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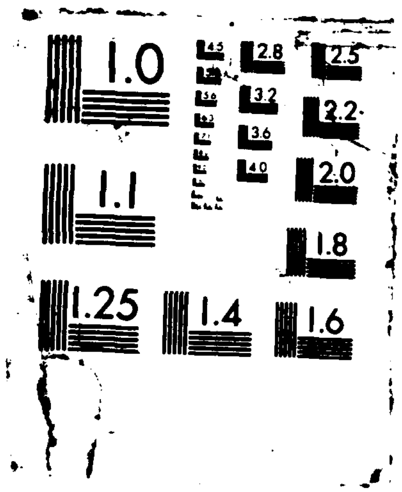
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Navy Personnel Research and Development Center

San Diego, CA 92152-6800 TN 88-15 January 1988

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Optimizing En Route Training in Enlisted Personnel Assignment

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Optimizing En Route Training in Enlisted Personnel Assignment

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This report identifies deficiencies of the Navy's current personnel assignment process and suggests a simultaneous optimization approach to improve the assignment of people to schools and jobs. This report should be of interest to Navy managers interested in improving the process of NEC detailing and school assignment, and for managers interested in improving the utilization of class quotas.

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FOREWORD

The research was conducted under Exploratory Development Project RM33M20, Task 6.1 (Career and Occupational Design), under the sponsorship of the Office of Naval Technology. The objective of the task was to develop new technologies to improve the Navy's personnel assignment system.

The report identifies deficiencies in the Navy's current personnel assignment process and suggests a simultaneous optimization approach to improve the assignment of people to schools and jobs. This method will be incorporated into the Enlisted Personnel Allocation and Nomination System (EPANS) to optimize the assignment process for ratings that require "C" school training. This report should be of interest to Navy managers interested in improving the processes of NEC detailing and "C" school assignment, and for managers interested in improving the utilization of class quotas.

SUMMARY

Problem

Although the Navy is dependent on the performance of technical jobs requiring multiple specialized skills, many of the enlisted personnel available for assignment to those jobs do not have the minimum required skills. As a result, personnel are often sent to a "C" school, en route to the job, in order to obtain the necessary qualifications. In trying to make the best possible assignments, detailers are faced with an enormous number of alternatives. This is because the decision to send a person to school, en route to the job, dramatically increases the assignment possibilities. The manual process currently used to make assignment decisions cannot consider all alternatives, and even automated sequential methods are too time consuming.

Numerical Example

A numerical example consisting of four people, five jobs, and two schools is used to highlight the problems of the current sequential or manual methods. We first illustrate the current process of assignment, showing how a hypothetical detailer might make one-at-a-time assignments while trying to hold down costs and make the most of school quotas.

Conclusions

The Navy Personnel Research and Development Center has developed an optimization procedure that produces person/job matches by simultaneously considering all individuals and all jobs. While the model is currently being applied to ratings requiring relatively little "C" school training, it is necessary to examine enlisted occupations requiring a significant amount of technical training. Expansion of the model to incorporate school training would be a step in improving the assignment and utilization of technically trained personnel.

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Problem

Although many of the Navy's technical jobs require multiple specialized skills, the persons available for assignment often do not possess the minimum skills needed for a good job match. In such cases, detailers may send a person to "C" school for advanced technical training to obtain the needed skills. These specialized skills are known as Navy Enlisted Classifications (or NECs). Jobs requiring multiple NECs create numerous options for detailers. That is, the same person can be sent to different schools to acquire the NECs needed to qualify for different jobs.

When all of the alternatives available for en route training are combined with the numerous ways of filling a job, it is practically impossible for a detailer to search all of the alternatives for the best one. For example, in a case of only 4 people, 5 jobs, and 2 schools, with each person eligible for every job and school, the total number of alternatives is 1,900. If we double the number of people, jobs, and schools to 8, 10, and 4 respectively, the total number of assignment alternatives exceed 100 billion (see Appendix A). As a practical matter, the manual process currently employed by detailers cannot consider all alternatives, and even automated sequential methods (e.g., sort and match) are too time-consuming. The purpose of this report is to illustrate the difficulties involved in manual or sequential methods of personnel assignment. In addition, the report will point to current developments to improve personnel assignment with en route training by *simultaneously* considering all people, jobs, and training alternatives.

Approach

A relatively simple numerical example will be used to highlight the problems of the sequential or manual method. The numerical example consists of only 4 people, 5 jobs, and 2 schools. Then, a few measures of effectiveness will be computed to compare the sequential method with a simultaneous or optimization procedure (The mathematical description for the optimization method is in Appendix B.)

Personnel assignment is a two-stage process. First, it is necessary to examine a list of to-be-available personnel and a list of to-be-vacant jobs to determine which personnel are eligible for which jobs. The eligibility criteria frequently involve a specification of required skills (or NECs). Second, a set of person/job matches is selected from the list of "eligibles." The eligibility network for the numerical example is shown in Figure 1. The cost of assigning a person to a new job includes the cost of moving a person from their previous duty station to School A or B and, upon completion of school, to their new duty station. Thus, a pair of moving costs are involved in each eligibility match, except where a person is eligible for a particular job without additional training. In Figure 1, each school node represents only one seat. The letter shown (A or B) in each school node denotes the particular school, not the number of available seats. There are only two seats in School A and only one seat in School B. The fact that six school nodes are shown reflects the *demand* for school seats needed in order to qualify personnel for jobs. The *supply* of school seats, as stated above, is only *three*.

If we focus on Person 3 alone, Figure 2 shows that Person 3 is eligible for Job 3 by undergoing training at School A; the cost is $0 + $700. Person 3 can become eligible for the very same job (Job 3) by acquiring additional training at School B, with moving costs of $200 + $1,100. Person 3 is also eligible for Job 5 without additional training, at a cost of $2,000. Finally, Person 3 is eligible for Job 1 by attending School B; the cost is $200 + $1,600.

