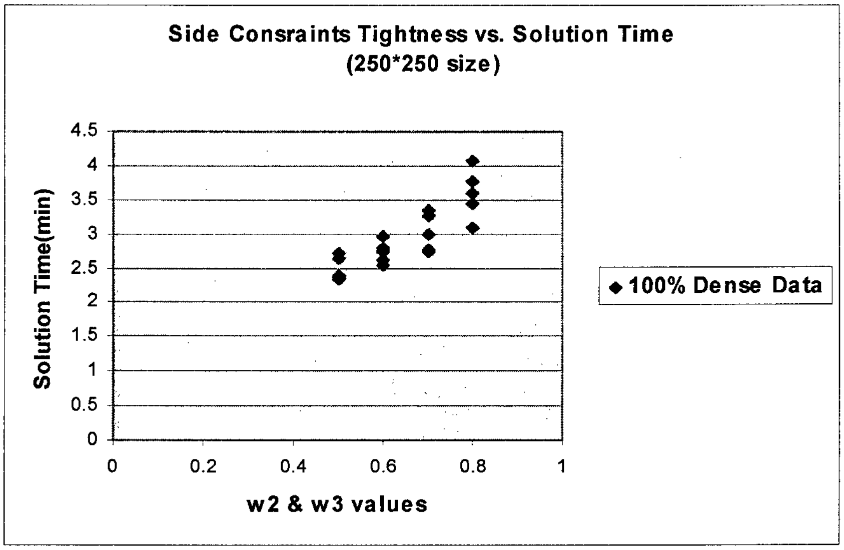

Figure 4.3 Side Constraints Rhs Tightness vs. Solution Time

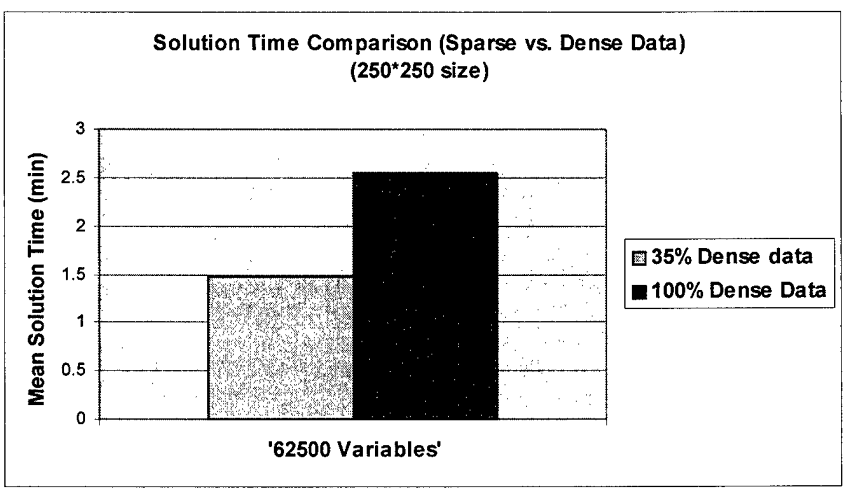

Figure 4.4 Solution Time Comparisons of Problems with Sparse vs. Dense Data

Chapter 5: Conclusions and Recommendations

In this research, we created a PA optimization model that can be integrated into a DSS. Several realistically sized IP problems with notional random data were tested. The mean solution time for different instances of the problem was reasonably short. However, the PA process is not as clearly structured and neatly performed in practice as the PA optimization model suggests. We cannot assume that assignment officials go through the process in lockstep fashion. Generally there is much give-and-take and intuitive thinking among the DM at different hierarchical stages of the PA process. Therefore it is important to note that an optimization-oriented approach to the system alone may not be sufficient in terms of operational feasibility. Nevertheless, this possibility does not negate the fact that the TAF or any large-scale organization can benefit from the use of optimization techniques in its management of the PA process. This can be a first step towards the automation of the assignment system.

Improvement actions in a process can be grouped in three basic action sets.

1. Cancel degenerate, obsolete processes in a system.
2. Add new processes.
3. Increase the capacity and capability of the current processes.

