A MANPOWER UTILIZATION MODEL FOR A NAVAL AIR REWORK FACILITY

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THESIS

A MANPOWER UTILIZATION MODEL
FOR A
NAVAL AIR REWORK FACILITY

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ABSTRACT

The management personnel at the Naval Air Rework Facility, North Island Naval Air Station, San Diego, California, are currently faced with two difficult planning problems inherent in any large industrial concern. These are the inability to smooth the workload so that it may be considered constant over a specific period of time and the determination of the optimal utilization of the direct labor force in order to produce the workload at minimum dollar wage cost. Assuming a constant workload, a mathematical model of this utilization problem, incorporating constraints and restrictions placed upon NARFSD by various agencies, is developed which can be solved as a minimal cost flow-with-gains network problem. By varying the constraint and restriction limits, several alternative manpower utilization options and their related costs are examined. Finally, various methods of smoothing variable workloads are suggested.

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TABLE I. DEFINITION OF SYMBOLS

Flow, Cost, and Efficiency Symbols

M = maximum number of hours available (upper bound)

$M_s(a)$ = upper bound on straight time labor in skill type a

$M_o(a)$ = upper bound on overtime labor in skill type a

$M_t(a)$ = upper bound on temporary labor which may be hired into skill type a

$M_{fo}(a)$ = upper bound on out-of-skill labor which may be drawn from skill type a

$M_{to}(a)$ = upper bound on out-of-skill labor which may be sent to skill type a

$M_w(a)$ = upper bound on workload requirement for skill type a

L = minimum number of hours which may be used (lower bound)

(note: subscripts same as those for M)

ex: $L_o(a)$ = lower bound on overtime labor in skill type a

X = number of hours which are used

(note: subscripts same as those for M)

ex: $X_o(a)$ = number of overtime hours used by skill type a

C = cost per hour of labor

(note: subscripts same as those for M)

ex: $C_o(a)$ = cost per hour of overtime labor in skill type a

TABLE I. DEFINITION OF SYMBOLS (Cont'd)

Flow, Cost, and Efficiency Symbols

e = efficiency of a worker

(note: subscripts same as those for M)

ex: $e_t(a)$ = efficiency of a temporary worker hired into skill type a

ex: $e_{to}(a,b)$ = efficiency of an out-of-skill worker from skill type b working as skill type a

ex: $e_{fo}(a,b)$ = efficiency of an out-of-skill worker from skill type a working as skill type b

I. INTRODUCTION

A. ORGANIZATION, ENVIRONMENT, AND GOAL

The Naval Air Rework Facility, Naval Air Station, North Island, San Diego, California (NARFSD) is probably one of the largest aircraft repair facilities in the world that operates under a variable workload. NARFSD is presently one of seven rework facilities servicing aircraft of the United States Navy and Marine Corps. It is directly responsible for all major maintenance, incorporation of technical changes, and repair of "crash-damaged" aircraft for West Coast based F-4 and E-2 aircraft and helicopters. The primary objective of NARFSD is to complete the required workload during a specific period of time at minimum total cost to the government.

NARFSD is directly responsible to the Naval Air Systems Command Representative, Pacific, in carrying out its assigned task (Figure 1). Fleet requirements are promulgated by the Commander-in-Chief, Pacific Fleet (CINCPACFLT), in conjunction with the Five-Year Defense Plan (FYDP) of the Department of Defense (DOD). CINCPACFLT, in order to meet the national offensive and defensive capabilities, determines the total number of operational F-4's, E-2's, and helicopters required by the Pacific Fleet. NARFSD is then directly responsible for the major overhaul and maintenance services necessary to keep these aircraft operational.

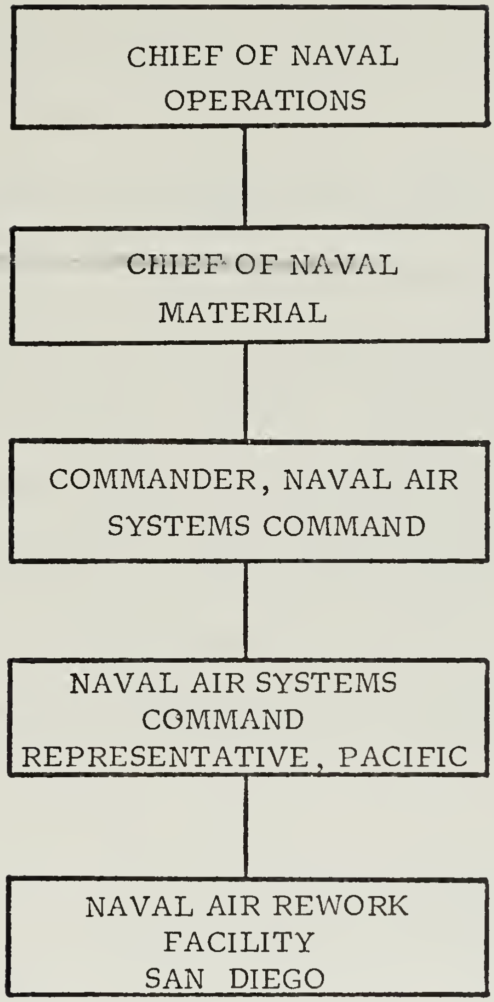


FIGURE 1. REPORTING CHAIN OF COMMAND FOR NARFSD

Organizationally, NARFSD is presently composed of nine major divisions (Figure 2). Each division is composed of a direct labor force and an indirect labor force, encompassing an overall labor force of approximately 6800 personnel. The indirect labor force is made up of managerial, secretarial, supervisory, and administrative personnel, while the direct labor force is comprised of the skilled tradesmen.

The physical plant of NARFSD represents a sizeable investment of government funds in buildings, test cells, laboratories, and airport facilities. The present plant, encompassing 298 acres, is valued at $115 million, plus another $18 million budgeted for rebuilding and expansion of existing facilities. NARFSD has a total yearly budget of $150 million and overhauls approximately 80 aircraft and 23,000 related components per quarter.

The major problems facing NARFSD are variable workload and optimal manpower utilization. During the quarterly conferences with aircraft manufacturers and CINCPACFLT representatives, NARFSD contracts to rework a specific number of aircraft and components during the upcoming fiscal quarter. The highly sophisticated and complex nature of a military aircraft necessitates periodic modifications of existing systems and major overhaul of component parts. Therefore, all aircraft are scheduled for preventative maintenance on a regular cycle during their life span. Prior to induction into a specific overhaul cycle ("PAR"), an estimate, based on historical data, of the man-hours required to update the aircraft

