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THESIS

DEVELOPMENT OF AUTOMATED ASSIGNMENT
MODEL FOR SAILORS IN PAKISTAN NAVY

by

Khan Hasham Bin Siddique

March 1991

Thesis Advisor:

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Development of Automated Assignment Model
for Sailors in Pakistan Navy

by

Khan Hasham Bin Siddique
Lieutenant Commander, Pakistan Navy
B.S., Pakistan Naval Academy, 1981

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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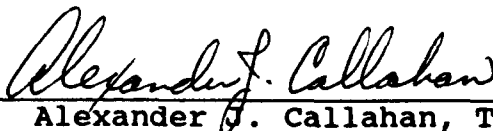
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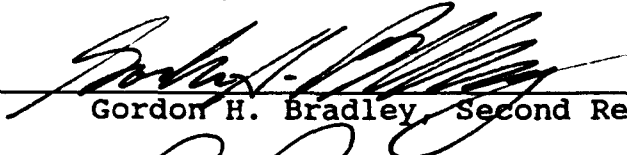


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ABSTRACT

AAMS (Automated Assignment Model for Sailors) is an automated model for the assignment of sailors to billets in the Pakistan Navy. The model will be used in an integrated allocation process. AAMS is a personnel assignment decision support system. It takes into account the personnel attributes such as trade, rate (skill level), current duty station area, date of availability for assignment and individual preference for next duty stations. It has a preprocessor (Fortran program), which compares the personnel attributes with those of job vacancies and develops cost coefficients for various policy criteria. These coefficients are governed by the eligibility rules and the degree of mismatch. A non preemptive technique is employed to solve the network formulation using the GAMS solver. The optimal criteria is based on minimizing the total cost incurred due to mismatches in rates, trades, time of availability, failure to meet personnel preferences and permanent change of station costs.



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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

A. BACKGROUND

The practice of operations research is in its infancy in the Pakistan Navy. There has been an endeavor in the recent past to automate personnel data and inventory control but manual methods still make up the brunt of managerial and organizational work load. The problems are a severe lack of resources and inadequate technical expertise. It is under these limitations that a simple decision support system is proposed to automate the bulk of the assignments of sailors in the Pakistan Navy. The model will specifically address the allocation of sailors, however, with some modification it can be used for officer assignment.

Personnel management in the navy includes the major functional areas of Recruiting, Training, Advancement, Retention, Retirement and Distribution. Most areas are well managed but the distribution process is not. Every month a large number of military personnel are available for new assignments, that is, they are due for rotation from one job to another, for example, ship to shore, ship to training classes, etc. Every rotation results in a vacancy. Additional vacancies are created by people retiring or leaving the service. Drafting orders for assignment of sailors are generally issued in bulk on a monthly or a bimonthly basis. The primary goal of the Navy personnel distribution system is to provide the quality and quantity of personnel to meet the manpower needs of each naval unit so that

it may accomplish its mission. Personnel preferences and individual professional needs are also incorporated to a lesser extent.

B. MANAGERIAL STRUCTURE

Figure 1 on the facing page shows the chain of command and responsibilities as they exist in the Navy. The policy decisions are made at the top. The major work is done at the Staff Officer (SO) level and his subordinate staff. Staff officers are responsible for preparing suggested assignments for the sailors of a particular branch for which they have charge. All drafting orders are issued under the signatures of the drafting authority. Assignment is one of many other jobs done by drafting authority thus, it tends to be neglected.

The Navy has numerous rules and policies that govern the assignments of its sailors. The allocation is made more complex by inventory or job mismatches, permanent change of station costs, individual preference, etc. These goals are often conflicting and present a large number of alternatives. The detailer must first determine all the possible choices and then select the best combination among all the possible alternatives while considering the relative importance of various policy criteria.

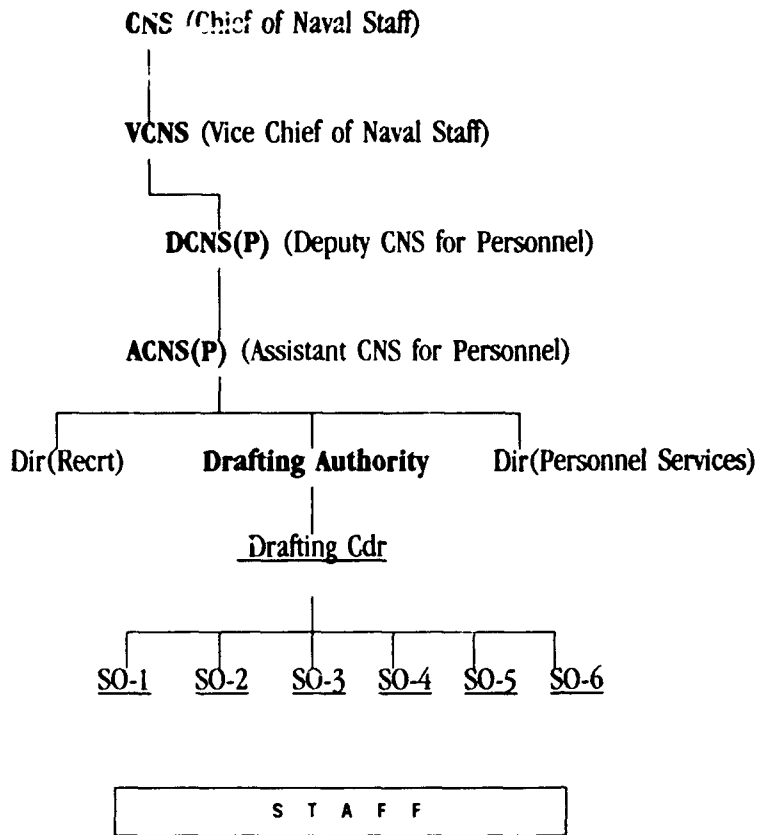


Figure 1
Pakistan Navy Organizational Structure

Currently, person to job matching is entirely a manual process which raises the following issues :

1. Efficiency in terms of time and cost.
2. Ability to identify all possible choices and select the best one.
3. Ability to successfully execute/incorporate all assignment policies.

Therefore, in the interest of reducing the detailers workload and improving policy executions, the model presented here will automate job, personnel

information, and assignment orders. Figure #2 shows a pictorial overview of the problem.

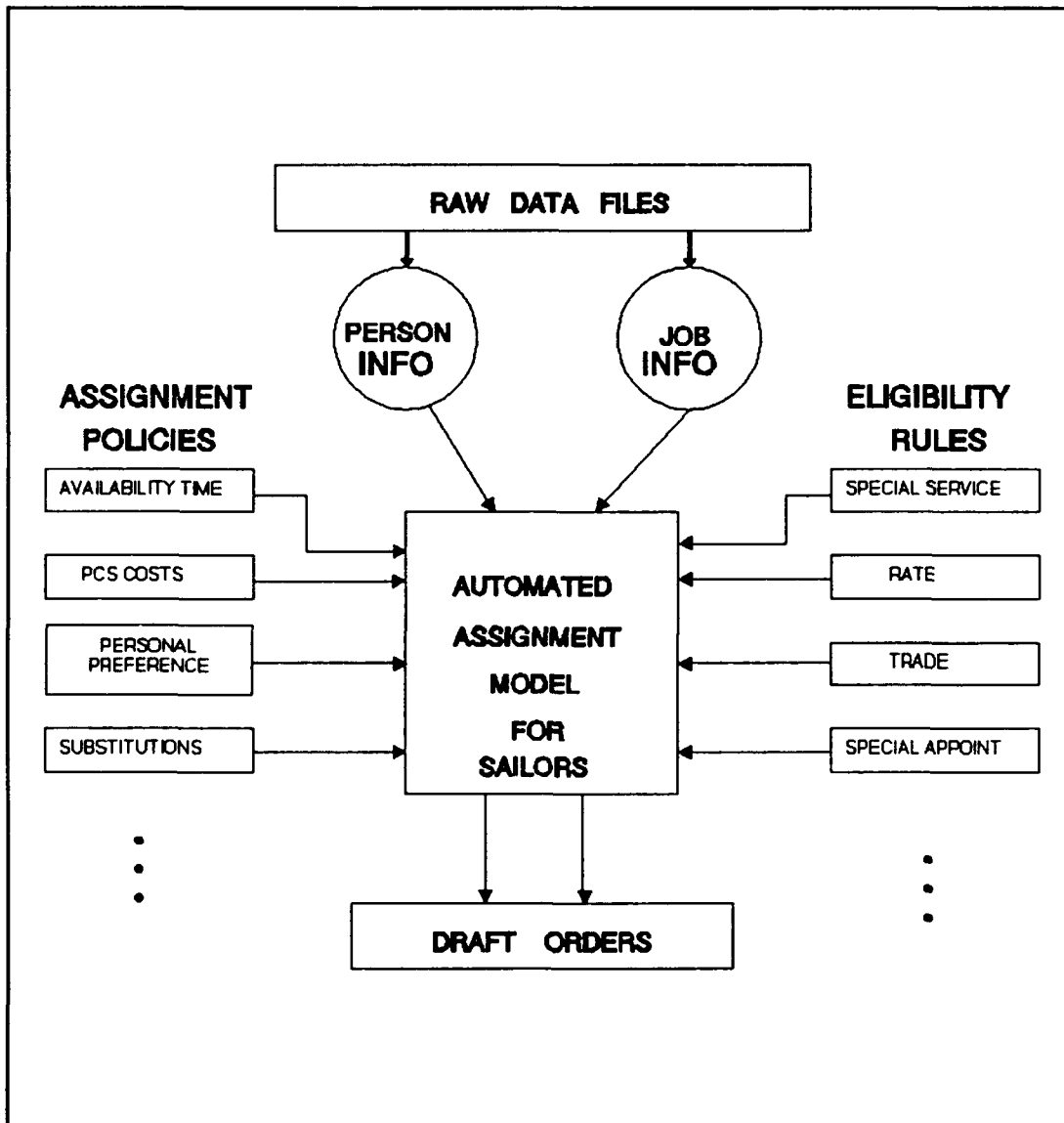


Figure 2

Overview Of Assignment Problem

C. METHODOLOGY

The methodology used in this thesis is to develop a mathematical model of the assignment process. The advantages of using a mathematical model over other techniques as described by Richard E. Trueman¹ are:

1. Relationships between various factors are more easily described and understood than by verbal description.
2. The mathematical relationships may lead to insights into more general problems that appear on the surface unrelated.
3. The problems can be viewed in its entirety, with all variables being considered simultaneously.
4. The model indicates the quantitative data needed to analyze the problem.
5. When considerable computational effort is necessary, such that a computer must be used, mathematical models are essential if a computer program must be written.

¹Quantitative Methods For Making Decisions in Business ch 1 by Richard E. Trueman

II. ORGANIZATION OF SAILORS IN PAKISTAN NAVY

A. TRADE STRUCTURE

A brief discussion of trade structure for sailors in Pakistan Navy is mentioned below. Each recruit is assigned a specific trade upon his entry into service. This assignment establishes a well defined career pattern in terms of training courses and advancements in his trade. The branch or trade assignment is permanent and rarely changed. The set of branches in fact represents the traditional areas of naval jobs.

1. Seamen Branch

a. Gunnery

- (1) Fire Control.
- (2) Armament

b. Torpedo Anti-Submarine

- (1) Sonar
- (2) Torpedo

c. Navigation

- (1) General
- (2) Radar

d. Communications

- (1) Tactical

(2) Radio

2. Technical Branch

a. Marine Engineering

b. Electrical Engineering

(1) General Electricians

(2) Radio/Electronics

c. Ordnance

3. DOMESTIC BRANCH

a. Stores

b. Chefs

c. Stewards

d. Writers

e. Medical

B. SPECIAL SERVICES GROUPS

There are three volunteer services in the navy. The personnel choosing such services are also assigned a trade.

1. Submarine Service

2. Special Services Group (Commandos)

3. Aviation

Only personnel qualified for a specific group can be assigned to the vacancies in that group. The fourth group by default is for sailors who serve aboard surface

ships. A sailor can be assigned a billet only if his service group matches that of the billet.

C. SPECIAL ASSIGNMENTS

There are a few areas where the jobs are highly sensitive, for example, intelligence duties, and chief of naval staff's personal staff. These vacancies are best filled manually after a strict scrutiny of the candidates.