The assignment system of the TAF is more suitable to the second type of improvement action. TAF support its logistics, operations and other main systems by way of automation through databases and various computer applications. The personnel system (especially assignment subsystem), in comparison to other systems, is in need of improvement both by qualitative and quantitative analysis techniques. Making use of applied psychology and statistics for better evaluation and utilization of personnel, developing a robust database to keep detailed track of personnel data and using these data to improve the quality of work and life of personnel are some of the new promising fields of research. There are many studies in these areas, but there is also a great need for the analysis and integration of all of the knowledge gained so far to deal with emerging organizational problems. Indeed, it is a matter of art and science to combine different disciplines to create practical and reliable models.

To obtain robust integrated models in the assignment system, we first need to analyze the system using *systems analysis* because our model will be based on the outcomes of this analysis. We definitely need the help of an improved personnel database. So, we need to develop proper database systems that can easily capture the system process data. For example, we need good objective function coefficients in our optimization model. We have to obtain these data from personnel databases. But we want to be as flexible as possible in extracting any information to perform any qualitative or quantitative analysis. The analysis should be flexible too, because of the changing values of the DM. Before the development of the software or database, we should do feasibility studies (NPRDS, 1989) and domain analysis. Domain analysis is needed to better obtain the knowledge about key aspects, operations, and relationships relevant to a personnel system domain. We recommend that a domain analysis be done on the personnel assignment system. It is much more difficult to understand and replicate a HR system than other systems (e.g. inventory or accounting) because of the highly dynamic and subjective nature of HR. But this does not mean that we should refrain from dealing with HR. Historical facts show us that the more we analyze HR, the more we find facts about HR that help us to improve the quality of HR.

To summarize the conclusions, following results are derived from this study.

- Optimizing PA process can help the automation of the process and decrease the workload of assignment officials. This creates productivity for the organization.

- Qualitative aspects of HR decision-making process should be emphasized to obtain reliable, acceptable models.

- State of the art database methods and equipment should be utilized to capture personnel/positions and other data.

- Valid data retrieval efforts should be supported. Good personnel evaluation and job analysis should be done.

- Strategic HR management should be emphasized in the organization.

- Appropriate quantitative decision-making and analysis (e.g. statistics) methods should be used throughout the whole process.

Further Research Topics: We recommend the following further research topics to extend this study both by diverse and intense studies:

- Need for strategic HR planning, systems analysis, domain analysis, feasibility studies to support the MA/PA system.

- Deterministic optimization can be supported by extending the model to probabilistic area.

- Implementation of different MODM methods such as Tchebycheff Method to obtain more alternative solutions in the multi-objectives solution space can be done.

We can recommend two other MOP methods as shown below:

1) Pareto Optimality Approach.

2) Weighted Sum of Objectives Optimization Approach

Max $\gamma 1(\mathbf{C1X1}) + \gamma 2(\mathbf{C2X2}) + \gamma 3(\mathbf{C3X3})$

s.t. **Ax=b** (supply-demand constraints)

Xi ε {0,1} for all i

γ : weights (priorities for he objectives)

3) Random Alternative Optimum Search within the Feasible Region of Goal Levels

Finding normalized random coefficients:

αij=randuniform [0,1] /$\Sigma\Sigma$ αij

βij is obtained by changing the direction of αij vector by 90 degrees.

Max $\Sigma\Sigma$ $\alpha ij*Xij$
Max $\Sigma\Sigma$ $-\alpha ij*Xij$
Max $\Sigma\Sigma$ $\beta ij*Xij$
Max $\Sigma\Sigma$ $-\beta ij*Xij$
s.t. $Z1>=w1*Z_1^{ub}$
$Z2>=w2*Z_2^{ub}$
$Z3>=w3*Z_3^{ub}$
X_{ij} ε {0,1} for all i and j

Finally, we would like to state that the readers of this thesis should ask the question: Can this methodology be applied to an assignment system? If so, to what extent? We hope to answer this question by preparing a follow-on research paper working with the Turkish Air Force Personnel Assignment Branch and other TAF units. We hope the feedback will contribute to this research.