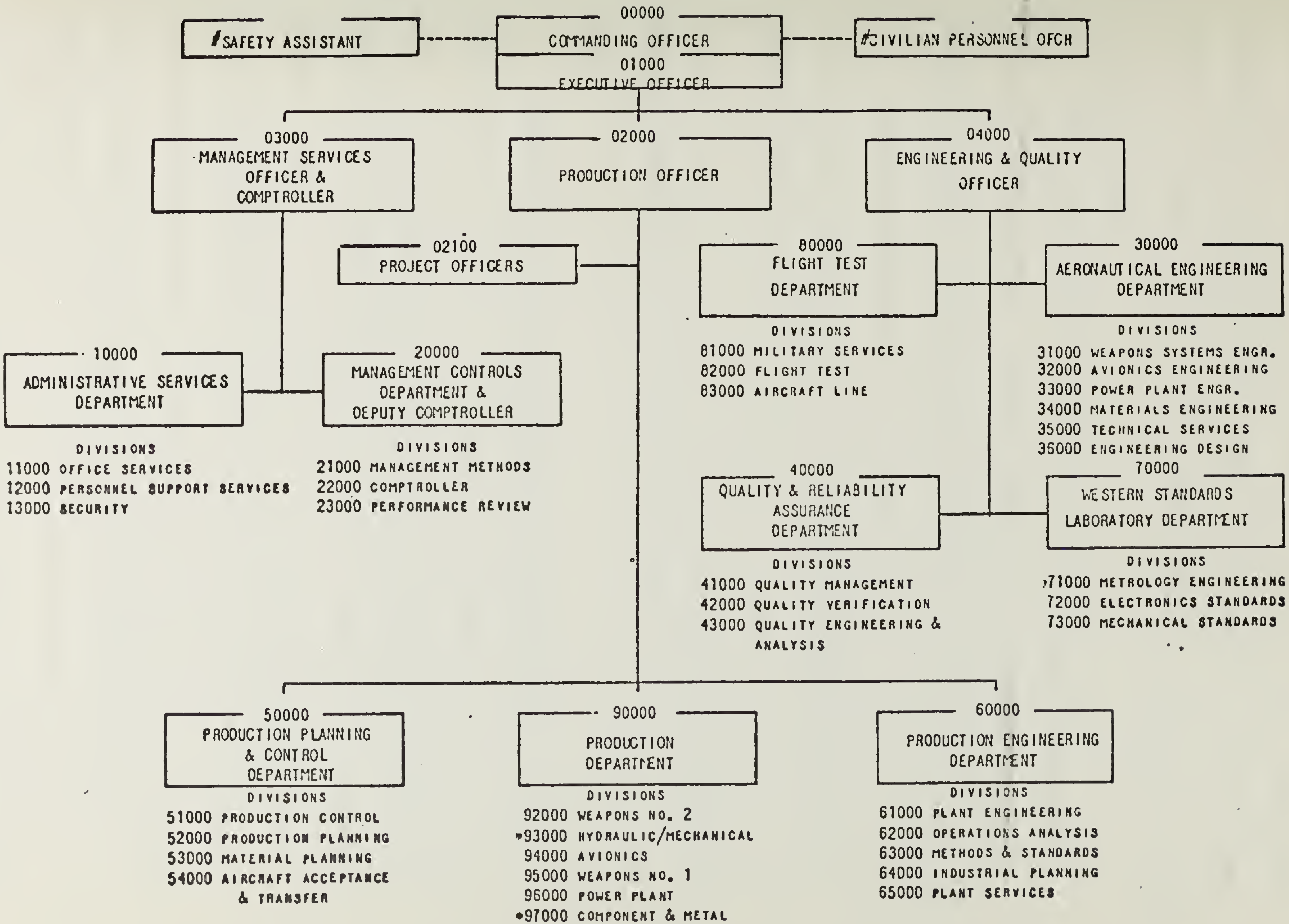


FIGURE 2. NAVAL AIR REWORK FACILITY, SAN DIEGO, ORGANIZATIONAL CHART

to present technical standards is obtained. As an example, a three-year old aircraft having made three combat cruises requires, on the average, both ten thousand man-hours and thirty-two days to complete the overhaul and update period.

When an aircraft is scheduled for a "PAR" induction date, the necessary components are ordered and managers must determine the optimal allocation of existing manpower resources necessary to accomplish the workload, yet retain several manpower utilization options in the event of unforeseen workload changes. In theory an aircraft arrives three to four days prior to scheduled maintenance, is prepared for induction, and on day zero, enters the system. It then takes exactly the required man-hours and number of days specified by the "PAR" cycle to complete overhaul.

Between the quarterly conferences and induction of the aircraft into the rework facility, many events may, and often do, take place that effect the predicted workload requirements at NARFSD. Extensions of deployments, immediate deployments to calm world crises, or inoperative systems could prevent an aircraft from arriving by the induction date. Upon arrival at NARFSD, the predicted man-hours could vary due to unexpected problems such as cracked wing spans or heavier than anticipated corrosion, recent technical changes, or lack of replacement parts. A series of "crash damaged" aircraft which require immediate repairs, a lack of skilled workers, and numerous other conditions can further effect

the hours needed to produce an operationally superb aircraft. Any of these problems could conceivably double the estimated (approximately 8,000 to 12,000) man-hours required to produce a finished product.

As of June, 1971, the total labor force employed by NARFSD was made up of nearly 6,800 personnel, with approximately 3,500 to 3,700 workers employed as part of the direct labor force. The indirect labor force appears to be invariant and to depend solely upon the amount of administrative services provided. The authors will therefore consider only the workload of the direct labor force and particularly that of the Production Department (Figure 3).

At the present time, the direct labor force is composed of a regular or straight time labor force, encompassing those individuals who work an eight-hour day, five days per week; a temporary labor force, made up of those individuals with less than one year's employment at NARFSD, but who also are working eight hours per day, five days per week; and lastly, an overtime labor force consisting of those individuals who work more than eight hours per day or more than forty hours per week. A labor force that will be investigated is an out-of-skill or cross-trained labor force, such as an electrician working as an aircraft instrument mechanic.

At the present time, leeway in management planning for the direct labor force is hampered by constraints and restrictions placed upon NARFSD by DOD, CINCPACFLT, labor unions, and NARFSD itself. These include