D. RATES (Pay Grades Structure)

The following is the list of rates used to indicate relative seniority of an individual in the service:

<u>RATE</u>	<u>TIME IN THE RATE</u>
Technician (second class)	3 Years
Technician (first class)	3 Years
Leading Technician	4 Years
Petty Officer	4 Years
Chief Petty Officer	3 Years
Fleet Chief Petty Officer	3 Years
Master Chief Petty Officer	3 Years

This thesis addresses the assignment problem of ratings in the Seamen branch since they comprise more than 50% of total allocations at any time. The other branches can be accommodated by modifying the input code.

III. MODEL DEVELOPMENT

The overall objective of this research is to develop an automated assignment model for Pakistan navy sailors (AAMS). It can be used to support an integrated personnel assignment system. In addition, it can quantify multiple conflicting goals, policy planning and assignment executions. The specific objectives of optimization model are as follows:

1. To optimize in order of importance
 - a. Maximize the trade match between persons and jobs.
 - b. Maximize the rate fit between persons and jobs.
 - c. Minimize the permanent change of station costs.
 - d. Minimize the mismatch in time of availability.
 - e. Meet individual preference for duty station.
2. To maximize the number of assignments of sailors, (i.e. all eligible sailors are assigned to vacant jobs no matter what the cost).
3. To reduce detailer work load by providing a tool for quick implementation and analysis of various policy criteria.
4. To obtain integer solutions for large assignment problems.

A complete overview of model in terms of verbal flow, data listing, control structure diagram and information flow is given in Appendix A.

The two major developing stages are:

- a. Input Module
- b. Optimization Module

B. INPUT MODULE

At present personnel records are kept in stacks of paper files and updated manually. The type of personnel and job information required for assignment of sailors is as follows:

1. Name
2. Official Number
3. Rate
4. Trade
5. Date of Availability
6. Current Assignment
7. Personal Preference for duty station
8. Current location
9. Number of dependents
10. Security Clearance
11. End of present Engagement
12. Projected date of Advancement
13. Special Service Group
14. Sea/Shore duty
15. Sensitive Appointments

The raw data in the files is coded using a simple scheme to make it usable for Fortran code which in turn develops input files for the optimization program written in GAMS.

1. Rate and Trade Designation

An eight digit code is used to represent the rate, trade, and special service group of an individual or a job.

- a. First two digits 01 through 07 indicate rate
- b. Second two digits 01 through 08 indicate trade
- c. The fifth character indicates special service group
 - (1) Submarine 'U'
 - (2) Aviation 'A'
 - (3) Commandos 'C'
 - (4) Surface 'S'
- d. The last three digits 001 to 999 are the serial number for each individual available for assignment.

2. Time of Availability

The time of availability for assignment is given by the last two digits of the year and the month.

3. Duty Station

There are five duty station areas for the purpose of calculating PCS costs 1 through 5.

4. Personal Preference

Personal preference is one of the five geographical areas for duty stations. So a typical line in the pertinent data file would be as follows:

```
0102S010      91 03      01      05 02
Navigation    March 1991   Area #1   Preferences
```

Technician-I (surface)

The Fortran program compares personnel and jobs attributes to develop eligibility and cost coefficients as dictated by the rules and policies for allocation.

B. ELIGIBILITY RULES

Given a set of personnel, a list of jobs and a set of eligibility requirements the detailers make a set of assignments. Let

m = # of availabilities

n = # of requisitions

c = # of possible assignment combinations

$$C = m! / (m - n)! \quad \text{for } m > n$$

$$C = n! / (n - m)! \quad \text{for } n > m$$

For any reasonable sized m and n it is quite time consuming to manually evaluate all possible combinations in terms of optimality. The combinations are achieved by matching one by one, every single person to every job. In fact this person to job match forms a network where personnel are like a set of m nodes

each with a supply of 1 and the jobs a set of n demand nodes each with a demand of 1.

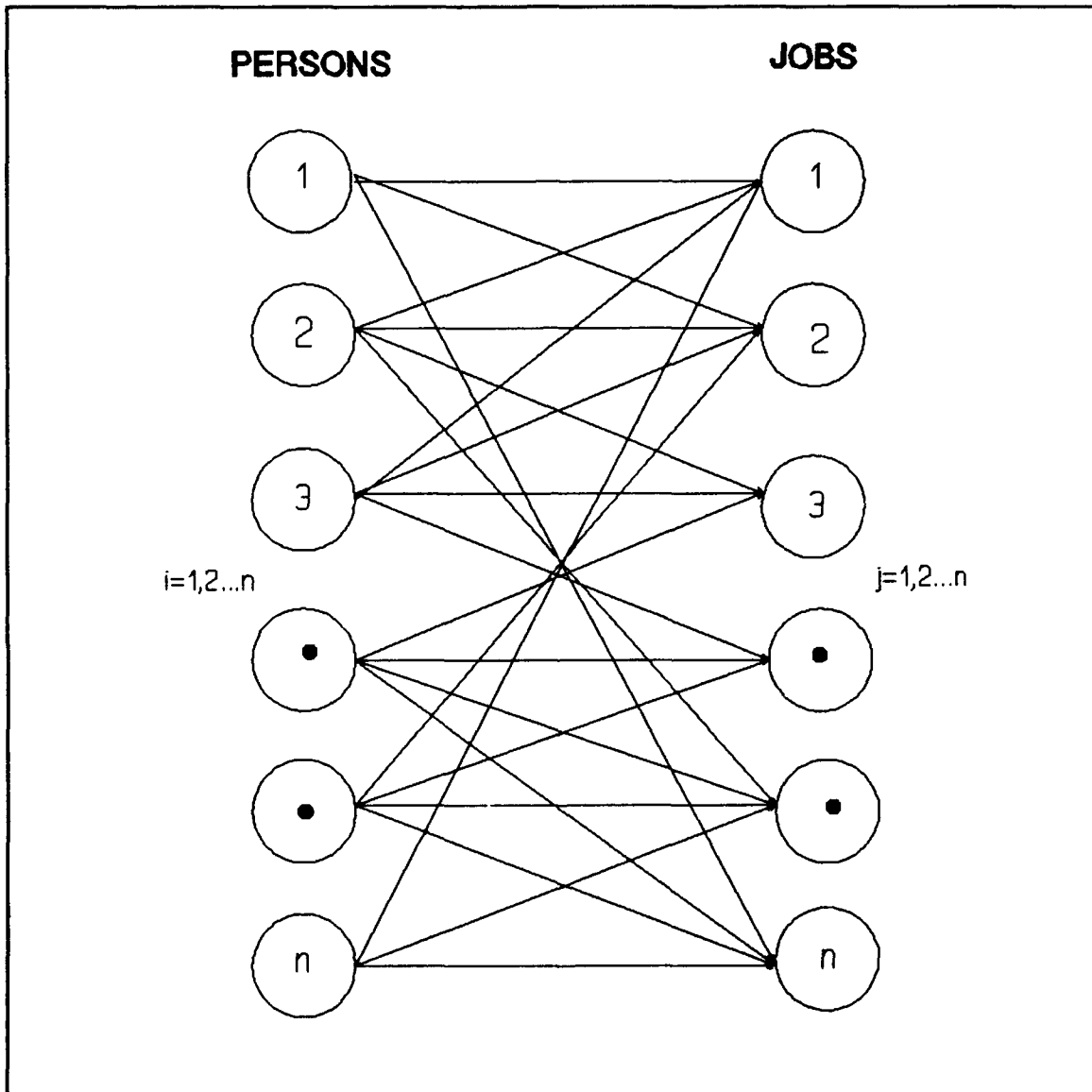


Figure 3

Person To Job Network

Each arc from *i* to *j* represents an eligibility of person *i* to job *j*. However, in a practical scenario the number of arcs is greatly reduced due to eligibility rules.

An eligibility matrix with regard to trades is represented below taking into consideration the structural organization of sailors in Pakistan navy. Trade substitution is not allowed unless the jobs are similar because each line of duty is distinct. Moreover, there is no inter-trade training at any stage of a sailor's career.

	N	R	S	T	F	A	C	C
	A	A	O	O	-	R	O	O
	V	D	N	R	C	M	M	M
	I	A	A	P	O	N	-	-
	G	R	R	D	N	T	T	R
NAVIGATION	Y	Y						
RADAR	Y	Y						
SONAR			Y	Y	Y	Y		
TORPEDO			Y	Y	Y	Y		
FIRE CONTROL			Y	Y	Y	Y		
ARMAMENT			Y	Y	Y	Y		
COMM (TACT)							Y	Y
COMM (RADIO)							Y	Y

Figure 4

Trade Substitution Matrix

Rate substitution is allowed one step higher or lower than the exact match, i.e. a billet for a petty officer is allowed to be filled by a chief petty officer or a leading technician. As a general rule, rate substitutions are permitted within trades only, except when trades are somewhat similar, for example, sonar men may substitute for torpedo men. The eligibility matrix is given below:

	T E C H I I	T E C H I	L E A D I N G	P E T T Y	C H I E F	F I R S T	M A X I M U M
TECH-II	Y	Y					
TECH-I	Y	Y	Y				
L-TECH		Y	Y	Y			
P O			Y	Y	Y		
C P O				Y	Y	Y	
F C P O					Y	Y	Y
M C P O					Y	Y	Y

Figure 5
(Rate Substitution Matrix)

The matrix is somewhat generic in the sense that some logical exceptions are made in the model. The one overriding eligibility rule ensures that the special service group of person matches that of the job.

D. QUANTIFICATION OF POLICIES

Once all eligible arcs are determined, the choice of optimal assignments depends on the cost coefficient on each arc. The assignment policies are incorporated into the network optimization model by converting them into numerical values that fall in a relatively narrow interval. Compressing policies that normally cover a wide range of values into a narrow interval enables us to accomplish two objectives. First, small values keep the model more tractable while still maintaining the proper order of importance. Second, scaling policy values in this way allows implementation of lower priority policies to be improved. For example, it is desirable to obtain an exact trade and rate fit but not at a great expense of PCS cost. So, a little compromise on rate or trade fit at a great reduction of PCS cost is much desirable.

The coefficients quantifying various assignment policies are determined in the following manner:

1. Trade Substitution Cost

As stated in an earlier section, it is undesirable to assign sailors to other than the trade for which they are trained. Exceptions are made for similar trades, i.e. it is fair to assign an armament technician to a fire control billet rather than a communications job. However, there are a number of petty jobs which are indifferent to the trades of individuals. These jobs are particularly meant for junior rates, therefore, assignments for junior rates to other than their own trade are less expensive than those of skilled and specialized senior rates.

Cost of assigning I to J = 0.0 for an exact match

Cost of assigning I to J = 40.0 for mismatch of junior rates

Cost of assigning I to J = 50.0 for mismatch of rates

Cost of assigning I to J = 200.0 for unspecified persons

2. Rate Substitution Cost

Every job requires a minimum level of skill and expertise, this is achieved through experience and training throughout the career. The rate of a sailor usually is a good indicator of this achievement hence it is undesirable to substitute rate. The rate mismatch costs a little less for junior rates than the senior rates.

Cost of assigning I to J = 0.0 for an exact match

Cost of assigning I to J = 25.0 for mismatch of junior rates

Cost of assigning I to J = 40.0 for mismatch of senior rates

Cost of assigning I to J = 200.0 for unspecified persons

3. Permanent Change Of Station Costs

A lot of expense is incurred on ill conceived assignments involving long travelling distances. Permanent change of station cost is an important consideration for assignment. PCS costs are a function of time, distance travelled, and number of dependents. The exact dollar amount of each individual varies over a wide range. The fact remains that the major portion of PCS cost is dependent on the geographical location of current and proposed duty station areas. In essence the duty station areas can be consecutively numbered 1 through 5. These numbers represent the geographical zones throughout Pakistan, the

greater the absolute difference higher the cost of movement. Therefore, it is possible to do without the exact PCS costs; an ordinal ranking suffices.

Cost coefficient with absolute difference of 1 area = 10.0

Cost coefficient with absolute difference of 2 areas = 20.0

Cost coefficient with absolute difference of 3 areas = 25.0

Cost coefficient with absolute difference of 4 areas = 150.0

Cost coefficient for assignment to unspecified job = 200.0

These coefficients ensure that travelling costs are kept to a minimum.