Appendix A: Vba Source Code and Related Excel Tables for Preprocessing Phase

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	....
P1	92	51	90	83	96	61	87	82	98	56	89	
P2	84	86	86	55	75	73	70	82	89	68	51	
P3	100	92	53	96	75	87	83	79	77	76	68	
P4	76	51	78	91	92	90	79	71	84	81	93	
P5	64	76	62	73	89	50	88	81	83	91	88	
P6	74	55	84	56	73	81	57	97	93	95	71	
P7	86	53	57	89	55	96	77	98	77	80	83	
P8	80	73	79	76	78	53	92	64	85	50	83	
P9	92	100	74	62	53	92	87	73	89	99	71	
P10	88	73	85	88	88	76	81	65	69	87	50	
P11	86	80	72	87	85	76	54	88	84	70	82	
....												
Stdev												
Max(i)												
Mean												
Lb												

Selecting Variable Elimination Degree:

← High lower bound(lb)   Low lower bound →

Commanbutton for the New Data Matrix Computation:

COMPUTE NEW PREPROCESSED DATA

The New Data Matrix:

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	....
P1	92	-1000	90	-1000	-1000	61	87	-1000	-1000	56	-1000	
P2	-1000	86	86	55	75	-1000	70	82	89	-1000	-1000	
P3	-1000	-1000	-1000	-1000	75	87	83	79	77	-1000	-1000	
P4	-1000	-1000	-1000	91	-1000	-1000	79	71	84	81	93	
P5	-1000	76	62	73	-1000	-1000	-1000	-1000	83	-1000	88	
P6	74	-1000	84	-1000	-1000	-1000	-1000	-1000	93	-1000	-1000	
P7	86	-1000	-1000	89	-1000	-1000	-1000	-1000	-1000	80	-1000	
P8	-1000	73	-1000	-1000	78	-1000	-1000	-1000	85	-1000	-1000	
P9	-1000	-1000	74	-1000	-1000	-1000	87	-1000	-1000	-1000	71	
P10	88	-1000	85	88	88	-1000	-1000	-1000	69	-1000	-1000	
P11	86	-1000	-1000	87	-1000	-1000	-1000	-1000	84	70	82	
....												

VBA Code:

```
Dim lb As Double
Dim pos(1 To 20, 1 To 20) As Double     'person-job match degree matrix.
Dim new1(1 To 20, 1 To 20) As Double  'the new person-job matrix formed by the
                                        chosen policy.

Sub main()

  Call readdata
  Call elimination
  Call writing

End Sub

Sub readdata()

   'input person-job match degree matrix
   Sheets("InitData").Select
```

```
    For col = 1 To 20

        For rw = 1 To 20
        pos(rw, col) = Cells(rw + 2, col + 2)
        Next rw

    Next col

End Sub



Sub elimination()

    Sheets("InitData").Select

    For col = 1 To 20
        lb = Cells(26, col + 2) - Cells(29, 10).Value * Cells(23, col + 2).Value

        For rw = 1 To 20

            If pos(rw, col) < lb Then
                new1(rw, col) = -1000
            Else
                new1(rw, col) = pos(rw, col)
            End If
        Next rw

    Next col

End Sub



Sub writing()

'writing the new person-job match degree matrix
    Sheets("write").Select
    For col = 1 To 20

        For rw = 1 To 20
        Cells(rw + 2, col + 2) = new1(rw, col)
        Next rw

    Next col
```

```
End Sub

Sub red()
  Sheets("write").Select

  For col = 1 To 28
    For rw = 1 To 28
      If Cells(rw + 2, col + 2) = -1000 Then
      Cells(rw + 2, col + 2).Select

      Selection.Font.ColorIndex = 3

      End If

    Next rw
  Next col

End Sub
```