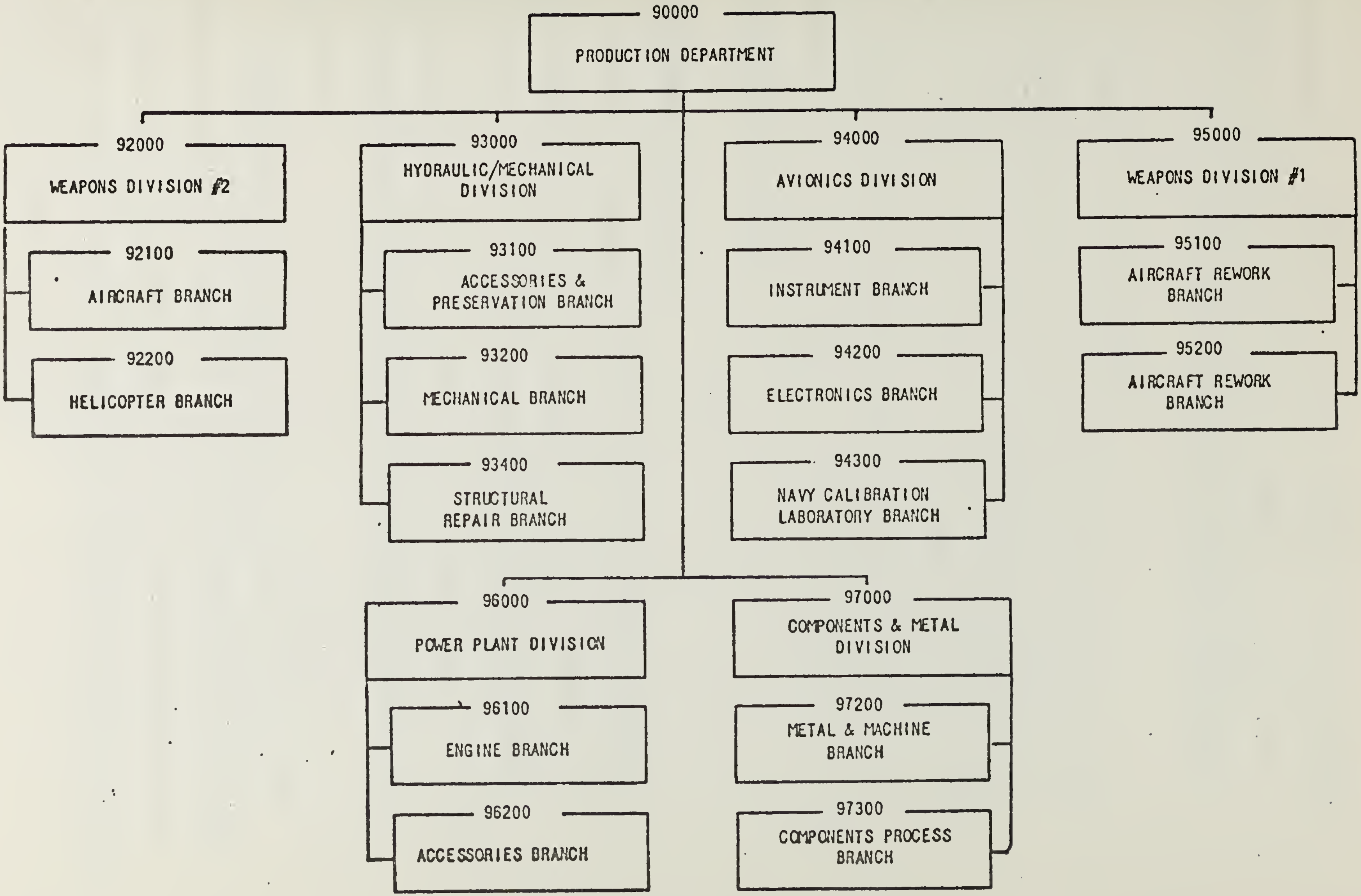


FIGURE 3. DIRECT LABOR FORCE STRUCTURE

such constraints as minimum and maximum bounds on overtime (NARFSD), a permanent labor force of 6,400 personnel (DOD), or a maximum time of 120 days that a worker may work out of his basic skill (labor union).

B. STATEMENT OF THE PROBLEM

Given planning estimates from CINCPACFLT of the required workload, the planners are to determine the optimal allocation of manpower resources. Options, such as overtime and the hiring and firing of temporary workers, are to be retained to satisfy any unexpected fluctuations and changes in the projected workload. Finally, the turnover in personnel must be kept at a minimum.

C. SCOPE OF THIS STUDY

The production planner's problem, under the constant workload, will be modeled as a network involving flows with gains. The values on each network arc will represent constraints on the Rework Facility involving available temporary, overtime, and out-of-skill personnel, as well as the physical plant size limitations upon the amount of working space in any given area.

A sample problem is solved to illustrate the model and parametric studies are conducted on several of the imposed constraints in the example and their overall effect on the ability of management to obtain an optimal manpower allocation. Finally, a discussion of possible methods of smoothing the variance in the workload is presented.

II. FORMULATION OF THE LABOR UTILIZATION MODEL

A. ASSUMPTIONS

The inputs to the problem will be workload requirements and available labor in the various skill categories. As previously stated, the workload will be assumed to be constant for the time period covered by this problem. Historical data for the period 1967 to 1971 verifies that the workload completed per quarter is within 2% of the projected workload.

It is also assumed that managers can supply planning personnel with the amount of labor presently employed in the permanent labor force and the workload requirements prior to the period for which the problem is to be solved. Although all labor skills are composed of various work grades, and within these, various wage scales, it is assumed that the wage of an individual in any skill is the average value of the wage of all men in that skill.

Because neither the temporary nor the out-of-skill labor produce the same amount of output as the straight time skilled labor in an equivalent period of time, some means of relating performance differences is needed. Efficiency factors will therefore be used to relate the effectiveness of out-of-skill labor to skilled labor. Permanent or in-skill labor (the basis of the straight time labor force) will be assumed to perform at a 1.0 efficiency. Relative to this figure, all other types of labor will have

an efficiency of 1.0 or less. Values are subjective and are assumed to be provided by labor supervisors.

Hiring will be assumed to be accomplished through the use of temporary labor. Firing will be assumed to be necessary if the sum of straight time and out-of-skill labor which is used in any skill is less than the upper bound on the straight time for that skill. Normal attrition is to be replaced on a one-for-one basis and is not considered in the model.

B. THE UTILIZATION MODEL AS A NETWORK

Prior to the use of network solution techniques, a brief overview of network theory is presented. Concurrently, the applicability of a labor utilization problem to network theory and solution techniques is shown.

1. Basic Description of a Network

Networks are made up of two basic components, nodes and arcs. A node may be thought of as an activity, which in the utilization problem could be a shop or management decision. Arcs, which join nodes, indicate a path along which a commodity may flow. An arc could thus be a labor type, such as overtime, used by a skill; the flow along that arc could be the application of overtime labor to a subsequent activity.

The representation (i) will be used throughout this paper to represent node i in a network. A line connecting two nodes is used to represent an arc. As an example, the node-arc relationship in the following sketch shows arc (i,j) joining node i with node j. The arrowhead indicates

that arc (i,j)

is a directed arc; arc (i,j) is defined as incident from node i and incident to node j ; and if commodity flow existed in arc (i,j) it would go from node i to node j.

A group of node-arc relationships which are connected, either directly or indirectly, is called a network. An example of a network is shown in Figure 4.

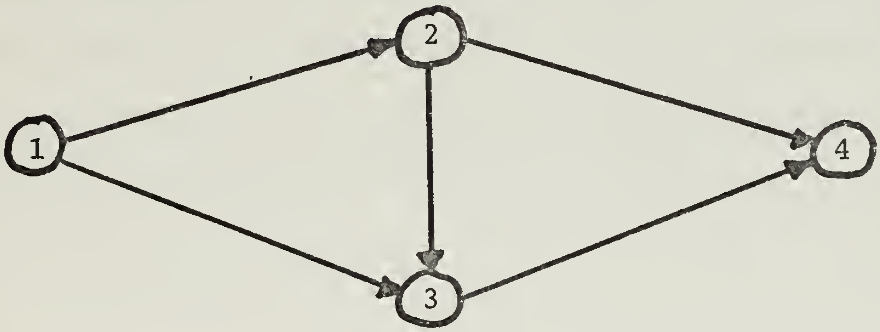
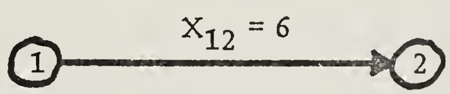


Figure 4. A Network

Two arcs are considered adjacent when they have at least one node in common. In Figure 4, arc (1, 2) and arc (1, 3) are adjacent. A sequence of adjacent directed arcs is a chain if the arcs are consistently directed. "Consistently directed" means that if one of two adjacent arcs is incident to a common node, then the other is incident from that node. A typical chain in Figure 4 is arc (1, 2), arc (2, 3), and arc (3,4) (in that order); these arcs constitute a chain from node 1 to node 4.

Two special nodes appear in a flow network; they are called the source and sink. In Figure 4, node 1 is the source and node 4 is the sink. In a network flow problem the source node is the only node through which external flow can enter the network; the sink node is the only node through which flow can leave the network. For the utilization problem, the source may be thought of as a pool of available labor resources and the sink as a pool of expended labor, which has been used to complete some workload.

In obtaining solutions to network flow problems, chains which reach from source to sink are used. The equivalent in a labor network is a chain along which labor may pass in order to fulfill workload requirements. The actual flow in an arc (i, j) will be represented by X_{ij}. For example, in the following illustration a flow of 6 labor hours is being drawn from activity 1 by activity 2.