Sequential Method

If we characterize the current method of assigning people as a *sequential* process, then we can illustrate the process by sequentially assigning each of the four persons in our example. These assignments show how a hypothetical detailer might make one-at-a-time assignments while trying to hold down moving costs and make the most of school quotas.

Assign Person 1: Figure 3 shows four alternatives for Person 1. Person 1 can be sent to School A enroute to Job 1 or Job 2 at a total PCS cost of $1,100 ($400 + $700) or $700 ($400 + $300), respectively. Person 1 can also be sent to Job 1 or Job 2 via School B at a total cost of $2,200 or $700, respectively. In comparing the alternative moves, we would expect Person 1 to be sent to School A enroute to Job 2. This would be a likely move since it is one of the least costly ($700) and because School A has two seats. Another inexpensive move ($700) would send Person 1 to Job 2 via School B, but this would use up the only school seat in School B. However, if a detailer makes a low cost move,

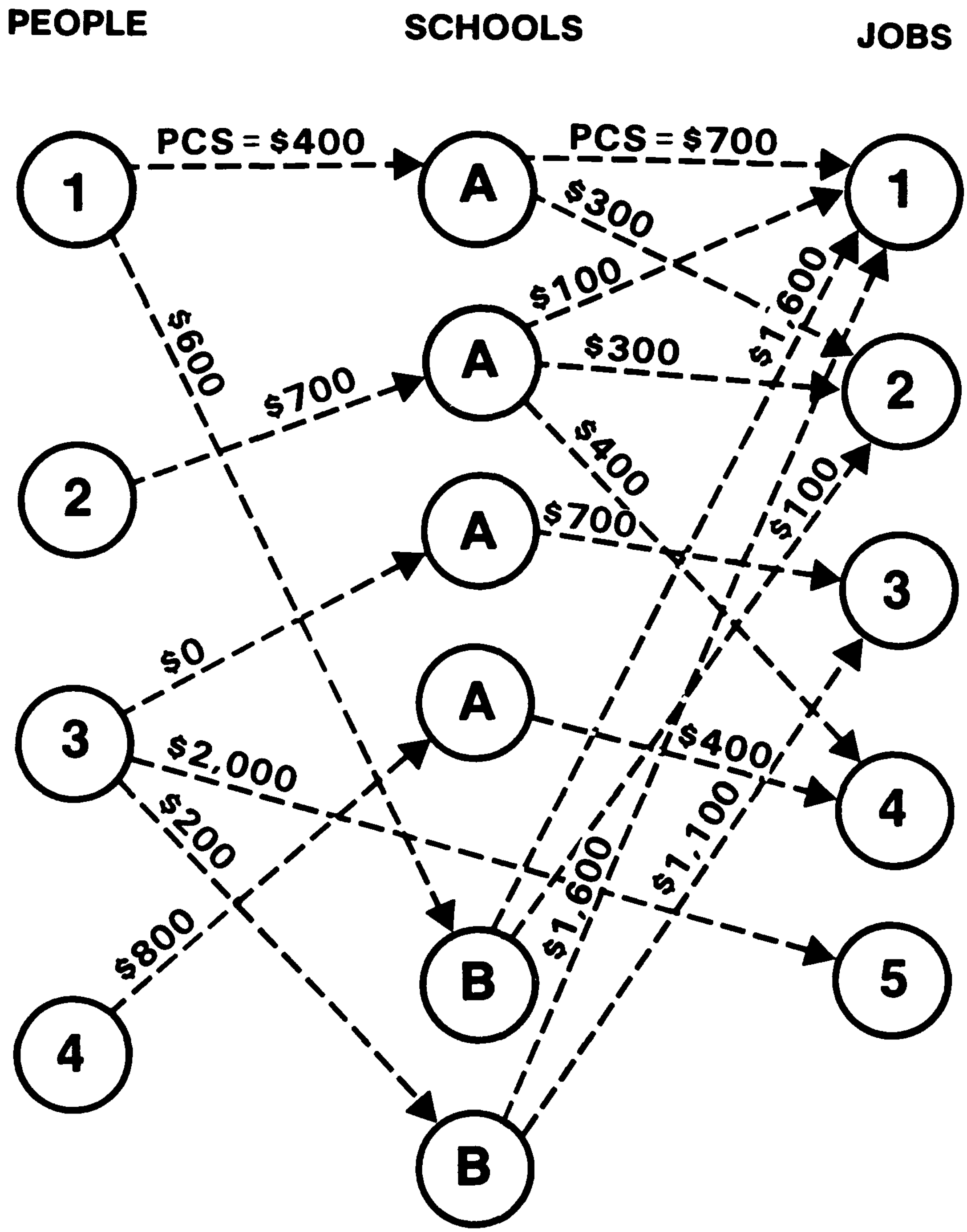

Figure 1. Eligibility diagram.