4. Cost For Mismatch In Time Of Availability

It is important to keep all billets occupied at all times, and yet there should be no delays due to waiting for assignment orders. Moreover, it is desirable to have an overlap of one month for smooth transition of jobs. The difference in time of availability is calculated as under

$$\text{DIFFA} = |(12*PY + PM) - (12*JY + JM)| - 1$$

where :

PY is the year of availability of individual

PM is the month of availability of individual

JY is the year of availability of job

JM is the month of availability of job

An overriding eligibility rule makes it highly unattractive to assign a sailor to a job with a mismatch of over 4 months.

Cost of mismatch of 2 months	=	5.0
Cost of mismatch of 3 months	=	10.0
Cost of mismatch of 4 months or over	=	150.0

5. Personal Preference Mismatch Cost

Each individual is allowed two preferences for future assignment of duty station area. The objective is to try and meet the first preference if this is not possible then the second. Optimizing personal preference is least important. It is met only when all other criteria have been optimized. At times it essential for the morale of personnel.

Cost coefficient if neither preference is met	=	10.0
Cost coefficient if second preference is met	=	5.0
Cost coefficient if first preference is met	=	0.0

6. Coefficients For Unspecified Persons & Jobs

Arcs emanating from "unspecified" person node and arcs going into "unspecified" job node carry a fixed large cost for each policy. This makes it highly unattractive for the model to assign an individual to and from these nodes. These assignments are made only after exhausting all eligible candidates. The cost coefficients are as follows:

Cost coefficient for rate or trade	=	200.0
Cost coefficient for PCS move	=	200.0
Cost coefficient for availability	=	200.0
Cost coefficient for preference	=	200.0

Assignments involving "unspecified" persons or jobs are carried through to next stage for future assignments.

E. CHOICE OF IMPLEMENTATION OF POLICIES

The input program used to develop cost coefficients for each arc allows the user to choose the assignment policies he or she wishes to consider. This enables the user to adapt to changes in policies from time to time.

E. OBJECTIVE FUNCTION

The cost or utility function is constructed as a simple additive function. The cost function computes the cost for each arc by iteratively comparing the corresponding attributes of the supply (persons) and demand (jobs) nodes for that arc. First, the rate and trade are compared and the coefficient is assigned. Second, time of availability are considered and the coefficient is assigned. Similarly current duty station area and job location area are compared to ascertain PCS costs. A cost coefficient for personal preference mismatch is added depending upon whether they are met or not. The above mentioned coefficients are calculated for eligible assignments only. The weighing of mismatches has been described in earlier sections. The proper weighing of various policies allows the optimization of all policies by one combined objective function. Therefore, the cost of each arc is a function

$C(i,j) = \text{fn} (\text{rate fit, trade fit, pcs cost, preference mismatch, difference in time of availability})$

Once the coefficients of each attribute mismatch are evaluated, they are simply added together to give a grand total cost for that arc.

$$\text{COST} = [\text{elig cost} + \text{pcs cost} + \text{avail cost} + \text{preference cost}].$$

The actual numeric value of optimal objective function means little in true sense. The prime reason for this is, that the cost coefficients do not represent dollar values, but are a means of ordering various policy criteria. The numerical value is used to compare results of two or more runs.

IV. OPTIMIZATION MODEL

A. APPROACH

Assignment models are a special case of the transportation model. In a classical manner we have n persons to be assigned to n jobs. The goal is to maximize the utility or minimize the cost of objective function. The mathematical statement of the standard form of the assignment model is

MAXIMIZE / MINIMIZE

$$Z = \sum_{i=1}^n \sum_{j=1}^n C_{ij} * X_{ij}$$

Subject to

$$\sum_{j=1}^n a_{ij} * X_{ij} = 1 \quad , \forall \quad i = 1, 2, 3, \dots, n.$$

$$\sum_{i=1}^n a_{ij} * X_{ij} = 1 \quad , \forall \quad j = 1, 2, 3, \dots, n.$$

$$X_{ij} = 0 \text{ or } 1$$

where :

X_{ij} is the decision variable of assigning person i to job j

C_{ij} is the cost coefficient or utility of assigning i th person to j th job

a_{ij} indicates the eligibility

The first set of constraints assures that each person is assigned to one job only and the second set of constraints one job is filled by one and only one person. The coefficient a_{ij} takes on the value of 1 if the i th person is eligible for j th job. The resultant solution is integer valued.

The number of personnel available and requisitions rarely match. Therefore, let m denote the number of personnel and n the number of jobs available for assignment. Furthermore, one or more persons may not be eligible for any job, similarly, some of the jobs may not be suitable for any person. So, the standard assignment model must be modified. A set of $m+1$ variables would have to be created to represent "unspecified" persons and set of $n+1$ jobs, to represent "unspecified" jobs. This means that there will be an increase of $m+n+1$ variables.

Considerable work has been done in the field of assignment problem by various agencies. In 1989 Rosenthal, Rapp et al. (ref 9) presented a paper dealing with marine corps officer assignment during mobilization. The sheer size of the problem; roughly one million variables, makes it prudent to use specialized data structures and specialized network solvers. They use node aggregation, arc screening and a heuristic to generate the arcs in an efficient manner. At present,

the assignment problem in Pakistan navy is fairly manageable without the use of special data structures. The eligibility matrix can be represented as in figure 6.

		Demand						
		(n+1) Jobs						
		J_1	J_2	J_j	J_n	J_{n+1}		
P_1		a_{11}	a_{12}	.	a_{1j}	.	a_{1n}	1
P_2		a_{21}	a_{22}	.	.	.	a_{2n}	1
.		.	.				.	1
Supply (m+1)Persons	P_i	a_{i1}	.		a_{ij}	.	.	1
	1
	P_m	a_{m1}	a_{m2}	.	.	.	a_{mn}	1
	P_{m+1}	1	1	1	1	1	1	1

Figure 6

Eligibility Matrix For Assignments

As stated earlier coefficient $a_{ij} = 1$ implies that i th person is eligible for j th job whereas $a_{ij} = 0$ indicates ineligibility of person i to job j . Let P represents the set of persons and J set of jobs. A person i may or may not be eligible for any job from j_1 to j_n they will always be eligible for "artificial" job J_{n+1} . This implies that $a_{i(n+1)}$ will always be equal to 1. Although a person may be eligible for many jobs including the "artificial" job, but will be assigned to one job only. Conversely, a

job j may or may not be suitable for any person from p_1 to p_m , but will always be suitable for "unspecified" person P_{m+1} . For example, $a_{ij} = 1$ indicates job j is suitable for person i and $a_{ij} = 0$ indicates job j is not suitable for the i th person, $a_{m+1j} = 1$ for all j indicates that job j is always suitable for the "artificial" person, which means that the job can always be left vacant. So, although a job j may be suitable for many persons it will be filled by one person only. The choice of person to job match will depend on the coefficients for decision variables in the objective function. The modified model is then written as:

MAXIMIZE / MINIMIZE

$$Z = \sum_{i=1}^{m+1} \sum_{j=1}^{n+1} C_{ij} * X_{ij}$$

Subject to

$$\sum_{i=1}^{m+1} a_{ij} * X_{ij} = 1 \quad , \forall \quad j = 1, 2, 3, \dots, n.$$

$$\sum_{j=1}^{n+1} a_{ij} * X_{ij} = 1 \quad , \forall \quad i = 1, 2, 3, \dots, m.$$

$$X_{ij} = 0 \text{ or } 1$$

B. NETWORK STRUCTURE FOR ASSIGNMENT OF SAILORS

A network is a collection of nodes and arcs. It is quite obvious that AAMS is a 0-1 integer programming model that can be cast into a network formulation. There are three distinct advantages in using network structure. First, network models are highly solvable. Second, network models, which emphasize diagrams rather than equations, simplify and stimulate communications between specialist and non specialist and third, insights into problem structure and understanding of problem solution are facilitated by the pictorial nature of network models.

The set of nodes (P_1, \dots, P_m) represents the personnel available for assignment and set (J_1, \dots, J_n) is a list of vacancies. The nodes P_{m+1} and J_{n+1} represent unspecified persons and jobs respectively. The arcs between nodes show the decision variables i.e eligibility of person i for a job j . All persons ineligible for any other job are assigned to the unspecified job node, whereas, jobs which remain unfilled are filled by the unspecified person node P_{m+1} .

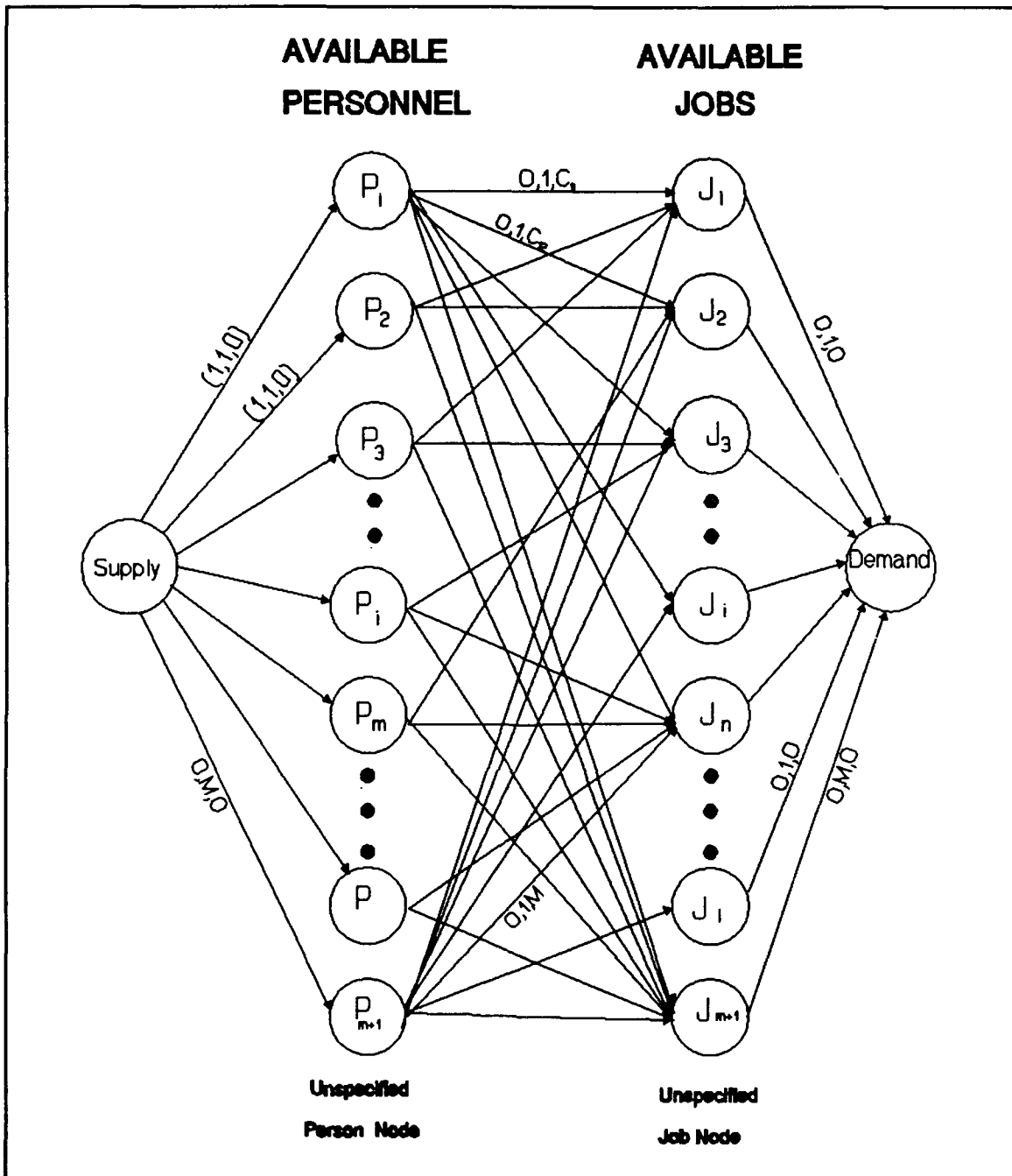


Figure 7

Network Diagram For Assignment Problem

The attributes on each arc are:

1. Lower Bound.

- a. The lower bound on any arc from P_i to J_j is 0.

2. Upper bound.

Since each node represents a specific person or a job so there can be at maximum an assignment of 1 from P_i to J_j . The requirement of an integer solution subject to a lower and an upper bound i.e $0 \leq X_{ij} \leq 1$ leaves us with the alternative of X_{ij} being equal to 0 or 1.