Each arc has associated with it a flow capacity M_{ij}, which designates the maximum flow capacity of that arc. A minimum flow capacity L_{ij} is also associated with each arc (i, j), and this capacity is always non-negative (in the utilization problem, negative labor flow has no meaning). Therefore, actual flow on arc (i, j) is bounded as follows:

$$0 \leq L_{ij} \leq X_{ij} \leq M_{ij} \quad .$$

The flow capacities and cost per unit flow associated with an arc will be written on the arc as L_{ij}, M_{ij}, C_{ij} in the network diagrams to be used in this thesis.

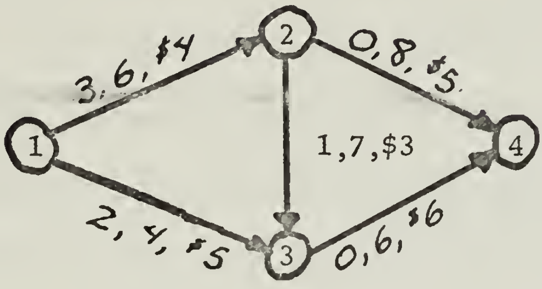


Figure 5. A Network with Bounds and Costs

In Figure 5, for example, arc (1, 2) has associated with it a lower bound on flow L_{12} of 3 units, an upper bound on flow M_{12} of 6 units, and a cost per unit flow C_{12} of $4 per unit.

A network flow problem must conform to certain special restrictions. Flow from the source to the sink is restricted to a single commodity (i.e., labor hours); flow in an arc must lie within bounds; and flow conservation for all nodes must be satisfied. Furthermore, two forms of flow conservation must be satisfied within a network. For all nodes, flow into the node must equal flow out of the node (i.e., net flow across the node must be equal to zero). Flow from the source and into the sink must be equal.

2. A "Network with Gains"

In the network structure described above, each arc (i,j) has an implied multiplier of 1.0 associated with it. This multiplier allows one unit of flow to transverse arc (i,j) from node i to node j and arrive as one unit of flow. In the utilization model, the unit of flow from node i can be acquired labor, while the flow needed at node j can be productive labor hours. In several cases, such as temporary labor, an acquired labor hour generates only a fraction of a productive labor hour because the efficiency of a temporary worker is less than 1.0.

This "reduction in flow" is easily incorporated in the utilization network by using the "Network with Gains" idea of W. S. Jewell (1958). In such a network, the gains are multipliers which increase or decrease the flow across the arc. These gains are analogous to the efficiency factors in the utilization model.

Jewell also provided an algorithm for solving such problems. It incorporates a primal-dual solution technique to reach an optimal flow solution at minimum cost, with the only major restriction being the fact that the lower bounds on the arcs must be zero. Therefore, prior to the use of Jewell's algorithm in the utilization model, all non-zero lower bounds will be "adjusted" to a zero value.

One difference in the flow conservation which arises in the use of Jewell's idea is that flow into the sink need not be equal to flow out of the source because of the effect of the multipliers. In the utilization model, the flow out of the source is viewed as total utilized labor hours.

The flow into the sink could be viewed as total productive labor hours, which may represent a reduction in the flow out of the source if any efficiency factors have been applied to that flow. In the utilization problem, total flow into the sink will be represented as Q, the total workload required for the network.

3. <u>The Labor Utilization Network</u>

The labor utilization network, when completely drawn, would be composed of nineteen subnetworks, each of which represents a basic skill type. A typical subnetwork for skill type 1 is shown in Figure 6. The labels in the arcs represent the values of L, M, and C. The subscripts used are defined as:

s = straight time labor

t = temporary labor

o = overtime labor

fo = out-of-skill labor sent from skill 1

to = out-of-skill labor sent to skill 1

w = workload requirements for skill type 1

Furthermore, "e" is defined as the efficiency of a type of labor. As an example, $e_t(1)$ represents the efficiency of a temporary worker in skill type 1. The efficiency factors for applicable arcs are enclosed in triangles in Figure 6.

In Figure 6, flow into node 3 represents the total hours of all work types (i.e., straight time, overtime, temporary, and out-of-skill)

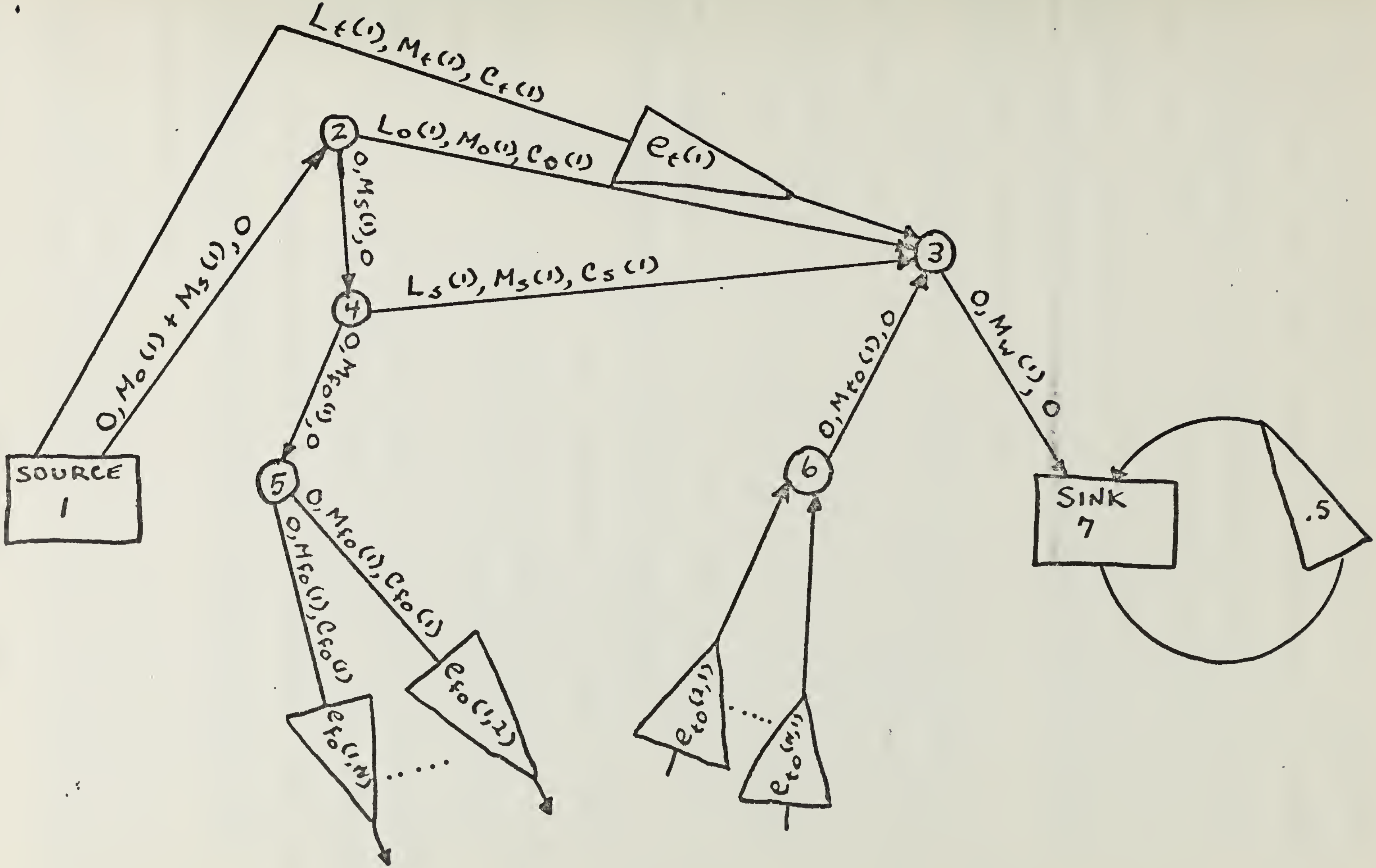


FIGURE 6. TYPICAL TRADE SKILL SUBNETWORK

available to produce the required workload. Flow into node 4 represents the available labor force hours from which straight time and out-of skill labor may be procured. The flow leaving node 5 is the out-of skill labor available from skill type 1 to be used as needed by other skill types. As an example, it could represent flow of electricians to several other skill types. Finally, the flow through node 6 is the flow of out-of-skill labor from all other skill types to skill type 1.