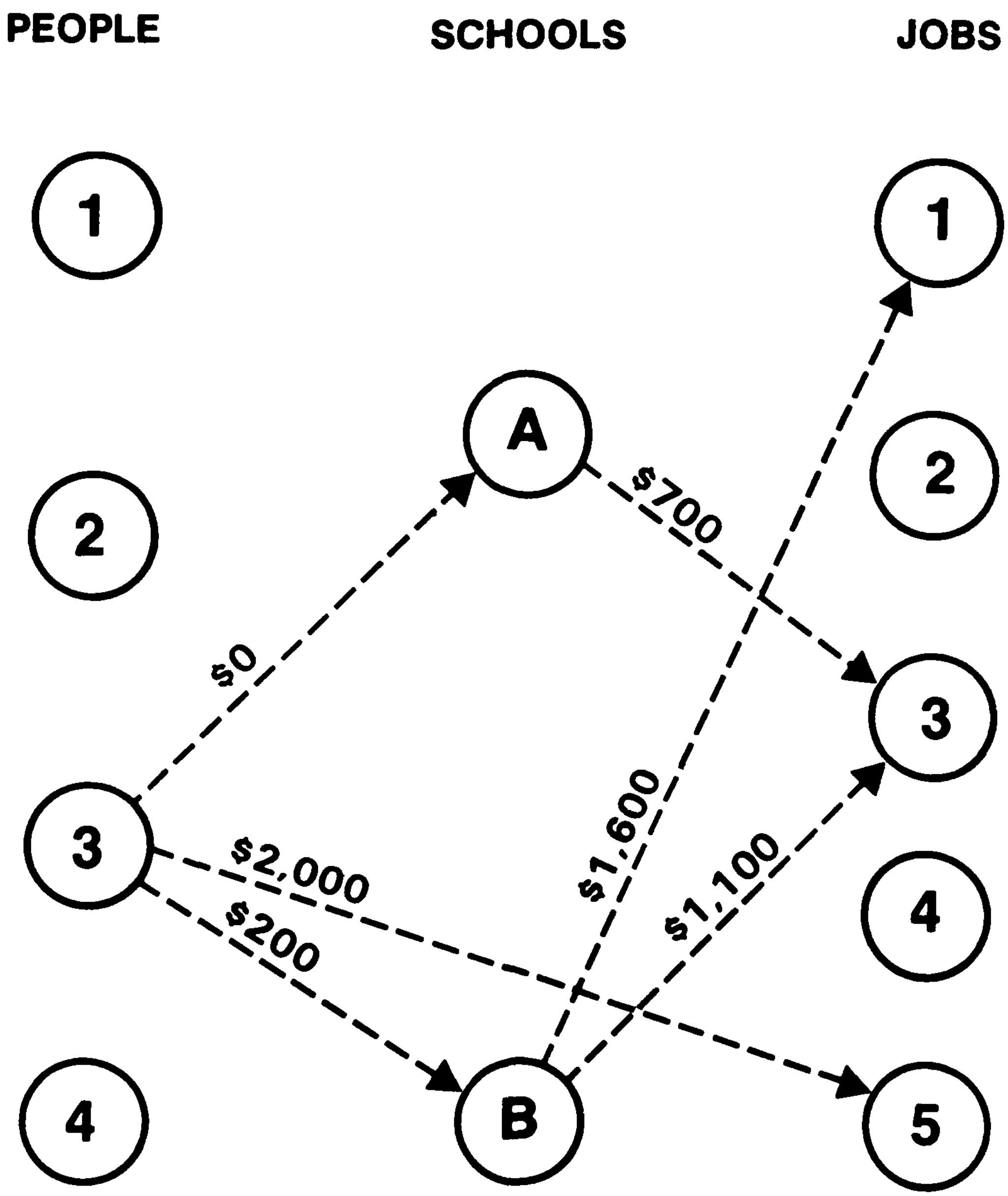

Figure 2. Eligibility network for person 3.

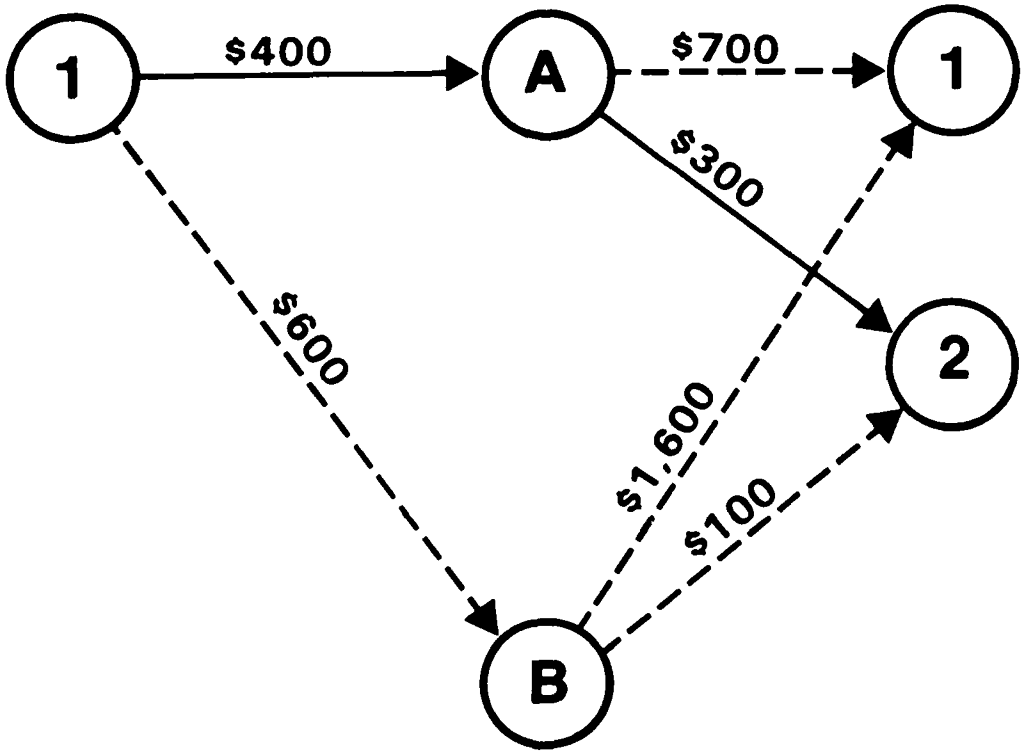

Figure 3. Sequential process for assigning the first person.

he/she would not know how this assignment affects the assignment options of other individuals. In addition, the detailer wouldn't know the effect of the assignment on minimizing the total PCS cost associated with assigning all four people.