Appendix B. Objective Functions Coefficient Data for Lingo Import

The Organizational (1st) Objective Function Coefficients Data Matrix

	J1	J2	J3	J4	J5	J6	J7	J8	J9	.....
P1	84	86	-1000	-1000	-1000	75	-1000	-1000	-1000	-1000
P2	77	-1000	-1000	80	-1000	-1000	-1000	-1000	-1000	88
P3	-1000	-1000	-1000	63	-1000	-1000	-1000	85	-1000	-1000
P4	88	81	-1000	-1000	85	-1000	77	-1000	-1000	88
P5	-1000	-1000	76	-1000	-1000	-1000	90	93	76	87
P6	-1000	-1000	-1000	-1000	-1000	79	-1000	-1000	-1000	82
P7	71	-1000	-1000	65	90	-1000	82	77	-1000	-1000
P8	85	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000	-1000
P9	75	92	-1000	-1000	-1000	-1000	-1000	-1000	-1000	67
......	83	-1000	-1000	86	-1000	-1000	-1000	-1000	79	81

The Career (2nd) Objective Function Coefficients Data Matrix

	J1	J2	J3	J4	J5	J6	J7	J8	J9	.....
P1	5	4	3	1	1	4	1	1	2	1
P2	2	1	1	2	1	1	1	1	1	1
P3	1	1	2	1	1	2	1	5	1	1
P4	3	1	1	4	3	1	3	1	1	3
P5	5	1	4	1	1	1	4	3	2	1
P6	1	5	1	1	1	2	1	1	1	5
P7	2	1	1	2	2	1	2	3	1	1
P8	3	1	2	1	1	5	1	1	2	1
P9	1	2	1	1	4	1	3	2	1	1
.....	2	1	1	2	1	1	1	1	3	3

The Preference (3rd) Objective Function Coefficients Data Matrix

	J1	J2	J3	J4	J5	J6	J7	J8	J9	.....
P1	4	8	9	0	1	6	0	5	1	1
P2	3	0	1	7	1	1	1	1	2	8
P3	0	1	4	0	1	4	0	7	0	1
P4	3	1	6	8	10	0	4	0	1	8
P5	1	8	0	1	1	1	10	10	7	9
P6	0	1	6	9	0	7	1	0	1	1
P7	10	1	1	0	8	1	10	4	9	0
P8	5	0	8	1	10	0	1	1	0	1
P9	10	8	1	7	0	3	6	2	1	2
.....	5	1	0	7	0	1	10	0	4	8

Appendix C. LINGO Code of the Mathematical Program

LINGO FORMULATION OF ASSIGNMENT PROBLEM WITH A *UNIFORM RANDOM DATA GENERATION* FEATURE. (The generator creates a totally dense bipartite network data)

```
MODEL:
SETS:
PERSONNEL/1..500/;
POSITIONS/1..500/;
LINKS(PERSONNEL,POSITIONS):COEFF3,COEFF2,COEFF1,ARC;
ENDSETS

MAX=@SUM(LINKS:COEFF1*ARC);
@FOR(POSITIONS(J):
@SUM(PERSONNEL(I):ARC(I,J))=1);

@FOR(PERSONNEL(I):
@SUM(POSITIONS(J):ARC(I,J))=1);

!Side Constraints with some percent (w2, w3) degredation
@SUM(LINKS:COEFF2*ARC)>=w2*5*@SIZE(POSITIONS);
@SUM(LINKS:COEFF3*ARC)>=w3*10*@SIZE(POSITIONS);

!All integer variables;
@FOR(LINKS:@BIN(ARC));
! Generating random coefficients;
 COEFF1(1,1) = .123456;
@FOR( PERSONNEL( I)| I #GT# 1:
   COEFF1(I,1) = 100*@RAND( COEFF1(I-1,@SIZE(POSITIONS)));
  );
 @FOR( LINKS(I,J)| J #GT# 1:
   COEFF1(I,J) = 100*@RAND( COEFF1(I,J-1));
   );
 COEFF2(1,1) = .3456;
```

```
@FOR( PERSONNEL( I)| I #GT# 1:
    COEFF2(I,1) = 5*@RAND( COEFF2(I-1,@SIZE(POSITIONS)));
  );
 @FOR( LINKS(I,J)| J #GT# 1:
    COEFF2(I,J) = 5*@RAND( COEFF2(I,J-1));
   );
 COEFF3(1,1) = .1236;
@FOR( PERSONNEL( I)| I #GT# 1:
    COEFF3(I,1) = 10*@RAND( COEFF3(I-1,@SIZE(POSITIONS)));
  );
 @FOR( LINKS(I,J)| J #GT# 1:
    COEFF3(I,J) = 10*@RAND( COEFF3(I,J-1));
   );
END
```