In Figure 6, the cost associated with arcs (1,2), (2,4), (4,5), (6,3), and 3,7) are all shown as zero, for no labor is expended or produced while transversing these arcs. These arcs are necessary for the network only to show a sequence of events that take place. Further, these arcs have no effect upon the final solution, other than to provide a path for labor flow, nor do they effect the final cost computations.

Arcs (4,5) and 6,3) play a special role in the sample network. Arc (4,5) is the arc through which all out-of-skill man-hours from the skill shown may flow. The upper bound on this arc designates the maximum number of out-of-skill man-hours available to other skills with insufficient labor to complete their required workload. Arc (6,3), that arc through which all out-of-skill man-hours transverse while entering the skill shown, and its upper bound, prevents the skill from becoming saturated with out-of-skill man-hours.

Arc (7,7) and its associated efficiency factor of .50 are included in the sample network only because they are necessary for computational procedures when using the "network with gains" algorithm.

C. CONSTRAINTS

1. Total Flow

In order to accomplish the workload required and simultaneously prevent any violation of conservation of flow in the network, the following flow constraints apply:

$$\text{a)} \quad (X_{iN} - e_{Ni} X_{Ni}) = Q \qquad i \neq N$$

$$\text{b)} \quad (X_{ij} - e_{ji} X_{ji}) = 0 \qquad (j=1,2,\ldots,N-1)$$

Equation a) represents total flow into the sink and equation b) represents conservation of flow within the network. Q represents the total workload required and e_{ij} is the efficiency factor for arc (i,j).

2. Bounds

Bounds exist on arc flows; that is,

$$L_{ij} \leq X_{ij} \leq M_{ij} \qquad (i,j = 0,1,2,\ldots,N); \; (L_{ij} \geq 0)$$

where X_{ij} is the actual hours of "flow," L_{ij} is its lower bound value, and M_{ij} is its upper bound value. Unless otherwise designated, L_{ij} is assumed to be zero.

Several of the arc flow bounds in the model are dependent on the bounds of other arcs because of administrative policies at NARFSD. These

involve maximum allowable percentages of overtime, temporary, and out-of-skill labor relative to the straight time labor. The minimum and maximum allowable overtime hours can be described by:

$$L_o(a) = A\ M_s(a)$$

$$M_o(a) = B\ M_s(a)$$

where $M_s(a)$ = upper bound on straight time labor in skill type a

$M_o(a)$ = upper bound on overtime labor in skill type a

$L_o(a)$ = lower bound on overtime labor in skill type a

and A and B are predetermined constants. As an example, if B = .10, the maximum overtime hours allowed [$M_o(a)$] is 10% of the available straight time hours in skill type a [$M_s(a)$].

The upper bound for temporary labor is then constrained as follows:

$$M_t(a) = D\ M_s(a)$$

where $M_t(a)$ = upper bound on temporary labor which may be hired into skill type a

and D is a predetermined constant. The lower bound is zero, which prevents a forced hiring of temporary labor. The constraint on the upper bound

limits the number of hours for temporary workers in a skill, maintaining a predominantly permanent labor force in that skill. As an example, if D= .07, skill type a may augment its work force through the hiring of temporary help in the total amount of 7% of the total available straight time labor hours of skill type a.

To prevent a skill from being composed largely of (or losing too many workers as) out-of-skill, bounds are imposed on the maximum number of out-of-skill workers allowed. The following equations describe these bounds:

$$M_{fo}(a) = F\,M_s(a)$$

$$M_{to}(a) = G\,M_s(a)$$

where $M_{fo}(a)$ = upper bound on out-of-skill labor which may be drawn from skill type a

$M_{to}(a)$ = upper bound on out-of-skill labor which may be sent to skill type a

and F and G are predetermined constants. For example, if F = .05, skill type a may send at most 5% of its available straight time labor force out-of-skill, and with G = .07, skill type a may augment its labor force by at most an amount equal to 7% of its available straight time hours.

D. OBJECTIVE FUNCTION

The desired solution to the labor utilization problem is that which minimizes total wage labor costs conditioned by the fact that the workload must be completed. The total labor costs incurred by a specified labor plan can be described algebraically by:

$$\sum_{(i,j)} C_{ij} X_{ij}$$

where C_{ij} is the cost of one hour of labor "flowing" from i to j and X_{ij} is the value of the total flow of labor hours.

E. COMPLETE MODEL AND ALGORITHM

Having defined the objective function, and applicable constraints, the mathematical description of the problem associated with the utilization model can be stated as "find values for X_{ij} $(i,j = 1,2,\ldots,N;\ i \neq j)$ that

$$\text{Minimize} \sum_{(i,j)} C_{ij}\, X_{ij}$$

subject to

$$\sum_{i} (X_{iN} - e_{Ni}\, X_{Ni}) = Q \qquad i \neq N$$

$$\sum_{i} (X_{ij} - e_{ij}\, X_{ij}) = 0 \quad (j = 1,2,\ldots,N-1)$$

$$L_{ij} \leq X_{ij} \leq M_{ij} \qquad (i = 0,1,2,\ldots,N) \quad (j = 1,2,\ldots N);\ i \neq j. \text{ "}$$

The algorithm for solving the problem is:

1) Satisfy all non-zero lower bounded arcs by sending any lower bound flow through the network.
2) Revise the network to show the change in lower bounds and upper bounds where flow has occurred. If an arc had a non-zero lower bound, flow has occurred at, and beyond, that arc. The revised network will show all bounds decreased by the amount flowing through each arc; this will in effect insure all lower bounds are zero and decrease the upper bounds by the amount of flow.
3) Apply Jewell's "network with gains" algorithm to the revised network to get the optimal flows.

III. SAMPLE PROBLEM

To illustrate the model, a small sample problem has been created which uses two of the nineteen major skill types available at NARFSD. These are the aircraft electricians (E.) and the electronics mechanics (E.M.). For purposes of the example problem, the electricians will be designated as skill type 1 and the electronics mechanics as skill type 2. All data is based on the status of NARFSD as of June 1971. Figure 7 is the network for this example; the numbers on the arcs represent L_{ij}, M_{ij},