Assign Person 2: Figure 4 shows the three alternatives for assigning Person 2: assignment to Jobs 1, 2, or 4, via School A. Since Job 2 has already been assigned to Person 1, the only options left are assignments to Job 1 or 4. After comparing the PCS costs for both of these alternatives, a detailer would likely assign Person 2 to Job 1 at a cost of $800. This is the lowest cost assignment even if Job 2 were still vacant, but note that the two seats in School A have now been filled.

Assign Person 3: As shown in Figure 5, Person 3 has three options: assignment to Job 3 via School A or School B, or to Job 5 directly. In order to control PCS costs, a detailer would most likely assign Person 3 to Job 3 via School B. First of all, one of the options (enroute training in School A) is no longer feasible because the two school seats have already been taken. Of the two feasible options, one is clearly less expensive than the other ($1,300 vs $2,000).

Assign Person 4: When we get to the last person, some of the deficiencies of the sequential, one-at-a-time process become apparent. Earlier assignments have reduced the feasible options available to persons assigned in the later stages. Figure 6 shows that even though Person 4 is eligible for Job 4, by qualifying with training in School A, the two seats at School A were already assigned to Persons 1 and 2. Therefore, Person 4 cannot be assigned.

In this example, because Person 4 cannot earn the appropriate NEC to qualify for the remaining jobs, we have a shortage of one seat in School A. So, Person 4 remains unassigned and Jobs 4 and 5 remain vacant. The example also shows how the sequential process of assigning people to jobs can contribute to apparent shortages and surpluses in "C" school seats and NEC inventories. Table 1 shows some other ways of assigning four people to five jobs, with their attendant costs.

Optimal Method

If we used an optimization procedure on the same example, we would first have to decide which policies took primacy in cases of conflicting policies. For example, if we simply wanted to maximize

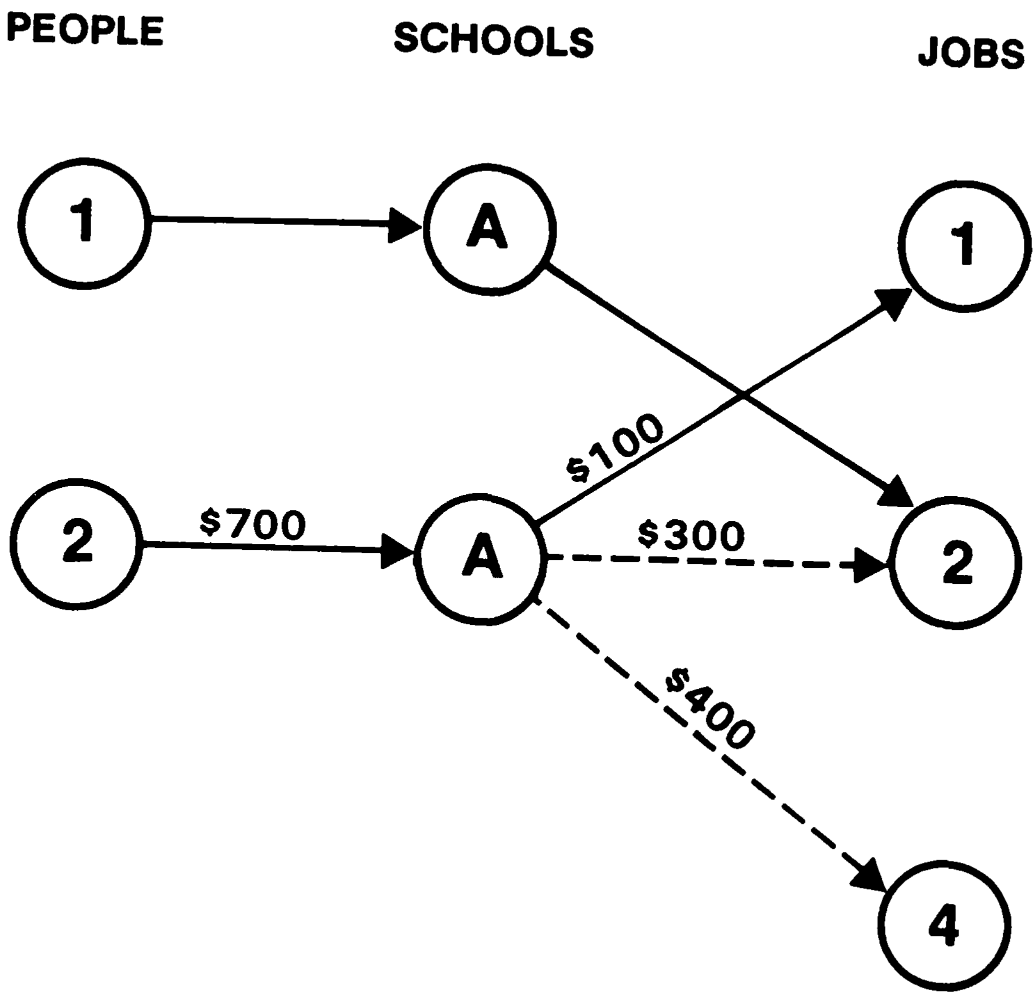

Figure 4. Sequential process for assigning the second person.