3. Cost Coefficients.

The cost coefficient on any arc X_{ij} is the benefit or cost of assigning person i to job j . There can be any number of arcs from each P to various J nodes. It is the cost on each arc that determines the choice of optimal arcs. The cost coefficients on arcs involving unspecified persons and jobs are given a large value M to make them undesirable as an optimal solution.

C. MULTIPLE CRITERION MODEL

The Pakistan navy assignment model is more complex than the standard problem. The detailers are often faced with conflicting multiple goals. For example, a billet for an MCPO at duty area #1 may be matched exactly by an MCPO currently serving at area #5 at a great cost of travel. A better alternative would be to assign an FCPO (thereby allowing a rate substitution) at no pcs costs.

Such a scenario is a special kind of linear programming called goal programming². It provides a way of striving towards several objectives simultaneously. There are two ways to deal with multiple objectives, the preemptive method and the non preemptive method (weighting method).

1. Preemptive Method

The preemptive method requires a hierarchy of priority levels for the goals, so that the goals of primary importance receive first priority attention, those of secondary importance receive second priority attention, and so forth. In a way it is a sequential elimination procedure, where the overall problem is solved by solving a sequence of linear programs. If the solution of highest priority goals results in a unique solution it is adopted immediately. On the other hand if there are multiple optimal solutions the second stage goals are incorporated to break ties. Let Z^* denote the optimal objective function value of a stage, this is used as a constraint in the following stage to ensure that any lower priority solution never violates optimality of a higher priority stage. The optimal solution may however, be quite different. Mathematically it is represented as:

² Introduction to Operations Research, Ch 8, Formulating Linear Programming models, including Goal Programming, by Hillier and Lieberman.

MINIMIZE / MAXIMIZE

$$z^k = \sum_{i=1}^{m+1} \sum_{j=1}^{n+1} c^k_{ij} * X_{ij}$$

Subject to:

$$\sum_{i=1}^{m+1} a_{ij} * X_{ij} = 1 \quad , \quad \forall j = 1, 2, 3, \dots, n$$

$$\sum_{j=1}^{n+1} a_{ij} * X_{ij} = 1 \quad , \quad \forall i = 1, 2, 3, \dots, m$$

$$\sum_{i=1}^{m+1} \sum_{j=1}^{n+1} c^{k-1}_{ij} * X_{ij} = z^{k-1} \quad k > 1$$

$$X_{ij} = 0 \text{ or } 1$$

The preemptive technique focuses on achieving the first priority goals, subsequent goals are considered only when multiple optimal solutions exist. The disadvantage of this method lies in ranking the objectives, and the assumption that an ordinal ranking of goals is sufficient to describe the relationship among the goals. It limits the decision maker's ability to observe trade offs amongst various policy criteria.

2. Non Preemptive Method

The non preemptive or weighting method allows the solution to be obtained in a single run. The decision maker first ascertains the trade offs among the objectives. The penalties for deviations are aggregated into a composite objective function. The cost coefficients are dependent upon the degree of deviation from the most desirable condition. The weighting method has the advantage of demonstrating policy trade offs and to be able to optimize all policy criteria in a single run. It is of vital importance that the weights are carefully chosen. The weights are constructed so that assignment policies are optimized in the order of priority. When searching for an optimal solution, an improvement in first policy is more important than the second policy which is more important than the third and so on. A lower policy usually breaks the ties between two or more solutions for the next higher policy. The weighting method, therefore, does not always give strict preemptive solutions. The benefits of computational simplicity outweigh the difficulties in using preemptive method. This technique has been employed for the model developed for AAMS. The mathematical representation is as below:

MINIMIZE

$$Z = \sum_{i=1}^{m+1} \sum_{j=1}^{n+1} \left(\sum_{k=1}^4 C_{ijk} * W_k \right) * X_{ij}$$

Subject to

$$\sum_{i=1}^{m+1} a_{ij} * X_{ij} = 1 \quad , \quad \forall \quad j = 1, 2, 3 \dots, n+1$$

$$\sum_{j=1}^{n+1} a_{ij} * X_{ij} = 1 \quad , \quad \forall \quad i = 1, 2, 3 \dots, m+1$$

X_{ij} is 0 or 1

Where :

X_{ij} is the decision variable

C_{ijk} is the cost coefficient for assigning i th person to j th job for k th policy criterion

W_k is the choice for implementing k th policy criterion.

Z is the objective function value.

a_{ij} is the eligibility of i th person for j th job.

The last two sets of constraints ensure that only one person is assigned to only one job. Now, if there is an inventory mismatch, the resultant solution will be infeasible. To alleviate this problem, the above mentioned constraints are relaxed for the "unspecified jobs and persons nodes in the actual implementation of the model. This scheme works because, the constraint supply equal demand, is always satisfied implicitly in the model. In fact, there is a dynamic supply of

personnel on the "unspecified" person node, bounded above by the maximum number of jobs to be filled. Therefore, all the jobs left vacant due to unsuitability, shortage of personnel or sub optimality are filled by the "artificial" persons from "unspecified" persons node. Similarly, the "unspecified" job node gets filled by personnel, unsuitable, sub optimal, or in excess of demand. In the worst case, all available personnel will be assigned to the "unspecified" job node.

V. COMPUTER IMPLEMENTATION AND RESULTS

A. GAMS IMPLEMENTATION

The model was written in a FORTRAN based language GAMS. This package was used because:

1. It is a high level language that allows a compact representation of large and complex models.
2. Documentation is crucial to the usefulness of mathematical models, in GAMS this is embedded within model itself and can be added elsewhere also.
3. Algebraic relationships can be stated unambiguously.
4. Changes to the model can be made with relative ease.

The above mentioned features along with its portability and simple syntax made it the logical choice, considering the lack of expertise of would be users of the model.

The use of \$ operator in exception handling in equations and other parameters ensures efficiency in generation of the problem. The sparsity of the problem is exploited by the way the model is written and formulated. The model also handles interactive choices of policy implementation without requiring any change. The Include statement has allowed the input data to be imported directly into the model.

The formulation of the model in a network structure enables it be solved as an ordinary LP and yet have integer solutions. Therefore, the MINOS solver is used to obtain optimal solutions, it is not necessary to use the Zero One Optimization Method (ZOOM) to obtain integer results. The optimal solution is achieved with relatively few iterations. The assignment problem of sailors in Pakistan navy at present, is a medium sized problem with any where from 150 to 200 assignments per fortnight.

B. RESULTS

A FORTRAN program preprocesses the personnel and job information to develop requisite files for optimization model. The program was compiled on AMDAHL-5990 at the Naval Postgraduate School using the CP / CMS time sharing system. FORTRAN compiler VS2 was used for compilation. Although real data was not available, a number of trial runs, of various sizes, were carried out using test data. The statistics presented here are based on results achieved on a problem of 150 avails and 150 vacancies.

1. The model successfully assigned 100% of all eligible personnel, ineligible personnel were assigned to "artificial" jobs, while, Unmatched jobs were filled up by "artificial" persons. The actual number of assignments involving artificial persons or jobs depends on the attributes of avails and vacancies.

2. The computational results achieved were quite good. Some of the more significant are as follows:

a. Compilation time.	3.32 sec
b. Generation time	1.38 sec
c. Execution time	1.48 sec
d. # of non zero elements	2583
e. # of single equations	301
f. # of iterations to obtain optimal solution	457

3. The conceptual model also ran successfully on an IBM 386-sx machine.

It is intended eventually, to be able to run this model on an AT-386 computer equipped with a mathematics coprocessor.

VI. CONCLUSION AND RECOMMENDATION

The personnel assignment system in the Pakistan navy employs a decision making process which takes into account personnel information and policy guidelines. The model presented in this thesis provides a theoretical basis to quantify various policies. The advantage of AAMS is its ability to simultaneously consider all assignment policies while searching for optimum sets of assignments. Since the optimization routine implicitly tries to maximize the number of assignments within eligibility limitations, the final solution may contain a nomination that may seem at odds with a particular assignment policy. For instance, minimizing PCS cost is the top priority among all the policies. Further, suppose that the optimal solution generated by AAMS requires a long distance move. Considered in isolation, this assignment may seem sub optimal, however, it is the overall PCS cost of the entire set of assignments which is minimized in that run. AAMS would also aid the decision makers in evaluating the impact of existing and proposed policies.

The overall approach for modeling the assignment system is a network formulation. This structure is efficient in solving large scale integer problems. The requirements of an exact match in special service groups, trade and rate eligibility restrictions are constraints. The utility or benefits of successful implementation of various policies is considered as the objective function.

With the implementation of AAMS the workload of detailers would be cut from days to a few hours. The savings in time, makes it possible to make a variety of runs with various policy criteria, to estimate the cost or benefits of alternatives. The alternatives and contingency plans are an important feature of military decision making. Personnel who do not get nominated can still be adjusted through manual process. The extra time afforded, can be used by detailers in tending to other important jobs that they are required to do.

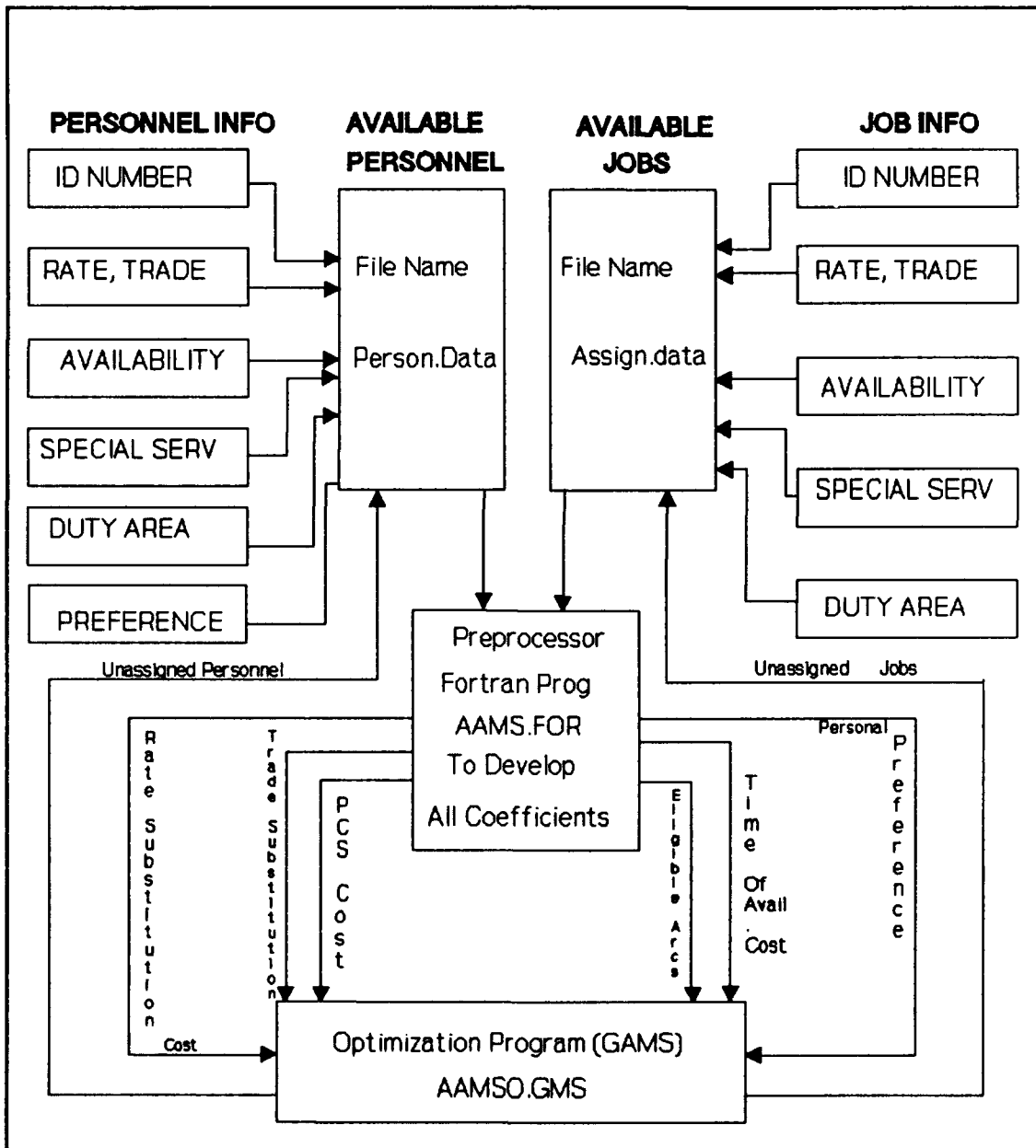
Improvement in assignment decision making would improve the overall efficiency of the force. Specifically, maximizing fill of billets would improve manning state, the rate and trade fit would considerably improve professional standards and training.