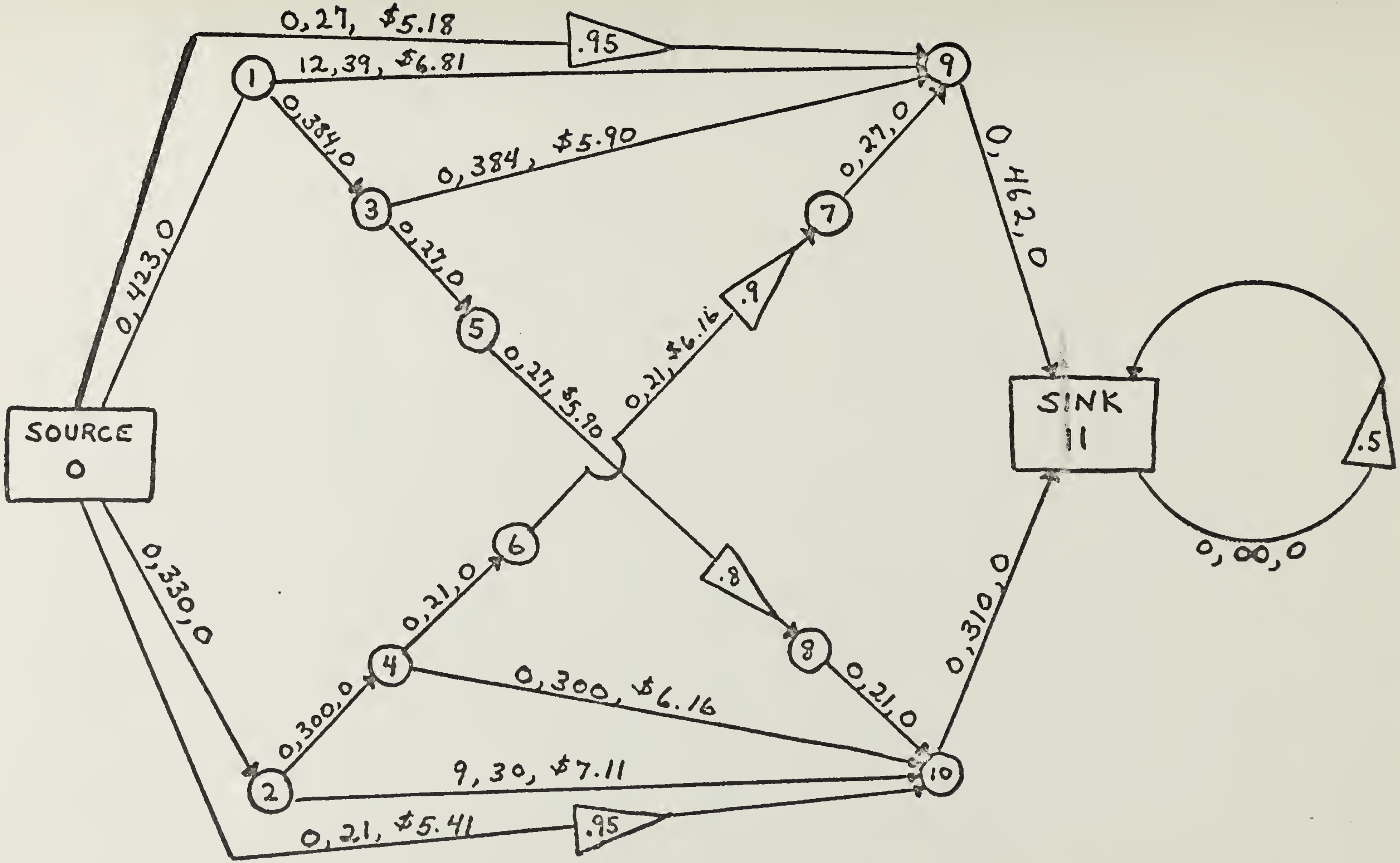


FIGURE 7. SAMPLE PROBLEM NETWORK

and C_{ij}. Table II summarizes the trade skill data. The constants used are:

$$A = 0.03$$

$$B = 0.10$$

$$D = 0.07$$

$$F = 0.07$$

$$G = 0.07$$

and the workload requirements are:

electricians = 462 man-hours

electronics mechanics = 310 man-hours.

The hourly costs for the electricians are computed as follows:

straight time hourly cost

$C_s(1)$ = hourly base wage * 1.083 * 1.2
= $4.54 * 1.083 * 1.2 = $5.90

overtime hourly cost

$C_o(1)$ = hourly base wage * 1.5

= $4.54 * 1.5 = $6.81

temporary labor hourly cost

$C_t(1)$ = hourly base wage * 1.083 * 1.054

= $4.54 * 1.083 * 1.054 = $5.18

TABLE II. SAMPLE PROBLEM INPUT DATA

TRADE SKILL	PARAMETER	WORK TYPE[1] s	o	t	fo	to
Electrician (skill 1)	M	384	39	27	27	27
	L	0	12	0	0	0
	C	5.90	6.81	5.18	5.90	0
	e	1.0	1.0	.95	.80	.80
Electronics Mechanics (skill 2)	M	300	30	21	21	21
	L	0	9	0	0	0
	C	6.16	7.11	5.41	6.16	0
	e	1.0	1.0	.95	.90	.90

1. Designations are the same as subscripts shown for the model.

Using the same general equations, the resultant hourly wages for the E.M. are:

$$C_s(2) = \$6.16$$

$$C_o(2) = \$7.11$$

$$C_t(2) = \$5.41$$

A. NETWORK DATA

The hourly wage and efficiency figures for the two skills were obtained from Tables III and X respectively. Workload requirements were chosen to allow the sample problem to utilize all work types. The workload requirements chosen could be representative of a situation at NARFSD should a large input of work for the aircraft electricians arise in the quarterly projections.

B. SOLUTION

The problem as shown in Figure 7 was solved by hand, although the algorithm is adaptable to computer solution. Step 1) must satisfy two lower bounds, both of which are concerned with overtime (12 man-hours for the aircraft electrician, 9 man-hours for the electronics mechanic). The required adjustments to the network are then made, resulting in the revised network shown in Figure 8. It is noted that the lower bounds on both overtime arcs are zero; the upper bounds have been reduced by 12 and 9

TABLE III. BASE HOURLY WAGES

TRADE SKILL	BASE HOURLY WAGE
Aircraft Electrician	$ 4.54
Aircraft Engine Mechanic	4.60
Aircraft Instrument Mechanic	4.52
Aircraft Mechanic	4.55
Aircraft Metalsmith	4.52
Bearing Reconditioner	4.01
Buffer and Polisher	4.50
Electronics Mechanic	4.74
Electroplater	4.42
Instrument Mechanic	5.03
Machinist	4.64
Metal Cleaner	3.94
Ordnance Mechanic	4.67
Painter	4.59
Plastics and Fiberglass Worker	4.53
Sandblaster	4.09
Toolmaker	5.26
Upholsterer	4.47
Welder	4.73