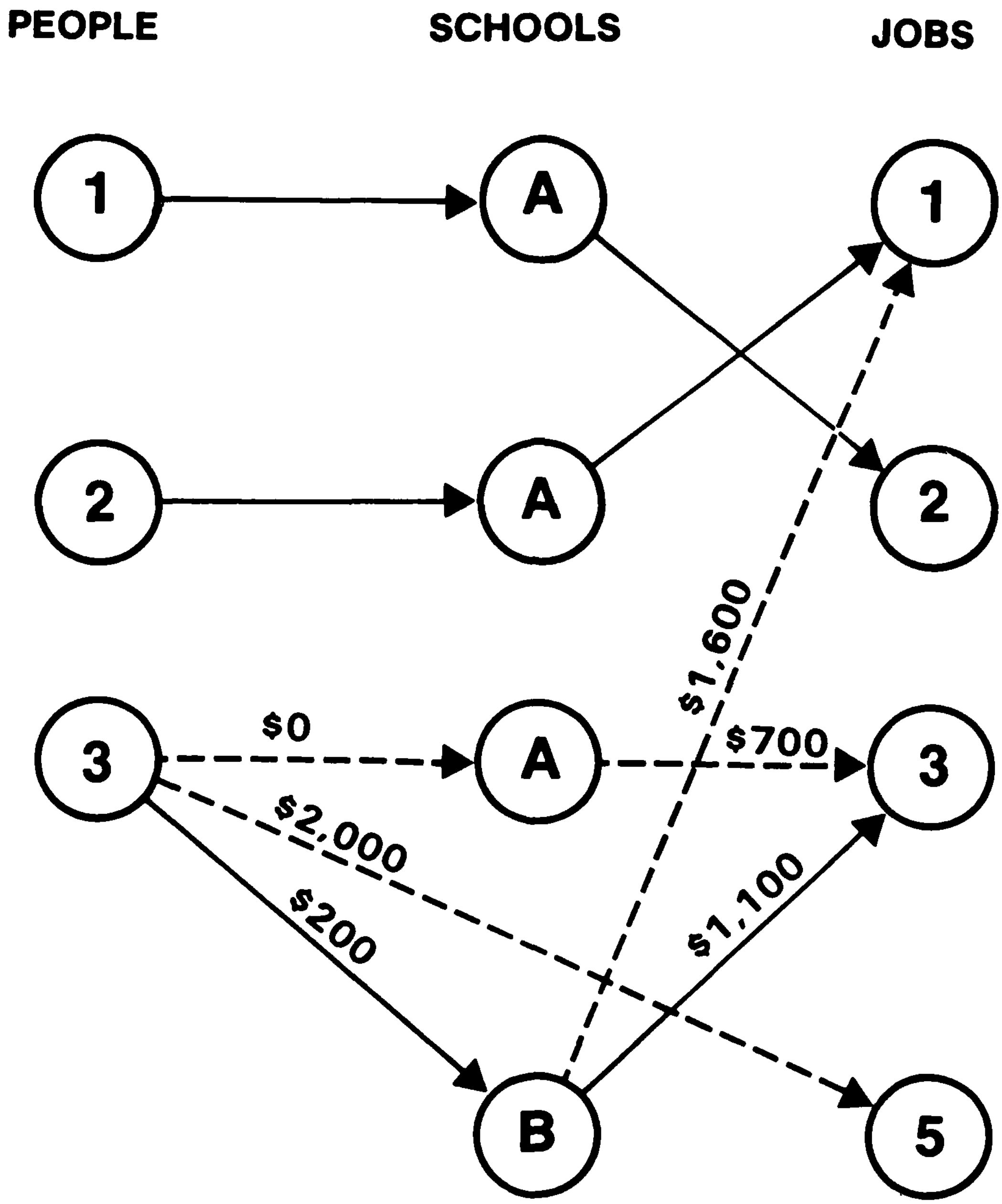

Figure 5. Sequential process for assigning the third person.