A. RECOMMENDATIONS

There has been a deliberate effort to keep the approach simple for obvious reasons. Improvements would be made as the situation warrants.

1. The scope of assignment model should be widened at a later stage to encompass all branches of the navy.
2. A detailed analysis should be done to quantify any benefits achieved through the automation of assignment process using real data.
3. The weighing of various policy criteria may have to be studied further to determine an accurate relationship between trade offs.
4. Should the current problem grow in size significantly, consideration should be given to employ a specialized network solver. Bradley, Brown and Graves (ref 10) pioneered with GNET solver which has been widely used, other variations include XNET and ENET; used in the marine corps assignment model.

APPENDIX A
INFORMATION FLOW



DATA LISTING

<u>Variable Name</u>	<u>Type</u>	<u>Shape</u>	<u>Remarks</u>
M	Integer	Scalar	# of Personnel available for assignment
N	Integer	Scalar	# of jobs available for assignment
Elig(*,*)	Real	Matrix	Eligibility of person I for job J
Cost(*,*)	Real	Matrix	Cost of Trade & Rate Mismatch
Cost1(*,*)	Real	Matrix	Cost of Avail mismatch
Cost2(*,*)	Real	Matrix	Cost of PCS
Cost3(*,*)	Real	Matrix	Cost of Preference mismatch
DINPUT	---	----	Subroutine for Writing Files for optimization model
PS	Character * 8		Personnel rate, trade, and special service designator
JS	Character * 8		Job designator
PA	integer	Scalar	Personnel duty Area designator
JA	integer	Scalar	Job area designator
PRF 1 & 2	integer	scalar	Personal preferences
PY & PM	integer	scalar	Personnel year & month of availability
JY & JM	integer	scalar	Jobs year & month of availability

VERBAL FLOW

M Total # of personnel available for assignments.

N Total # of jobs vacancies.

{ Do for all personnel attributes

 Read personnel attributes

 { Do for all jobs

 Read job attributes

 Compare special service groups

 { If exact match occurs then

 Compare Rate & Trade designators

 Set Eligibility = 1.0

 Set pertinent cost coefficient for eligibility

 Compare time of availability

 Set requisite cost coefficient for mismatch

 Compare duty station areas

 Set PCS cost coefficients

 Compare Personal preferences

 Set pref cost coefficient

 } Else

 Set Eligibility = 0.0

 End if

 Set eligibility = 1.0 for unspecified job

 Set fixed cost penalties for all policies

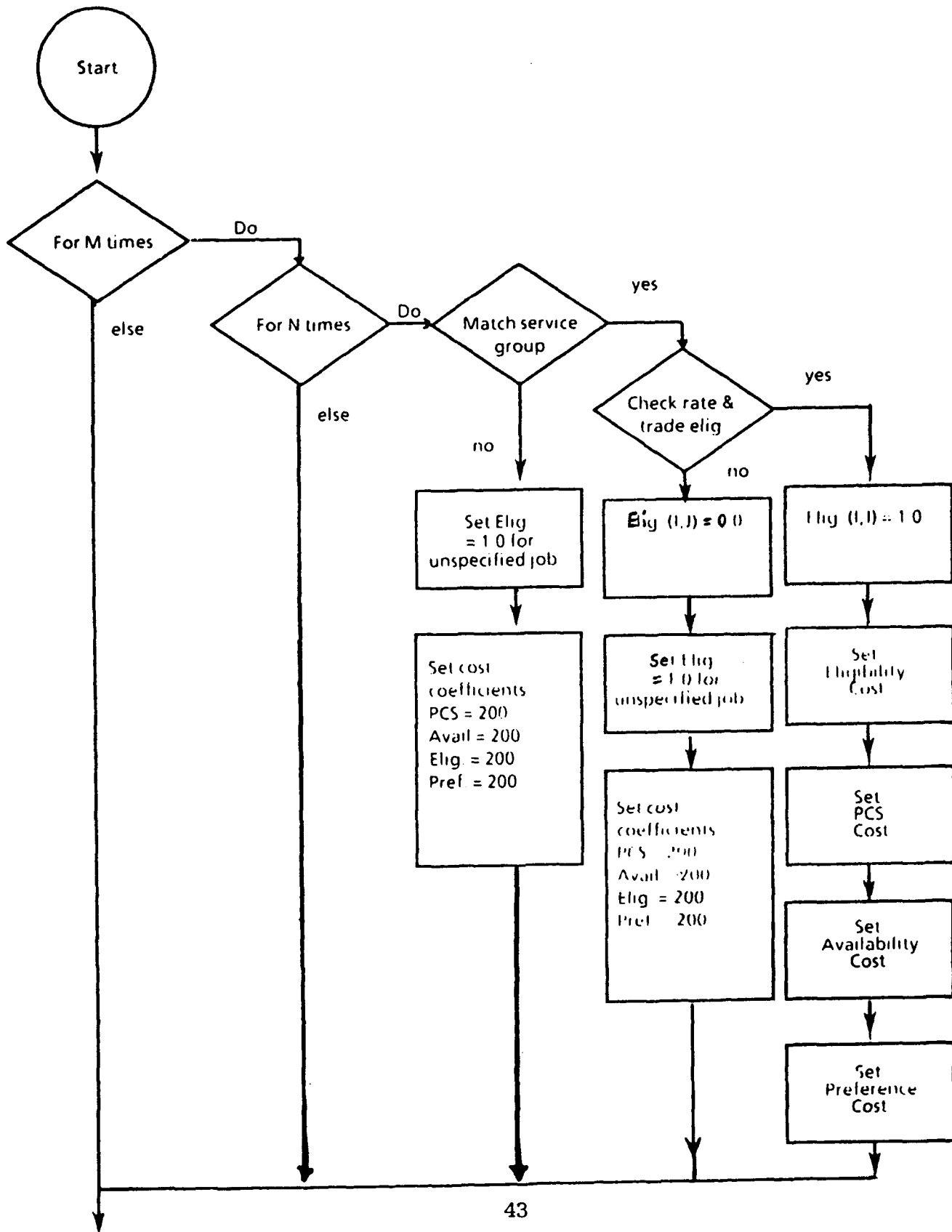
 Write results into files

 } Continue

} continue

STOP

CONTROL STRUCTURE DIAGRAM



APPENDIX B

PREPROCESSING PROGRAM

PROGRAM AAMS

- * BY: LT CDR KHAN HASHAM BIN SIDDIQUE
- * NAVAL POST GRADUATE SCHOOL
- * MONTEREY CALIFORNIA.

- * THIS PROGRAM READS THE PERSONNEL AND JOBS INFORMATION
- * FROM THE RESPECTIVE INPUT FILES. THE DATA IS THEN USED TO
- * DEVELOP AN ELIGIBILITY MATRIX AND COST MATRICES FOR VARIOUS
- * POLICY CRITERIA. SUBROUTINE DINPUT WRITES THE DEVELOPED
- * OUTPUT INTO FILES TO BE LATER USED BY THE OPTIMISATION
- * MODEL. THE CODING KEYS USED IN THE PROGRAM ARE GIVEN BELOW.

* CODING KEYS

*

-
- * FIRST TWO DIGITS INDICATE RATE (PAY GRADE)

- * TECHNICIAN (2ND CLASS) '01'
- * TECHNICIAN (1ST CLASS) '02'
- * LEADING TECHNICIAN '03'
- * PETTY OFFICER '04'
- * CHIEF PETTY OFFICER '05'
- * FLEET CHIEF PETTY OFFICER '06'
- * MASTER CHIEF PETTY OFFICER '07'

*-----

- * SECOND TWO DIGITS INDICATE TRADE (SKILL)

- * NAVIGATION (GENERAL) '01'
- * RADAR MEN '02'
- * SONAR MEN '03'
- * TORPEDO MEN '04'
- * FIRE CONTROL '05'
- * ARMAMENT '06'
- * COMMUNICATIONS (TACTICAL) '07'
- * COMMUNICATIONS (RADIO) '08'

*-----

- * THE FIFTH CHARACTER INDICATES THE SERVICE GROUP

- * ELIGIBLE FOR SURFACE DUTIES S

- * ELIGIBLE FOR SUBMARINE SERVICE ONLY U
- * ELIGIBLE FOR AVIATION SERVICE ONLY A
- * ELIGIBLE FOR SSG(N) C

*-----
*

* LAST THREE DIGITS INDICATE SERIAL NUMBER

*-----

* VARIABLE DECLARATION

*-----

PARAMETER (MAXMEN = 300)
PARAMETER (MAXJOB = 300)
COMMON/OPTION/ ELIG,COST,COST1,COST2,COST3,
+M,N,W1,W2,W3,W4
REAL ELIG(MAXMEN,MAXJOB),COST(MAXMEN,MAXJOB)
+, COST1(MAXMEN,MAXJOB),COST2(MAXMEN,MAXJOB)
+, COST3(MAXMEN,MAXJOB),W1,W2,W3,W4
INTEGER M,N ,PY,PM,JY,JM,PA,JA,PPR1,PPR2,DIFF,DIFFA
CHARACTER*8 MEN,JOBS
CHARACTER*4 PS,JS
CHARACTER*1 ANS

* VARIABLE KEY

*-----

- * ELIG(*,*) ... ELIGIBILITY OF PERSON I TO JOB J
- * COST(*,*) ... COST COEFFICIENT OF TRADE OR RATE MISMATCH
* BETWEEN PERSON I AND JOB J
- * COST1(*,*) ... COST COEFFICIENT OF AVAILABILITY MISMATCH
* BETWEEN PERSON I AND JOB J
- * COST2(*,*) ... COST COEFFICIENT OF PCS COST OF PERSON I TO
* JOB J
- * COST3(*,*) ... COST COEFFICIENT OF PREFERENCE MISMATCH
* BETWEEN PERSON I AND JOB J
- * PY , PM ... YEAR AND MONTH OF AVAILABILITY OF PERSON
- * JY , JM ... YEAR AND MONTH OF AVAILABILITY OF JOB
- * PA ... PRESENT ASSIGNMENT AREA OF PERSON
- * JA ... LOCATION AREA OF JOB
- * PPR1 ... FIRST PREFERENCE FOR ASSIGNMENT AREA
- * PPR2 ... SECOND PREFERENCE FOR ASSIGNMENT AREA
- * PS ... RATE AND TRADE INDICATOR OF PERSON
- * JS ... RATE AND TRADE INDICATOR OF JOB
- * M ... TOTAL NUMBER OF MEN AVAILABLE FOR ALLOCATION

* N ... TOTAL NUMBER OF JOBS AVAILABLE FOR ALLOCATION

*

* INPUT DATA FILES

CALL EXCMS ('FILEDEF 9 DISK PERSON DATA A1')
CALL EXCMS ('FILEDEF 10 DISK ASSIGN DATA A1')

* INTERACTIVE CHOICE FOR MEMBER OF MEN AND JOBS

PRINT *, 'PLEASE INPUT # OF MEN AVAILABLE FOR ALLOCATION',
+ 'IT SHOULD BE AN INTEGER'
READ *, M
IF (M .LT. 1) THEN
PRINT*, 'THE FIGURE ENTERED AS NUMBER OF MEN IS INVALID'
+ ', THE PROGRAM HAS HALTED'
STOP
END IF
PRINT *, 'PLEASE INPUT # OF JOBS AVAILABLE FOR'
+ ', ALLOCATION IT SHOULD BE AN INTEGER'
READ *, N
IF (N .LT. 1) THEN
PRINT*, 'THE FIGURE ENTERED AS NUMBER OF JOBS IS'
+ ', INVALID THE PROGRAM HAS HALTED'
STOP
END IF

C INTERACTIVE OPTION FOR CHOICE OF POLICIES

PRINT*, 'DO YOU WANT ALL POLICIES TO BE IMPLEMENTED ?'
+ ', IF YES PRESS Y IF NO PRESS N '
READ*, ANS
IF (ANS .NE. 'Y'.AND. ANS .NE. 'N') THEN
PRINT*, 'ILLEGAL CHARACTER ENTERED PROGRAM HAS HALTED'
STOP
ELSE IF (ANS .EQ. 'Y') THEN