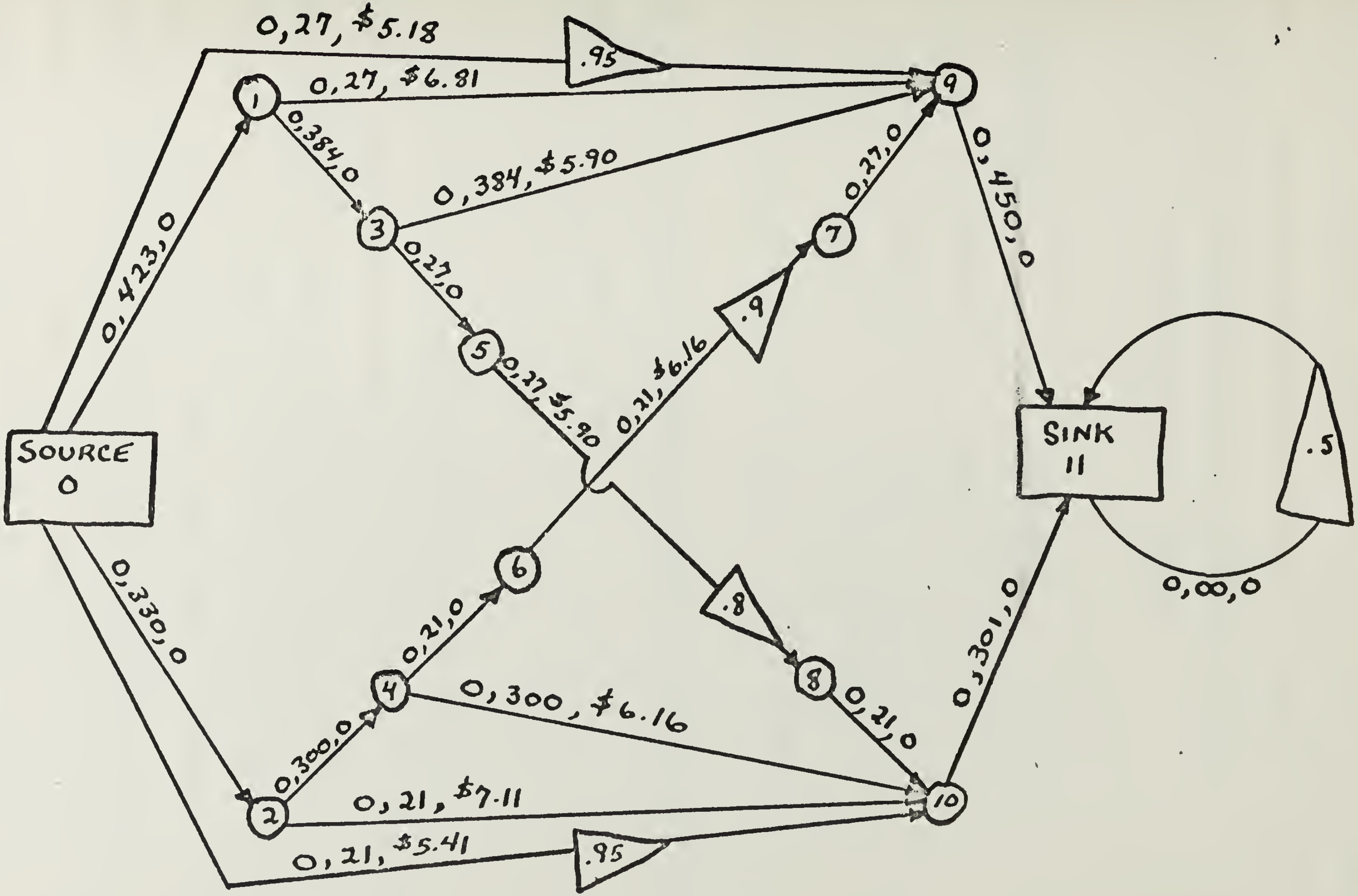


FIGURE 8. REVISED SAMPLE PROBLEM NETWORK

respectively; and workload requirements have been reduced by an equal amount. Now that the conditions for using Jewell's algorithm are met, the "networks with gains" algorithm was used, as per Step 3).

The results of the sample problem are as follows:

skill type 1	skill type 2
$X_s(1) = 384$ man-hours	$X_s(2) = 281.05$ man-hours
$X_o(1) = 39$ man-hours	$X_o(2) = 9$ man-hours
$X_t(1) = 27$ man-hours	$X_t(2) = 21$ man-hours
$X_{to}(1) = 13.35$ man-hours	$X_{fo}(2) = 14.83$ man-hours

With the above utilization of available man-hours of labor, the required workload of 772 man-hours is met.

C. DISCUSSION OF RESULTS

The solution to the sample problem points out, subject to the specific constraints and workload requirements, that the aircraft electrician skill used all options available. The electrician skill employed 384 man-hours of straight time labor, 39 man-hours of overtime labor, and 27 man-hours of temporary labor. Due to the .95 efficiency of the temporary labor force, the productive man-hours supplied are actually 25.65. The total productive man-hours of labor for the electrician skill is 448.65, thereby requiring 13.35 more man-hours to complete the required workload of 462 man-hours.

The final solution further points out that the electronics mechanic skill was able to complete its required workload by using 281.05 man-hours of straight time labor, the minimum of 9 man-hours of overtime, and the hiring of 21 man-hours of temporary labor (.95 efficiency factor reduces this to 19.95 productive man-hours), for a total of 310 man-hours of productive labor. At the same time, the E.M. skill had available 18.95 man-hours of labor to be used as needed out-of-skill or to be fired.

In reaching the solution to the sample problem, the value of the out-of-skill labor force becomes apparent. If this work type were not available, the electrician skill would have been forced to increase its overtime by 13.35 units (a change in B to 13.6%) or hire 13.35 productive man-hours of temporary labor (i.e., 14.05 total man-hours in order to account for the .95 efficiency factor). Likewise, the E.M. skill would have been forced to fire 18.95 man-hours of labor.

The use of the out-of-skill labor force has a two-fold advantage. First, it reduced the necessity for large scale hiring and firing. The E.M. skill was able to provide 14.83 man-hours of labor, at an efficiency of .90, to the electricians' skill. This equates to 13.35 man-hours of productive labor, exactly that needed to complete the required workload in the electrician skill. This use of out-of-skill labor reduced the amount of E.M. labor to be fired from 18.95 to 4.12. Secondly, it alleviates the necessity of incurring hiring and firing expenses, such as severance pay and training costs.

D. PARAMETRIC STUDIES

By performing parametric studies on the sample problem data, it is possible to investigate the effect of potential data variations on the total minimum cost.

1. Temporary Labor Hourly Cost

In comparing the hourly costs of individual labor types, the data indicates that the temporary labor is the least expensive. This results from the assumption that the hourly cost for the temporary labor includes no formal training, morale, or severance (in the case where permanent labor is fired due to the hiring of the less expensive temporary labor) costs. It also results from the fact that temporary labor accrues no annual leave benefits. To examine the effect of including these corrections in the cost of the temporary labor, a parametric study was conducted on the temporary labor force hourly wage (Table V).

It has been noted that the sample problem,in which workload requirements were designed that necessitate the use of out-of-skill labor, reached an optimal solution which forced the firing of 4.12 man-hours of E.M. (electronics mechanic) permanent employees. However, as indicated in Table V,as the cost of the temporary E. (electrician) labor exceeds $6.50 per hour, the firing of permanent E.M. employees is no longer necessary, for those employees which would have been fired are sent out-of-skill. This plateau is the point at which the out-of-skill E.M. labor ($6.16 per hour at an efficiency of 0.90) is cheaper than the temporary

TABLE V. RESULTS OF PARAMETRIC STUDY OF A CHANGE IN THE COST OF TEMPORARY ELECTRICIAN AND TEMPORARY ELECTRONICS MECHANIC

Changed Cost Parameter	Electronics Mechanic Labor Input [1,2] (man-hours)			
	s	o	fo	t
None (Base)[3]	281.05	9.00	14.83	21.00
Temp. E. = $6.50/hr	281.05	9.00	18.95	21.00[4]
Temp. E.M. = $5.85/hr	285.17	9.00	14.83	16.66
= $6.75/hr	285.17	24.83	14.83	0

1. Electrician labor inputs are the results of the sample problem (except where noted).
2. Designations are work types (same as subscripts used in model).
3. Costs as shown in sample problem (temporary electrician = $5.18, temporary electronics mechanic = $5.41).
4. 23.10 temporary electrician man-hours (as opposed to sample problem value of 27 man-hours) are hired.

E. labor ($6.50 per hour at an efficiency of 0.95). It is interesting to note in this situation that only 18.95 E.M. man-hours are sent out-of-skill. To send more would require increased use of overtime labor (since sufficient E.M. straight time labor to meet that skill's workload would no longer be available). This overtime use would also make it more expensive to send the E.M. out-of-skill than to use him within his own skill.