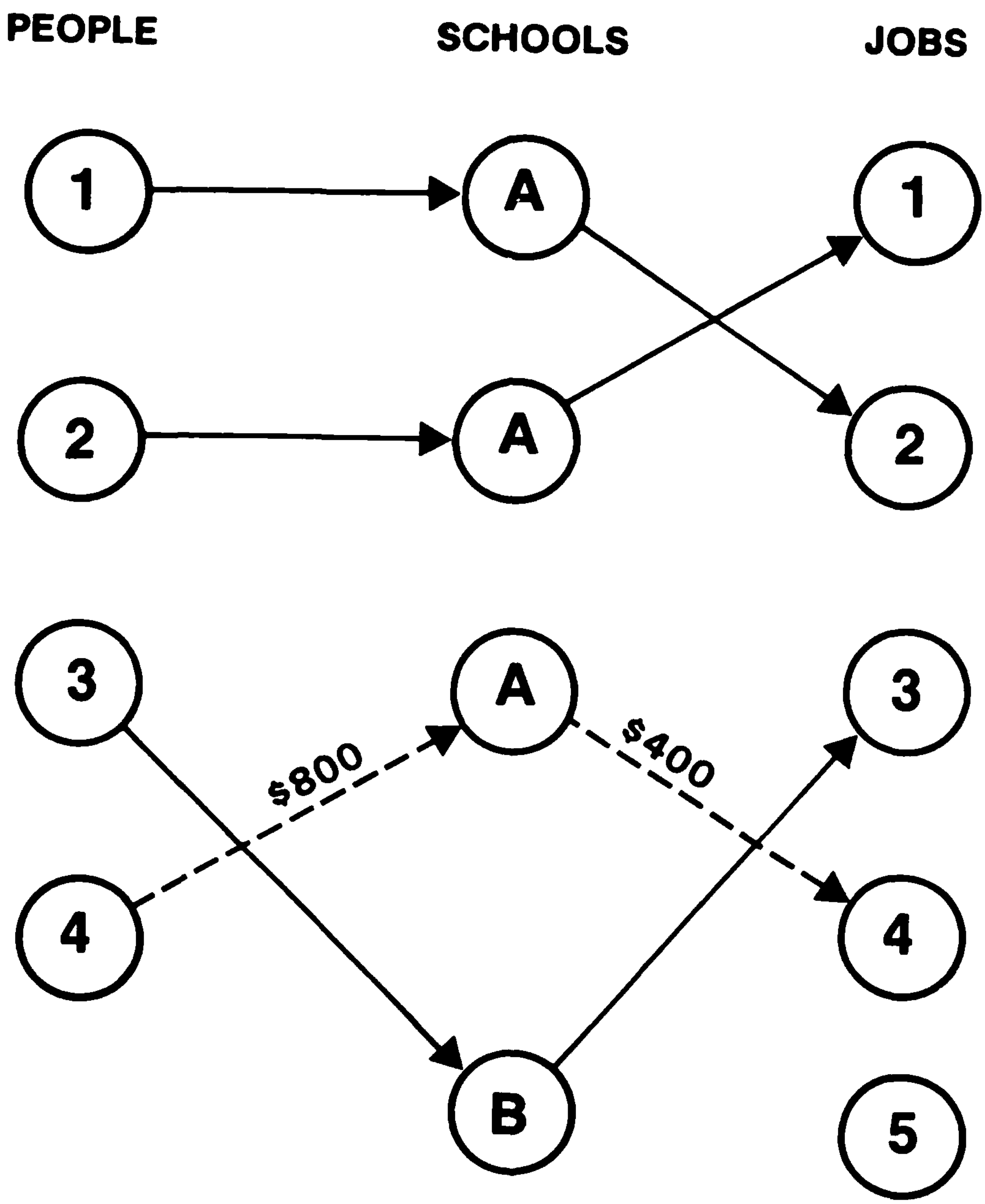

Figure 6. Sequential process for assigning the fourth person.

Table 1

Assignment Alternatives via En Route Training				
Alternative	**People**	**Via Schools**	**Jobs**	**PCS Cost($)**
1	1	A	2	700
	2	A	1	800
	3	B	3	1,300
	4	--	Unassigned	
				2,800
2	1	A	2	700
	2	A	1	800
	3	--	5	2,000
	4	--	Unassigned	
		(vacant seat)		3,500
3	1	A	1	1,100
	3	A	3	700
	2	--	Unassigned	
	4	--	Unassigned	
		(vacant seat)		1,800

Table 1 (continued)

Assignment Alternatives via En Route Training				
Alternative	People	Via Schools	Jobs	PCS Cost($)
4	1	A	1	1,100
	2	A	2	1,000
	3	--	5	2,000
	4	--	Unassigned	
		(vacant seat)		4,100
5	1	A	1	1,100
	3	--	5	2,000
	2	A	4	1,100
	4	--	Unassigned	
		(vacant seat)		4,200
6	1	A	1	1,100
	3	B	3	1,300
	2	A	2	1,000
	4	--	Unassigned	
				3,400

Table 1 (Continued)

Assignment Alternatives via En Route Training				
Alternative	People	Via School	Jobs	PCS Cost($)
7	1	A	1	1,100
	3	B	3	1,300
	2	A	4	1,100
	4	--	Unassigned	
				3,500
8	1	A	2	700
	3	A	3	700
	2	--	Unassigned	
	4	--	Unassigned	
		(vacant seat)		1,400
9	1	A	2	700
	3	--	5	2,000
	2	A	4	1,100
	4	--	Unassigned	
		(vacant seat)		3,800

Table 1 (Continued)

Assignment Alternatives via En Route Training				
Alternative	People	Via Schools	Jobs	PCS Cost($)
10	1	A	2	700
	3	B	1	1,800
	2	A	4	1,100
	4	--	Unassigned	
				3,600
11	1	B	1	2,200
	2	A	2	1,000
	3	--	5	2,000
	4	A	4	1,200
				6,400
12	1	B	2	700
	2	A	1	800
	3	--	5	2,000
	4	A	4	1,200
				4,700

the number of personnel assigned, Figure 7 shows a solution that has all four people assigned: Person 1 to Job 1 via School B; Person 2 to Job 2 via School A; Person 3 to Job 5 directly; and Person 4 to Job 4 via School A. For this solution (Alternative 11 in Table 1), there is no shortage or surplus of school seats, and the PCS cost is $6,400. The assignment is "optimal" in terms of maximizing the number of assignments under the school seat constraints.

If we want to minimize PCS cost, in addition to maximizing the number of assignments, the assignment alternative shown in Figure 8 is optimal. This solution (Alternative 12 in Table 1) assigns all four people at a PCS cost of only $4,700.