W1=1.0
W2=1.0
W3=1.0
W4=1.0
ELSE
PRINT*, 'DO YOU WANT TRADE & RATE SUBSTITUTION POLICY'
+ ', BE IMPLEMENTED ? PRESS Y TO SAY YES OR ANY OTHER KEY'
+ ', TO SAY NO'
READ*, ANS
IF (ANS .EQ. 'Y') THEN

```

      W1=1.0
      END IF
      PRINT*,'DO YOU WANT AVAILABILITY MISMATCH POLICY BE',
+ 'IMPLEMENTED ? PRESS Y TO SAY YES OR ANY OTHER KEY'
+ ', TO SAY NO'
      READ*,ANS
      IF (ANS .EQ. 'Y')THEN
        W2=1.0
      END IF
      PRINT*,'DO YOU WANT PCS COST CONSIDERATION POLICY BE'
+ ',IMPLEMENTED ? PRESS Y TO SAY YES OR ANY OTHER KEY'
+ ',TO SAY NO'
      READ*,ANS
      IF (ANS .EQ. 'Y')THEN
        W3=1.0
      END IF
      PRINT*,'DO YOU WANT PREFERANCE MISMATCH COST TO BE'
+ ',IMPLEMENTED ? PRESS Y TO SAY YES OR ANY OTHER KEY'
+ ', TO SAY NO'
      READ*,ANS
      IF (ANS .EQ.'Y')THEN
        W4=1.0
      END IF
      END IF

```

C INITIALISE ELIGIBILITY AND COST MATRICES

```

      DO 1 I=1,M
      DO 1 J=1,N
      ELIG(I,J) = 0.0
      COST(I,J) = 0.0
      COST1(I,J) = 0.0
      COST2(I,J) = 0.0
      COST3(I,J) = 0.0

```

1 CONTINUE

C START READING INPUT FILES

```

      DO 3 I=1,M
      READ (9,*) MEN ,PY,PM,PA,PPR1,PPR2
      PS = MEN (1:4)
      DO 2 J=1,N
      READ (10,*) JOBS,JY,JM,JA
      JS = JOBS (1:4)
      IF (MEN(5:5) .EQ. JOBS(5:5)) THEN
      IF (PS .EQ. JS) THEN
      ELIG(I,J) =1.0

```


GOTO 2
END IF

C.....

C**** NAVIGATION ****

```
IF (PS .EQ. '0101') THEN
  IF (JS .EQ. '0102') THEN
    COST (I,J) =25.0
    ELIG(I,J) =1.0
  ELSE IF (JS .EQ. '0102' .OR. JS .EQ. '0103'
+   .OR. JS .EQ.'0104' .OR. JS .EQ. '0105'
+   .OR. JS .EQ. '0106') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF

ELSE IF (PS .EQ. '0201') THEN
  IF (JS .EQ. '0101' .OR. JS .EQ. '0301') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0202') THEN
    ELIG (I,J) =1.0
    COST (I,J) = 40.0
  END IF

ELSE IF (PS .EQ. '0301') THEN
  IF (JS .EQ. '0201' .OR. JS .EQ. '0401') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0302') THEN
    ELIG (I,J) =1.0
    COST (I,J) = 40.0
  END IF

ELSE IF (PS .EQ. '0401') THEN
  IF (JS .EQ. '0301' .OR. JS .EQ. '0501')THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF

ELSE IF (PS .EQ. '0501') THEN
  IF (JS .EQ. '0601' .OR. JS .EQ. '0701') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
```

```
END IF
ELSE IF (PS .EQ. '0601') THEN
  IF (JS .EQ. '0501' .OR. JS .EQ. '0701') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0701') THEN
  IF (JS .EQ. '0601' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
END IF
```

C

***** R A D A R *****

```
IF (PS .EQ. '0102') THEN
  IF (JS .EQ. '0202' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0101') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0202') THEN
  IF (JS .EQ. '0102' .OR. JS .EQ. '0302') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0102') THEN
    ELIG(I,J) =1.0
    COST(I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0302') THEN
  IF (JS .EQ. '0202' .OR. JS .EQ. '0402') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0402') THEN
  IF (JS .EQ. '0302' .OR. JS .EQ. '0502') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
```

END IF

```
ELSE IF (PS .EQ. '0502') THEN
  IF (JS .EQ. '0602' .OR. JS .EQ. '0702') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0602') THEN
  IF (JS .EQ. '0502' .OR. JS .EQ. '0702') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0702') THEN
  IF (JS .EQ. '0602' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
END IF
```

C

***** S O N A R *****

```
IF (PS .EQ. '0103') THEN
  IF (JS .EQ. '0203') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0104' .OR. JS .EQ.
+   '0105' .OR. JS .EQ. '0106') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0203') THEN
  IF (JS .EQ. '0103' .OR. JS .EQ. '0303') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0204') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0303') THEN
  IF (JS .EQ. '0203' .OR. JS .EQ. '0403') THEN
```

```

    ELIG(I,J) = 1.0
    COST (I,J) =25.0
ELSE IF (JS .EQ. '0304') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
END IF
ELSE IF (PS .EQ. '0403') THEN
    IF (JS .EQ. '0303' .OR. JS .EQ. '0503')THEN
        ELIG(I,J) = 1.0
        COST (I,J) =25.0
    END IF
ELSE IF (PS .EQ. '0503') THEN
    IF (JS .EQ. '0603' .OR. JS .EQ. '0703') THEN
        ELIG(I,J) = 1.0
        COST (I,J) =25.0
    END IF
ELSE IF (PS .EQ. '0603') THEN
    IF (JS .EQ. '0503' .OR. JS .EQ. '0703') THEN
        ELIG(I,J) = 1.0
        COST (I,J) =25.0
    END IF
ELSE IF (PS .EQ. '0703') THEN
    IF (JS .EQ. '0603' ) THEN
        ELIG(I,J) = 1.0
        COST (I,J) =25.0
    ELSE IF (JS .EQ. '0704') THEN
        ELIG (I,J) =1.0
        COST (I,J) =40.0
    END IF
END IF

```

C
******* T O R P E D O *******

```

    IF (PS .EQ. '0104') THEN
        IF (JS .EQ. '0204') THEN
            ELIG(I,J) = 1.0
            COST (I,J) =25.0
        ELSE IF (JS .EQ. '0103' .OR. JS .EQ.
+ '0105' .OR. JS .EQ. '0106') THEN
            ELIG (I,J) =1.0
            COST (I,J) =40.0

```

END IF

```
ELSE IF (PS .EQ. '0204') THEN
  IF (JS .EQ. '0104' .OR. JS .EQ. '0304') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0203') THEN
    ELIG (I,J) = 1.0
    COST (I,J) = 40.0
  END IF
```

```
ELSE IF (PS .EQ. '0304') THEN
  IF (JS .EQ. '0204' .OR. JS .EQ. '0404') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0303') THEN
    ELIG (I,J) = 1.0
    COST (I,J) = 40.0
  END IF
```

```
ELSE IF (PS .EQ. '0404') THEN
  IF (JS .EQ. '0304' .OR. JS .EQ. '0504') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0504') THEN
  IF (JS .EQ. '0604' .OR. JS .EQ. '0704') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0604') THEN
  IF (JS .EQ. '0504' .OR. JS .EQ. '0704') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0704') THEN
  IF (JS .EQ. '0604' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0703') THEN
    ELIG (I,J) = 1.0
```

```
    COST (I,J) = 40.0
  END IF
END IF
```

C

***** FIRE CONTROL *****

```
  IF (PS .EQ. '0105') THEN
    IF (JS .EQ. '0205') THEN
      ELIG(I,J) = 1.0
      COST (I,J) =25.0
    ELSE IF (JS .EQ. '0103' .OR. JS .EQ.
+     '0104' .OR. JS .EQ. '0106') THEN
      ELIG (I,J) =1.0
      COST (I,J) =40.0
    END IF

    ELSE IF (PS .EQ. '0205') THEN
      IF (JS .EQ. '0105' .OR. JS .EQ. '0305') THEN
        ELIG(I,J) = 1.0
        COST (I,J) =25.0
      ELSE IF (JS .EQ. '0206' .OR. JS .EQ. '0204' .OR.
+     JS .EQ. '0203')THEN
        ELIG(I,J) = 1.0
        COST (I,J) =40.0
      END IF

      ELSE IF (PS .EQ. '0305') THEN
        IF (JS .EQ. '0205' .OR. JS .EQ. '0405') THEN
          ELIG(I,J) = 1.0
          COST (I,J) =25.0
        ELSE IF (JS .EQ. '0306' .OR. JS .EQ. '0304' .OR.
+     JS .EQ. '0303')THEN
          ELIG(I,J) = 1.0
          COST (I,J) =40.0
        END IF

        ELSE IF (PS .EQ. '0405') THEN
          IF (JS .EQ. '0305' .OR. JS .EQ. '0505')THEN
            ELIG(I,J) = 1.0
            COST (I,J) =25.0
          ELSE IF (JS .EQ. '0406' ) THEN
            ELIG (I,J) =1.0
            COST (I,J) =40.0
          ELSE IF (JS .EQ. '0403' .OR. JS .EQ. '0404') THEN
```

ELIG (I,J) =1.0
COST (I,J) =50.0
END IF

ELSE IF (PS .EQ. '0505') THEN
IF (JS .EQ. '0605' .OR. JS .EQ. '0705') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
ELSE IF (JS .EQ. '0506') THEN
ELIG (I,J) =1.0
COST (I,J) =40.0
END IF

ELSE IF (PS .EQ. '0605') THEN
IF (JS .EQ. '0505' .OR. JS .EQ. '0705') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
ELSE IF (JS .EQ. '0606') THEN
ELIG (I,J) =1.0
COST (I,J) =40.0
END IF

ELSE IF (PS .EQ. '0705') THEN
IF (JS .EQ. '0605') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
ELSE IF (JS .EQ. '0706') THEN
ELIG (I,J) =1.0
COST (I,J) =25.0
END IF
END IF

C

***** A R M A M E N T *****

IF (PS .EQ. '0106') THEN
IF (JS .EQ. '0206') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
ELSE IF (JS .EQ. '0103' .OR. JS .EQ.
+ '0104' .OR. JS .EQ. '0105') THEN
ELIG (I,J) =1.0
COST (I,J) =40.0
END IF

```

ELSE IF (PS .EQ. '0206') THEN
  IF (JS .EQ. '0106' .OR. JS .EQ. '0306') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0205' .OR. JS .EQ. '0204' .OR.
+   JS .EQ. '0203')THEN
    ELIG(I,J) = 1.0
    COST (I,J) =40.0
  END IF

ELSE IF (PS .EQ. '0306') THEN
  IF (JS .EQ. '0206' .OR. JS .EQ. '0406') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0305' .OR. JS .EQ. '0304' .OR.
+   JS .EQ. '0303')THEN
    ELIG(I,J) = 1.0
    COST (I,J) =40.0
  END IF

ELSE IF (PS .EQ. '0406') THEN
  IF (JS .EQ. '0306' .OR. JS .EQ. '0506')THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0405' ) THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  ELSE IF (JS .EQ. '0403' .OR. JS .EQ. '0404') THEN
    ELIG (I,J) =1.0
    COST (I,J) =50.0
  END IF

ELSE IF (PS .EQ. '0506') THEN
  IF (JS .EQ. '0606' .OR. JS .EQ. '0706') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0505') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF

ELSE IF (PS .EQ. '0606') THEN
  IF (JS .EQ. '0506' .OR. JS .EQ. '0706') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0

```



```
ELSE IF (JS .EQ. '0605') THEN
  ELIG (I,J) =1.0
  COST (I,J) =40.0
END IF
```

```
ELSE IF (PS .EQ. '0706') THEN
  IF (JS .EQ. '0606' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0705') THEN
    ELIG (I,J) =1.0
    COST (I,J) =40.0
  END IF
END IF
```