LINGO FORMULATION OF ASSIGNMENT PROBLEM WITH *DATA IMPORT AND EXPORT TO EXCEL SPREADSHEET* FEATURE. (We generated sparse bipartite network data with excel)

```
MODEL:
SETS:
PERSONNEL;
POSITIONS;
LINKS(PERSONNEL,POSITIONS):COEFF3,COEFF2,COEFF1,ARC;
ENDSETS

MAX=@SUM(LINKS:COEFF1*ARC);

@FOR(POSITIONS(J):
@SUM(PERSONNEL(I):ARC(I,J))=1);

@FOR(PERSONNEL(I):
@SUM(POSITIONS(J):ARC(I,J))=1);

@SUM(LINKS:COEFF1*ARC)>= w2*5*@SIZE(POSITIONS);
@SUM(LINKS:COEFF2*ARC)>= w3*10*@SIZE(POSITIONS);

@FOR(LINKS:@BIN(ARC));
DATA:
 PERSONNEL, POSITIONS, COEFF3, COEFF2, COEFF1=

   @OLE( 'C:\LINGO6\SAMPLES\ \123-50.XLS',

    'PERSONNEL', 'POSITIONS', 'COEFF3', 'COEFF2', 'COEFF1');

   @OLE( 'C:\LINGO6\SAMPLES\Re123-50.XLS',
    'ARC')= ARC;

ENDDATA

END
```

Appendix D. An Illustrative Assignment Results Exported to Excel Table

	J1	J2	J3	J4	J5	J6	J7	J8	J9	(=1)
P1	0	**1**	0	0	0	0	0	0	0	1
P2	0	0	0	0	0	0	0	0	**1**	1
P3	0	0	0	**1**	0	0	0	0	0	1
P4	0	0	0	0	0	**1**	0	0	0	1
P5	0	0	0	0	0	0	0	**1**	0	1
P6	0	0	0	0	0	0	**1**	0	0	1
P7	0	0	0	0	**1**	0	0	0	0	1
P8	0	0	**1**	0	0	0	0	0	0	1
P9	**1**	0	0	0	0	0	0	0	0	1
(=1)	1	1	1	1	1	1	1	1	1	

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
20-03-2001	Master's Thesis	Jun 2000-March 2001

4. TITLE AND SUBTITLE A MULTI-OBJECTIVE DECISION SUPPORT MODEL FOR THE TURKISH ARMED FORCES PERSONNEL ASSIGNMENT SYSTEM	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR Cimen, Zubeyir, 1st Lieutenant, TUAF	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENS) 2950 P Street, Building 640 WPAFB OH 45433-7765	**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GOR/ENS/01M-06
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Turkish Armed Forces (TAF) assigns more than 25,000 active duty personnel annually. TAF wants to obtain maximum utilization of its personnel by assigning the right person to the right job at the right time. To accomplish this task, decision-makers and personnel assignment staff should consider conflicting multiple objectives that create the widely known problem called "personnel assignment problem".

To assist in this complicated task from a quantitative perspective, a preemptive goal programming approach was used to develop an integer programming (IP) model to capture the multiple objectives flexibly and interactively. A realistic size IP problem with random data was tested for computational efficiency and analysis. The mean solution time for different instances of the problem was reasonably small.

An application of the methodology in an actual assignment decision support system of any large-scale government or non-government organization has a potential to help decision-makers make better use of their personnel.

15. SUBJECT TERMS
Assignment, Personnel Assignment, Manpower Allocation, Mathematical Programming, Preemptive Goal Programming, Integer Programming, Personnel Evaluation and Selection, Bipartite Weighted Network Matching, Large-scale Optimization

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** James T. Moore, Lt Col, USAF (RET)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER**
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18