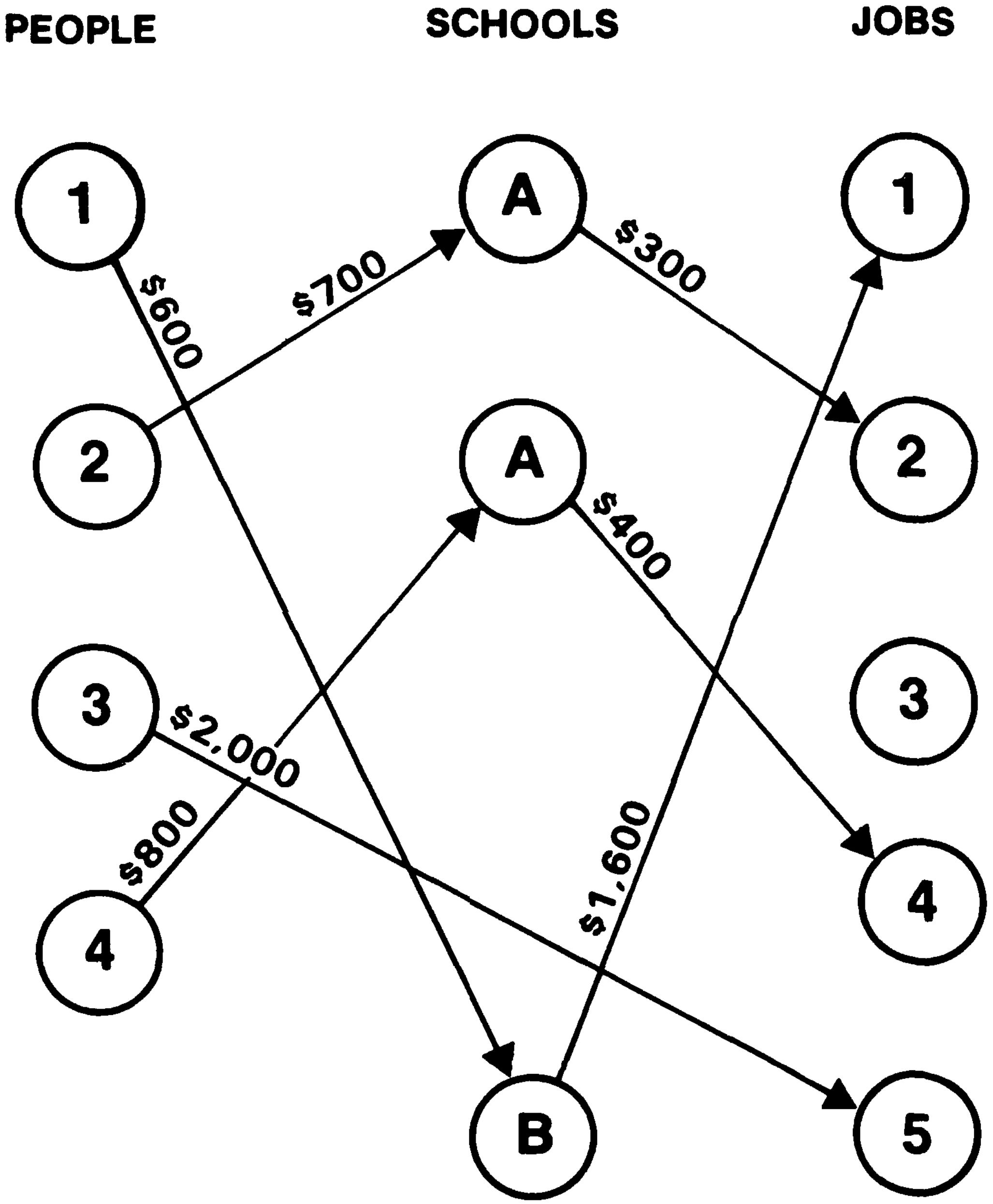

Figure 7. Optimal solution: Maximizing the number of assignments.