C

*****COMMUNICATION (TACTICAL)*****

```
IF (PS .EQ. '0107') THEN
  IF (JS .EQ. '0207') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0108') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0207') THEN
  IF (JS .EQ. '0107' .OR. JS .EQ. '0307') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0208') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =40.0
  END IF
```

```
ELSE IF (PS .EQ. '0307') THEN
  IF (JS .EQ. '0207' .OR. JS .EQ. '0407') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0308') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =50.0
  END IF
```

```
ELSE IF (PS .EQ. '0407') THEN
```

```
IF (JS .EQ. '0307' .OR. JS .EQ. '0507') THEN
  ELIG(I,J) = 1.0
  COST (I,J) =25.0
END IF
```

```
ELSE IF (PS .EQ. '0507') THEN
  IF (JS .EQ. '0607' .OR. JS .EQ. '0707') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0607') THEN
  IF (JS .EQ. '0507' .OR. JS .EQ. '0707') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  END IF
```

```
ELSE IF (PS .EQ. '0707') THEN
  IF (JS .EQ. '0607' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0708' ) THEN
    ELIG(I,J) = 1.0
    COST (I,J) =50.0
  END IF
END IF
```

C

***** COMMUNICATIONS (RADIO) *****

```
IF (PS .EQ. '0108') THEN
  IF (JS .EQ. '0208') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0107') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =50.0
```

END IF

```
ELSE IF (PS .EQ. '0208') THEN
  IF (JS .EQ. '0108' .OR. JS .EQ. '0308') THEN
    ELIG(I,J) = 1.0
    COST (I,J) =25.0
  ELSE IF (JS .EQ. '0207') THEN
```

ELIG(I,J) = 1.0
COST (I,J) =50.0
END IF

ELSE IF (PS .EQ. '0308') THEN
IF (JS .EQ. '0208' .OR. JS .EQ. '0408') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0

349X END IF

ELSE IF (PS .EQ. '0408') THEN
IF (JS .EQ. '0308' .OR. JS .EQ. '0508') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
END IF

ELSE IF (PS .EQ. '0508') THEN
IF (JS .EQ. '0608' .OR. JS .EQ. '0708') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
END IF

ELSE IF (PS .EQ. '0608') THEN
IF (JS .EQ. '0508' .OR. JS .EQ. '0708') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
END IF

ELSE IF (PS .EQ. '0708') THEN
IF (JS .EQ. '0608') THEN
ELIG(I,J) = 1.0
COST (I,J) =25.0
ELSE IF (JS .EQ. '0707') THEN
ELIG(I,J) = 1.0
COST (I,J) =50.0
END IF

END IF

*

* DEVELOPMENT OF COST COEFFICIENTS FOR MISMATCH IN
* IN AVAILABILITY OF PERSONS AND JOBS

*

IF (ELIG(I,J) .EQ. 1.0) THEN

```

DIFF= ABS( REAL((12*PY-PM) - (12*JY+JM)))-1
IF (DIFF .EQ. 1) THEN
  COST1(I,J)=5.0
ELSE IF (DIFF.EQ. 2) THEN
  COST1(I,J)=10.0
ELSE IF (DIFF .EQ. 3) THEN
  COST1(I,J) =15.0
ELSE IF(DIFF .GT. 3) THEN
  COST1(I,J) =150.0
END IF
END IF

```

```

*
*-----
* DEVELOPMENT OF COST COEFFICIENTS FOR PERMANENT
* CHANGE OF STATION COSTS.
*-----

```

```

IF (ELIG(I,J) .EQ. 1.0)THEN
  DIFFA = ABS( REAL(PA - JA))
  IF (DIFFA .EQ. 1) THEN
    COST2(I,J)=10.0
  ELSE IF (DIFFA .EQ. 2) THEN
    COST2(I,J)=20.0
  ELSE IF (DIFFA .EQ. 3) THEN
    COST2(I,J) =25.0
  ELSE IF(DIFFA .EQ. 4) THEN
    COST2(I,J) =35.0
  END IF
END IF

```

```

*
*-----
* DEVELOPMENT OF COST COEFFICIENTS FOR PREFERENCE MISMATCH
*-----

```

```

IF (ELIG(I,J) .EQ. 1.0)THEN
  IF (PPR1.NE. JA .AND. PPR2 .NE. JA) THEN
    COST3(I,J) = 10.0
  ELSE IF (PPR1.NE. JA .AND. PPR2 .EQ. JA) THEN
    COST3(I,J) = 5.0
  END IF
END IF
END IF
END IF
2 CONTINUE
REWIND (10)
3 CONTINUE

```

CALL DINPUT
STOP
END

* SUBROUTINE *

SUBROUTINE DINPUT

C THIS SUBROUTINE WRITES ELIGIBILITY MATRIX, COST COEFFICIENTS
C INTO FILES DEFINED BELOW. THE FORMAT OF THESE FILES IS IN
C ACCORDANCE WITH THAT REQUIRED BY GAMS. ONLY NON ZERO ENTRIES
C ARE WRITTEN. THE SUBROUTINE USES ONE COMMON BLOCK FOR DATA
C EXCHANGE. THE VARIABLES USED ARE SAME AS THE MAIN PROGRAM.

PARAMETER (MAXMEN= 300)
PARAMETER (MAXJOB = 300)
REAL ELIG(MAXMEN,MAXJOB) ,COST(MAXMEN,MAXJOB),
+ COST1 (MAXMEN,MAXJOB),COST2(MAXMEN,MAXJOB)
+, COST3(MAXMEN,MAXJOB),W1,W2,W3,W4
INTEGER M,N,M1,M2,N1,N2,I1,J1,PY,PM,JY,JM,PA,JA
COMMON/OPTION/ ELIG,COST,COST1,COST2,COST3,M,N
+,W1,W2,W3,W4

C DEFINITION OF OUTPUT FILES

* -----

CALL EXCMS ('FILEDEF 11 DISK ELGMAT OUT A1')
CALL EXCMS ('FILEDEF 12 DISK ELGCST OUT A1')
CALL EXCMS ('FILEDEF 13 DISK AVL CST OUT A1')
CALL EXCMS ('FILEDEF 14 DISK PCSCST OUT A1')
CALL EXCMS ('FILEDEF 15 DISK PRFCST OUT A1')
CALL EXCMS ('FILEDEF 16 DISK POLOPT OUT A1')

C FORMATTING DATA FOR OPTIMISATION MODULE

* -----

M1=M+1
M2=M1+100
N1=N+1
N2=N1+100

WRITE(11,100)M2,N2
WRITE(12,200)
WRITE(13,300)
WRITE(14,400)

```

WRITE(15,500)

DO 70 I=1,M1
  I1=I+100
  ELIG(I,N1) =1.0
  COST(I,N1) = 200.0
  COST1(I,N1)= 200.0
  COST2(I,N1) = 200.0
  COST3(I,N1)= 200.0

DO 70 J=1,N1
  J1=J+100
  ELIG(M1,J)=1.0
  COST(M1,J)=200.0
  COST1(M1,J)=200.0
  COST2(M1,J)=200.0
  COST3(M1,J)=200.0
  IF (ELIG(I,J) .GT. 0.0) THEN
    WRITE (11,101) I1,J1,ELIG(I,J)
    WRITE (12,201) I1,J1, COST(I,J)
    WRITE (13,201) I1,J1,COST1(I,J)
    WRITE (14,201) I1,J1, COST2(I,J)
    WRITE (15,201) I1,J1,COST3(I,J)
  END IF
70 CONTINUE
WRITE (11,102)
WRITE (12,102)
WRITE (13,102)
WRITE (14,102)
WRITE (15,102)
WRITE (16,600) W1,W2,W3,W4

100 FORMAT (1X,'SETS',2X,'I',3X,'PERSONNEL',4X,
+ '/ P101 * P',I3,'/',6X,'J',3X, 'JOBS',9X,
+ '/J101 * J',I3,'/',6X,'K',3X,'POLICIES',4X
+ ',/ K1*K4 / ;',
+ ///, 1X,'PARAMETER ELIG(I,J)' ,/,1X, '/')
200 FORMAT (1X,'PARAMETER ELGCST(I,J)' ,/,1X, '/')
300 FORMAT (1X,'PARAMETER AVLCST(I,J)' ,/,1X, '/')
400 FORMAT (1X,'PARAMETER PCSCST(I,J)' ,/,1X, '/')
500 FORMAT (1X,'PARAMETER PRFCST(I,J)' ,/,1X, '/')
600 FORMAT (1X,'PARAMETER W(K)',/, 1X,'/', 'K1 '
+ ',F3.1',/,1X,'K2 ',F3.1,/, 1X,'K3 ',F3.1,/,1X
+ ',K4 ',F3.1, '/' ;')

```

```
101  FORMAT(1X,'P',I3,'J',I3,3X,F3.1)
201  FORMAT(1X,'P',I3,'J',I3,3X,F5.1)
102  FORMAT (1X,' ;')
      RETURN
      END
```

APPENDIX C

OPTIMIZATION PROGRAM

\$TITLE AUTOMATED ASSIGNMENT MODEL FOR SAILORS
\$OFFUPPER OFFSYMXREF OFFSYMLIST
OPTION LIMROW =0 , LIMCOL=0 , SOLPRINT =OFF ;
\$ONTEXT

THIS IS A MODEL USED TO ASCERTAIN OPTIMAL ASSIGNMENTS FOR THE SAILORS OF PAKISTAN NAVY, THE MODEL USES INPUT DATA FROM FILES LISTED BELOW IN INCLUDE STATEMENTS. THE MODEL IS A VARIATION OF TRADITIONAL TRANSPORTATION MODEL.

\$ OFFTEXT
\$INCLUDE ELGMAT OUT A
\$INCLUDE ELGCST OUT A
\$INCLUDE AVLCST OUT A
\$INLCUDE PCSCST OUT A
\$INCLUDE PRFCST OUT A
\$INCLUDE POLOPT OUT A

VARIABLES

X(I,J) ASSIGNMENT OF PERSON I TO JOB J
Z TOTAL COST OF ASSIGMENTS ;

POSITIVE VARIABLE X;

EQUATIONS

COST DEFINE OBJECTIVE FUNCTION
PERSON(I) PERSON IS ASSIGNED ONLY ONCE
JOB(J) ONLY ONE PERSON IS ASSIGNED TO A JOB ;

COST .. Z =E= SUM(I,J),(ELGCST(I,J)\$W('K1')
+ AVLCST(I,J)\$W('K2')
+ PCSCST(I,J)\$W('K3')
+ PRFCST(I,J)\$W('K4')) * X(I,J);

PERSON (I)\$ (ORD(I) LT CARD (I)) .. SUM(J,X(I,J))
\$ELIG(I,J) =E= 1;

JOB (J)\$ (ORD (J) LT CARD (J)) .. SUM(I,X(I,J))
\$ELIG(I,J) =E= 1;


```
MODEL    AAMS  /ALL/;  
SOLVE AAMS USING LP MINIMIZING Z;  
OPTION X:1:0:1 DISPLAY X.L ;
```

APPENDIX D

RESULTS (TRIAL RUN)

This appendix contains the results achieved through one of the trial runs. The input data files containing personnel and job information are also given.

A. PERSONNEL INPUT DATA

'0101S001'	90	12	1	2	3
'0202S002'	90	12	3	2	4
'0304S003'	91	01	2	2	5
'0504S004'	91	02	1	4	3
'0505S005'	91	05	5	2	2
'0605A006'	91	04	3	1	2
'0707U007'	90	12	4	3	5
'0708A008'	91	09	5	1	4
'0104A009'	91	04	2	5	3
'0603A010'	90	12	3	4	1
'0307A011'	91	01	5	4	2
'0202U012'	90	12	3	2	3
'0307S013'	90	12	4	1	3
'0604U014'	91	01	2	2	4
'0701S015'	91	01	1	4	5
'0301S016'	91	04	5	2	1
'0207S017'	91	03	4	4	3
'0702S018'	90	11	2	1	2
'0708S019'	91	10	1	4	3
'0706S020'	91	04	2	5	1
'0102S021'	90	12	2	2	3
'0203S022'	90	11	5	1	4
'0208S023'	91	04	2	1	5
'0504S024'	90	12	4	1	3
'0405U025'	91	05	5	2	1
'0305S026'	91	04	3	1	2
'0107U027'	90	12	4	3	5
'0708A028'	91	09	5	1	4
'0104A029'	91	04	2	5	3
'0603U030'	90	12	3	4	1
'0507U031'	91	01	5	4	2
'0402U032'	90	12	3	2	3
'0303S033'	90	12	2	3	3
'0604S034'	91	01	1	2	5

'0706S035' 91 01 1 4 5
'0601S036' 91 04 3 1 1
'0607S037' 91 03 4 1 3
'0702U038' 90 11 4 1 2
'0208S039' 91 10 2 4 3
'0306U040' 91 04 5 1 5
'0101S041' 90 12 5 4 3
'0102S042' 90 12 4 3 2
'0203U043' 91 01 1 3 2
'0204S044' 91 02 5 5 3
'0205S045' 91 05 4 3 2
'0206S046' 91 04 2 2 3
'0207U047' 90 11 3 4 5
'0206A048' 91 07 4 2 4
'0105A049' 91 03 1 1 3
'0604A050' 90 12 2 5 1

B. JOBS DATA

'0101S001' 90 12 3
'0202S002' 90 11 4
'0303S003' 90 09 2
'0503S004' 91 01 1
'0505S005' 91 03 5
'0606S006' 91 06 5
'0707U007' 91 03 3
'0708A008' 91 04 2
'0103A009' 90 10 4
'0204A010' 90 12 1
'0603A011' 90 08 2
'0205S012' 91 07 1
'0207S013' 91 03 5
'0603U014' 91 04 5
'0302U015' 91 02 3
'0308A016' 91 02 2
'0108A017' 90 12 5
'0207A018' 91 11 3
'0103A019' 91 09 1
'0405A020' 91 01 2
'0605A021' 91 03 3
'0703A022' 91 06 4
'0101S023' 91 03 2
'0708S024' 91 02 1

'0101S025' 90 12 3
'0301A026' 90 12 4
'0207S027' 90 11 4
'0303S028' 90 010 3
'0401S029' 91 02 5
'0405S030' 91 03 1
'0607S031' 91 01 2
'0708A032' 91 02 3
'0308S033' 91 05 4
'0203U034' 90 10 4
'0701S035' 90 12 1
'0507U036' 90 08 1
'0202U037' 91 07 5
'0603U038' 91 01 3
'0404U039' 91 02 2
'0305U040' 91 03 1
'0505S041' 91 03 2
'0205A042' 90 11 4
'0108U043' 91 11 2
'0107U044' 91 09 5
'0303S045' 91 01 1
'0105A046' 91 03 2
'0104A047' 91 06 4
'0103A048' 91 03 3
'0102S049' 91 02 2
'0601S050' 90 10 2
'0603A051' 90 11 1
'0705S052' 90 11 2
'0105S053' 90 07 4
'0206S054' 91 02 3
'0307S055' 91 01 2
'0604A056' 90 11 2
'0702S057' 90 11 3
'0605U058' 91 01 4
'0504S059' 91 02 3
'0505S060' 91 01 2

C. ELIGIBLE ASSIGNMENTS (ARCS)

The list below is one of the outputs of the preprocessor program. It enumerates all the combinations of valid assignments that can be made by matching job and personnel data. The validity of each combination (arc) is dictated by the eligibility rules.

P101.J101	1.0
P101.J123	1.0
P101.J125	1.0
P101.J149	1.0
P101.J153	1.0
P101.J161	1.0
P102.J102	1.0
P102.J149	1.0
P102.J161	1.0
P103.J103	1.0
P103.J128	1.0
P103.J145	1.0
P103.J161	1.0
P104.J159	1.0
P104.J161	1.0
P105.J105	1.0
P105.J141	1.0
P105.J152	1.0
P105.J160	1.0
P105.J161	1.0
P106.J121	1.0
P106.J161	1.0
P107.J107	1.0
P107.J161	1.0
P108.J108	1.0
P108.J132	1.0
P108.J161	1.0
P109.J109	1.0
P109.J110	1.0
P109.J119	1.0
P109.J146	1.0
P109.J147	1.0
P109.J148	1.0
P109.J161	1.0
P110.J111	1.0

P110J122 1.0
P110J151 1.0
P110J161 1.0
P111J116 1.0
P111J118 1.0
P111J161 1.0
P112J115 1.0
P112J137 1.0
P112J161 1.0
P113J113 1.0
P113J127 1.0
P113J133 1.0
P113J155 1.0
P113J161 1.0
P114J161 1.0
P115J135 1.0
P115J150 1.0
P115J161 1.0
P116J129 1.0
P116J161 1.0
P117J113 1.0
P117J127 1.0
P117J155 1.0
P117J161 1.0
P118J157 1.0
P118J161 1.0
P119J124 1.0
P119J161 1.0
P120J106 1.0
P120J152 1.0
P120J161 1.0
P121J101 1.0
P121J102 1.0
P121J123 1.0
P121J125 1.0
P121J149 1.0
P121J161 1.0
P122J103 1.0
P122J128 1.0
P122J145 1.0
P122J161 1.0
P123J113 1.0
P123J127 1.0
P123J133 1.0

P123.J161	1.0
P124.J159	1.0
P124.J161	1.0
P125.J139	1.0
P125.J140	1.0
P125.J161	1.0
P126.J103	1.0
P126.J112	1.0
P126.J128	1.0
P126.J130	1.0
P126.J145	1.0
P126.J161	1.0
P127.J143	1.0
P127.J144	1.0
P127.J161	1.0
P128.J108	1.0
P128.J132	1.0
P128.J161	1.0
P129.J109	1.0
P129.J110	1.0
P129.J119	1.0
P129.J146	1.0
P129.J147	1.0
P129.J148	1.0
P129.J161	1.0
P130.J114	1.0
P130.J138	1.0
P130.J161	1.0
P131.J107	1.0
P131.J136	1.0
P131.J161	1.0
P132.J115	1.0
P132.J161	1.0
P133.J103	1.0
P133.J128	1.0
P133.J145	1.0
P133.J161	1.0
P134.J159	1.0
P134.J161	1.0
P135.J106	1.0
P135.J152	1.0
P135.J161	1.0
P136.J135	1.0
P136.J150	1.0

P136.J161	1.0
P137.J131	1.0
P137.J161	1.0
P138.J161	1.0
P139.J113	1.0
P139.J127	1.0
P139.J133	1.0
P139.J161	1.0
P140.J140	1.0
P140.J161	1.0
P141.J101	1.0
P141.J123	1.0
P141.J125	1.0
P141.J149	1.0
P141.J153	1.0
P141.J161	1.0
P142.J101	1.0
P142.J102	1.0
P142.J123	1.0
P142.J125	1.0
P142.J149	1.0
P142.J161	1.0
P143.J134	1.0
P143.J161	1.0
P144.J161	1.0
P145.J112	1.0
P145.J153	1.0
P145.J154	1.0
P145.J161	1.0
P146.J112	1.0
P146.J154	1.0
P146.J161	1.0
P147.J144	1.0
P147.J161	1.0
P148.J110	1.0
P148.J142	1.0
P148.J161	1.0
P149.J109	1.0
P149.J119	1.0
P149.J142	1.0
P149.J146	1.0
P149.J147	1.0
P149.J148	1.0
P149.J161	1.0

P150J156 1.0
P150J161 1.0
P151J101 1.0
P151J102 1.0
P151J103 1.0
P151J104 1.0
P151J105 1.0
P151J106 1.0
P151J107 1.0
P151J108 1.0
P151J109 1.0
P151J110 1.0
P151J111 1.0
P151J112 1.0
P151J113 1.0
P151J114 1.0
P151J115 1.0
P151J116 1.0
P151J117 1.0
P151J118 1.0
P151J119 1.0
P151J120 1.0
P151J121 1.0
P151J122 1.0
P151J123 1.0
P151J124 1.0
P151J125 1.0
P151J126 1.0
P151J127 1.0
P151J128 1.0
P151J129 1.0
P151J130 1.0
P151J131 1.0
P151J132 1.0
P151J133 1.0
P151J134 1.0
P151J135 1.0
P151J136 1.0
P151J137 1.0
P151J138 1.0
P151J139 1.0
P151J140 1.0
P151J141 1.0
P151J142 1.0

P151.J143 1.0
 P151.J144 1.0
 P151.J145 1.0
 P151.J146 1.0
 P151.J147 1.0
 P151.J148 1.0
 P151.J149 1.0
 P151.J150 1.0
 P151.J151 1.0
 P151.J152 1.0
 P151.J153 1.0
 P151.J154 1.0
 P151.J155 1.0
 P151.J156 1.0
 P151.J157 1.0
 P151.J158 1.0
 P151.J159 1.0
 P151.J160 1.0
 P151.J161 1.0

D. MODEL STATISTICS

COMPILATION TIME = 0.780 SECONDS
 BLOCKS OF EQUATIONS 3 SINGLE EQUATIONS 111
 BLOCKS OF VARIABLES 2 SINGLE VARIABLES 231
 NON ZERO ELEMENTS 534
 GENERATION TIME = 0.260 SECONDS
 EXECUTION TIME = 0.330 SECONDS

S O L V E S U M M A R Y

MODEL AAMS OBJECTIVE Z
 TYPE LP DIRECTION MINIMIZE
 SOLVER BDMLP FROM LINE 1217

**** SOLVER STATUS 1 NORMAL COMPLETION
 **** MODEL STATUS 1 OPTIMAL
 **** OBJECTIVE VALUE 17585.0000

RESOURCE USAGE, LIMIT 0.162 1000.000
 ITERATION COUNT, LIMIT 62 1000
 WORK SPACE NEEDED (ESTIMATE) -- 11142 WORDS.
 WORK SPACE AVAILABLE -- 11142 WORDS.

MAXIMUM OBTAINABLE -- 303838 WORDS.)
EXIT -- OPTIMAL SOLUTION FOUND.

**** REPORT SUMMARY : 0 NONOPT
 0 INFEASIBLE
 0 UNBOUNDED

E. OPTIMAL SOLUTION

The list below represents the optimal solution for assignment of personnel to the vacancies available.

VARIABLE	X.L	ASSIGNMENT OF PERSON I TO JOB J
P101.J125	1.0	
P102.J102	1.0	
P103.J103	1.0	
P104.J161	1.0	
P105.J160	1.0	
P106.J121	1.0	
P107.J107	1.0	
P108.J132	1.0	
P109.J148	1.0	
P110.J151	1.0	
P111.J116	1.0	
P112.J137	1.0	
P113.J155	1.0	
P114.J161	1.0	
P115.J135	1.0	
P116.J129	1.0	
P117.J113	1.0	
P118.J157	1.0	
P119.J124	1.0	
P120.J106	1.0	
P121.J149	1.0	
P122.J128	1.0	
P123.J133	1.0	
P124.J159	1.0	
P125.J139	1.0	
P126.J130	1.0	
P127.J143	1.0	

P128.J108 1.0
P129.J147 1.0
P130.J138 1.0
P131.J136 1.0
P132.J115 1.0
P133.J145 1.0
P134.J161 1.0
P135.J152 1.0
P136.J150 1.0
P137.J131 1.0
P138.J161 1.0
P139.J127 1.0
P140.J140 1.0
P141.J123 1.0
P142.J101 1.0
P143.J134 1.0
P144.J161 1.0
P145.J112 1.0
P146.J154 1.0
P147.J144 1.0
P148.J142 1.0
P149.J146 1.0
P150.J156 1.0
P151.J104 1.0
P151.J105 1.0
P151.J109 1.0
P151.J110 1.0
P151.J111 1.0
P151.J114 1.0
P151.J117 1.0
P151.J118 1.0
P151.J119 1.0
P151.J120 1.0
P151.J122 1.0
P151.J126 1.0
P151.J141 1.0
P151.J153 1.0
P151.J158 1.0

F. ANALYSIS OF RESULTS

# OF PERSONNEL AVAILABLE FOR ASSIGNMENT	= 50
# OF JOBS AVAILABLE FOR ASSIGNMENT	= 60
# OF ELIGIBLE ASSIGNMENTS	= 247
# OF ASSIGNMENTS MADE (ACTUAL)	= 45
# OF PERSONNEL ASSIGNED TO UNSPECIFIED JOBS	= 5
# OF JOBS FILLED BY UNSPECIFIED PERSONS	= 15
% OF TOTAL PERSONNEL ASSIGNED (ACTUAL)	= 90

It is obvious that we started with an inventory mismatch of 10 personnel, i.e. for 60 vacancies only 50 personnel were available. The optimal solution resulted in assigning five more persons to unspecified job node. Of these five, four did not fit eligibility criteria for any of the available jobs, the remainder was edged out by optimality considerations. There are two ways to deal with these men first, eligibility rules can be relaxed to assign them to one of the unfilled jobs or carry them forward for assignment at a later stage. Consideration will also be given so as not to unduly delay their assignment orders.

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