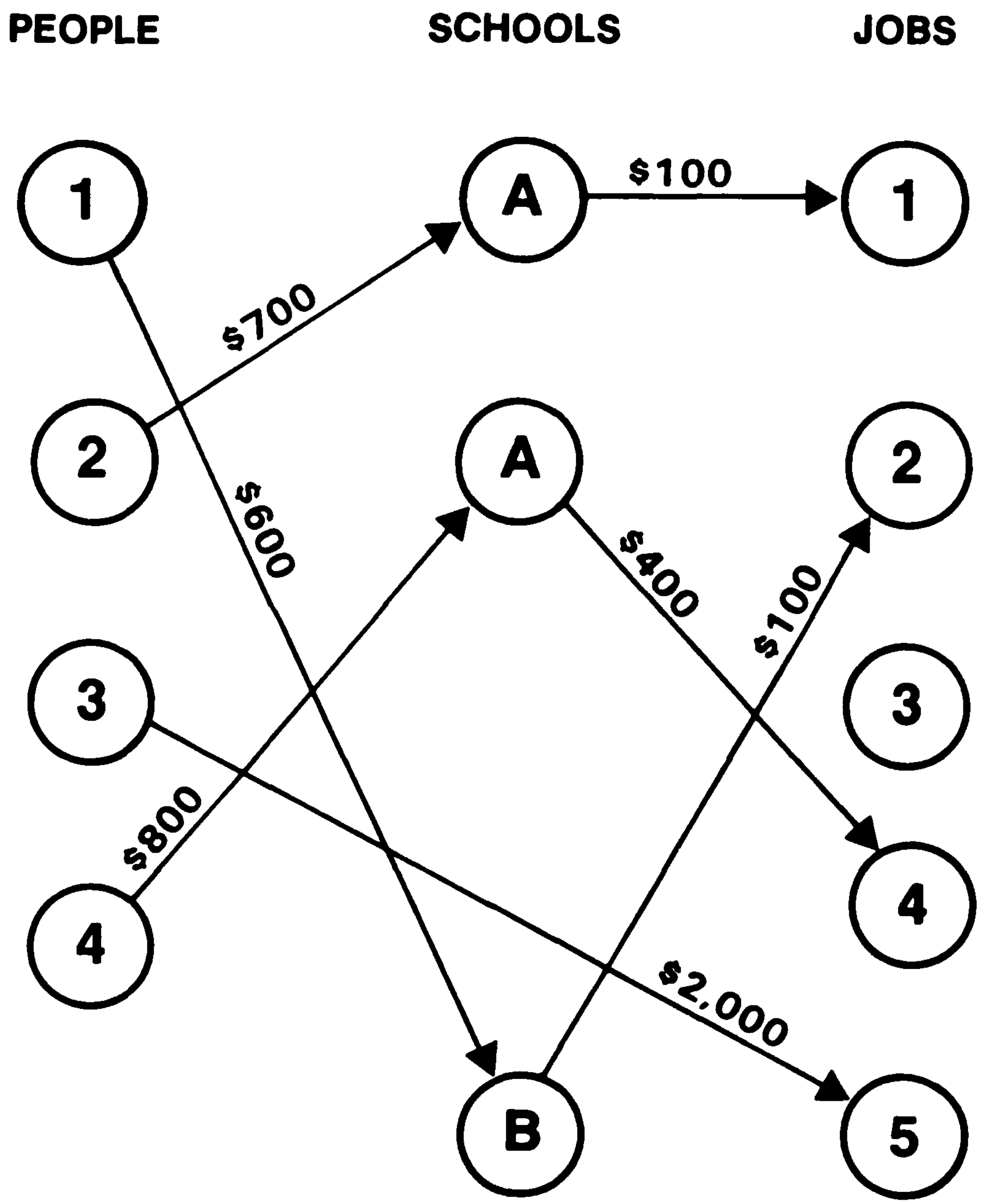

Figure 8. Optimal solution: Maximizing number of assignments and minimizing PCS cost.

Conclusions

Using a simple numerical example, we have shown some of the deficiencies caused by an assignment process where only a limited number of alternatives are considered in making an assignment. Many of the deficiencies can be overcome by using optimization methods which exhaustively search all possible alternatives for the "best" set of assignments. "Best" can be defined in terms of maximizing the number of assignments, minimizing PCS costs, utilizing school seats, and a variety of other objectives -- alone or in combination.

Recently, the Navy Personnel Research and Development Center developed an optimization procedure which produces person/job matches by simultaneously considering all individuals and all jobs (Liang and Thompson, 1987). When embedded in software, the procedure is called the Enlisted Personnel Allocation and Nomination System, or EPANS. EPANS was first applied to Seaman, Fireman, and Airman (Liang, and Thompson, 1986) and is now being tested for the Quartermaster, Signalman, and other ratings which require relatively little "C" school training (Liang, Thompson, and Zimmerman, 1986).

Based on preliminary results attained with non-rated personnel, the Navy Military Personnel Command is committed to the implementation of EPANS for all ratings. In anticipation of applying EPANS Navy-wide, it is necessary to examine enlisted occupations requiring a significant amount of technical training. This report is intended as a first step in that process. The numerical example reinforces the observation that the problem of personnel assignment with en route training is so large and complex that optimal search methods are essential.

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APPENDIX A

METHOD OF CALCULATING ALTERNATIVES

Appendix A

Method of Calculating Alternatives

Counting the number of alternatives is a permutation problem. The formula used to calculate permutations can be found in most probability and statistics textbooks. In our example of matching people to jobs, let m be the number of people and n be the number of jobs, the permutation may be stated as follows:

$${}_nP_m = n!/(n-m)! = n(n-1)...(n-m+1)$$

1. We match 4 people to 5 jobs assuming each person is eligible for every job directly:

   $${}_5P_4 = 5!/(5-4)! = 5 \times 4 \times 3 \times 2 = 120$$

2. We match 4 people to 5 jobs via 2 schools assuming each person is eligible for every job through en route training at any school. The permutation problem may be stated as follows:

   (a). the first person has 10 chances

   (b). the second person has 8 chances after excluding the job taken by the first person

   (c). the third person has 6 chances after excluding the jobs taken by the first and the second persons

   (d). the fourth person has 4 chances after excluding the jobs taken by the first, second, and third persons.

   Therefore, the permutation is,

   $$P = 10 \times 8 \times 6 \times 4 = {}_5P_4 \times 2^4$$
   $$= 1{,}920$$

3. Match 8 people to 10 jobs via 4 schools:

   $$P = {}_{10}P_8 \times 4^8$$
   $$= 118{,}908{,}518{,}400$$

APPENDIX B

MATHEMATICAL MODEL

Appendix B

Mathematical Model

The problem can be formulated as follows:

$$\textit{Maximize} \qquad \sum_{(i,j,k)\in F} u_{ijk} \; x_{ijk} \tag{1}$$

subject to

$$\sum_{(j,k)\in F_i} x_{ijk} \le 1, \qquad \text{for } i=1,\ldots,I, \tag{2}$$

$$\sum_{(i,k)\in F_j} x_{ijk} \le 1, \qquad \text{for } j=1,\ldots,J, \tag{3}$$

$$\sum_{(i,j)\in F_k} x_{ijk} \le q_k, \qquad \text{for } k=1,\ldots,K, \text{ and} \tag{4}$$

$$x_{ijk} = 0 \;\; or \;\; 1 \qquad \text{for } i=1,\ldots,I;\;\; j=1,\ldots,J;\;\; k=1,\ldots,K. \tag{5}$$

where I = number of available people;

J = number of job vacancies;

K = number of classes;

F = set of feasible assignments;

F_i = set of feasible assignments for person i;

F_j = set of feasible assignments for job j;

F_k = set of feasible assignments for school k;

x_{ijk} = 1 if person i is assigned to class k for job j;

0 otherwise;

u_{ijk} = utility measure of person i for job j and class k;

q_k = available seats for class k.

The objective is to maximize the total utility while satisfying three sets of constraints. Inequalities (2) require that each person can be assigned to at most one job. Inequalities (3) require that each job can be given to at most one person. Inequalities (4) require that the number of people assigned to a class should not exceed the available seats in the class. This model may be viewed as an integer network problem with side constraints. Either (2), (3), or (4) can form the side constraints and we have used (4) in our experimental model.

In this model, each decision variable represents the assignment of a school seat and a job to a person. Utilities represent payoffs of the Navy's policies. In a cost minimization problem, the costs can be transformed into a utility by measuring cost savings.

The objective was to minimize the total cost needed to match people to schools and jobs. Then, the costs were transformed into utilities by substracting individual costs from a large constant. We used a modification of NETSID (1987) to solve our problem.

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