Table V also indicates two other plateaus in the E.M. manning level due to the increase of the temporary E.M. cost. The first of these is $5.85, at and above which the firing of E.M. permanent employees ceases, due to the fact that the productive temporary E.M. labor is now more expensive than an equivalent amount of E.M. straight time labor. The second plateau occurs at $6.75, at and above which no temporary E.M. labor is hired, since at this point E.M. overtime labor is more productive.

2. Temporary Labor Efficiency Factors

In further investigating the .95 efficiency factor obtained for the temporary labor, it appears that a misinterpretation of the area of the questionnaire pertaining to the temporary labor may have occurred. The intent of the questionnaire was to measure the overall temporary labor efficiency compared with permanent labor at NARFSD. Such items as the ability to use special equipment, learning a new administrative system, and adjusting to the idiosyncrasies of NARFSD must be included in this overall efficiency of the temporary labor. However, the supervisors apparently rated temporary labor only on its ability to perform a

skill-oriented task. To examine the effect of a change in the efficiency factor to represent this overall efficiency (if, in fact the misinterpretation occurred), a parametric study was conducted. The results of this study may be seen in Table VI.

TABLE VI. RESULTS OF PARAMETRIC STUDY OF A CHANGE IN THE EFFICIENCY FACTOR FOR A TEMPORARY ELECTRICIAN OR ELECTRONICS MECHANIC

Changed Efficiency Parameter	Electronics Mechanic Labor Input[1,2] (man-hours) s	o	fo	t
None (Base)[3]	281.05	9.00	14.83	21.00
Temp. E. Eff. = .85	281.05	9.00	17.83	21.00
= .76	279.17	10.88	20.83	21.00
= .74		INFEASIBLE		
Temp. E.M. Eff. = .88	285.17	9.00	14.83	18.62
= .76	285.17	24.83	14.83	0

1. Electrician labor inputs are the results of the sample problem.
2. Designations are work types (same as subscripts used in model).
3. Efficiency factors are as shown in sample problem (temporary electrician = .95, temporary electronics mechanic = .95).

In examining the effect of a decrease in the temporary E. efficiency factor, it was found that more E.M. labor must be sent out-of-skill to assist the E. labor in meeting its required workload. As more labor is sent out-of-skill, the E.M. skill must begin to increase the use of overtime to meet its own workload requirements (on Table V, shown as .76 and below). Once the temporary E. efficiency reaches a value of .74 or below, the problem becomes infeasible, since the electrician skill can no longer (even with a maximum allowed amount of out-of-skill labor) meet its workload requirement.

On the other hand, a decrease in the temporary E.M. to below .88 creates a situation in which the E.M. straight time labor is more productive ($5.41 per hour at .88 as compared to $6.16 at 1.0) at an equal cost and as such, less temporary labor is used in the E.M. manning level. Once the efficiency factor is .76 or less, overtime E.M. labor becomes more productive, and temporary E.M. labor is no longer hired.

Since all temporary labor has been identified by only one efficiency factor (i.e., .95), there is a possibility that each skill has a different factor (as was the case for out-of-skill efficiency factors). To examine this possibility, a parametric study was conducted on combinations of decreases in the two temporary labor efficiency factors. The results of these studies appear in Table VII.

TABLE VII. RESULTS OF PARAMETRIC STUDY OF COMBINATIONS OF CHANGES IN THE EFFICIENCY FACTORS FOR TEMPORARY ELECTRICIANS AND TEMPORARY ELECTRONICS MECHANICS

Changed Efficiency Parameter Temp. E.	Temp E.M.	Electronics Mechanic Labor Input[1,2] (man hours) s	o	fo	t
None (Base)	None (Base)[3]	281.05	9.00	14.83	21.00
= .85	= .85	282.17	9.98	17.83	21.00
= .75	= .85	279.17	12.98	20.83	21.00
= .85	= .75	282.17	27.83	17.83	0
= .75	= .75	279.17	30.00	20.83	1.11
= .74	= .75	INFEASIBLE			

Several interesting observations can be made from the above table. First, as efficiency factors decrease, the E.M. skill is forced to use more overtime and send more labor out-of-skill to meet workload requirements. However, as the temporary E.M. efficiency drops below .76 (see Table V), that skill will use temporary labor only when all other

1. Electrician labor inputs are the results of the sample problem.
2. Designations are work types (same as subscripts used in model).
3. Efficiency factors as shown in sample problem (temporary electrician = .95, temporary electronics mechanic = .95).

options for meeting its workload (and assisting the electrician skill) have been exhausted. Finally, when the temporary E. labor efficiency factor reaches .74, no feasible solution can be reached without a change in the constraints (i.e., raise M_o to above .10 M_s).

3. Out-of-Skill Efficiency Factors

The major result of the efficiency questionnaire was the investigation of efficiency factors for the out-of-skill labor force, a labor force seldom used by NARFSD. As noted, this labor utilization tool could be an extremely valuable input to the labor force if accurate efficiency factors could be obtained. However, since the values for the factors used were the result of averaging of data which itself was based on managerial experience (and as such was subjective), a parametric study of these factors was made. Results of this study appear in Table VIII.

A decrease in the efficiency of electrician labor capable of being sent out-of-skill to the E.M. skill does not effect the manning level for either skill, since this option is not used (input data was set up to force this situation). However, a decrease in the efficiency of the E.M. labor capable of being used out-of-skill results in an increased amount of labor having to be sent to the E. skill for that skill to complete the workload requirements. This decrease further results in an increased use of overtime in the E.M. skill (increased to 9.12 man-hours). As this efficiency factor decreases to .63 or below, the problem becomes infeasible, since the E.M. skill can no longer provide sufficient out-of-skill labor to allow the electrician skill to complete the required workload.

TABLE VIII. RESULTS OF PARAMETRIC STUDY OF A CHANGE IN THE EFFICIENCY FACTOR FOR OUT-OF-SKILL LABOR

Changed Efficiency Factor	Electronics Mechanic Labor Input[1,2] (man hours)			
	s	o	fo	t
None (Base)[3]	281.05	9.00	14.83	21.00
Eff. of E. to E.M.				
= .70	NO CHANGE			
Eff. of E.M. to E.				
= .80	281.05	9.00	16.69	21.00
= .70	280.93	9.12	19.07	21.00
= .63	INFEASIBLE			

1. Electrician labor input are the results of the sample problem.
2. Designations are work types (same as subscripts used in model).
3. Efficiency factors as shown in sample problem (electrician sent out-of-skill to electronics mechanic = .80, electronics mechanic sent out-of-skill to electrician = .90).

4. Cost of Data Variations

In Table IX, the dollar cost of increasing the temporary hourly wage by one dollar and reducing all efficiency factors by .10 are shown. Column one displays the increased cost above that of the sample problem solution due to the noted changes in parameters. Column two projects these man-hour costs to man-quarter costs. This cost demonstrates the significance of variations in the input data when projected to a 500 man-hour quarter, which is approximately the number of hours that the average worker will expend per quarter.

TABLE IX. PROJECTED QUARTERLY COSTS

Parameter Changed	Increase in Man-hour Total Cost[1]	Increase in Man-Quarter Total Costs
Temp. E. = $6.18	$26.32	$13,160.00
Temp. E.M. = $6.41	18.56	9,280.00
Temp. E. Eff. = .85	18.48	9,240.00
Temp. E.M. Eff. = .85	12.50	6,250.00
Eff. of E.M. to E. = .80	11.46	5,730.00
Eff. of E. to E.M. = .70	NO CHANGE	NO CHANGE

1. Above the cost obtained in the sample problem ($4,671.27).

IV. DISCUSSION OF ASSUMPTIONS AND ESTIMATED PARAMETERS

In the development of a mathematical model, assumptions and estimations were made in order to obtain a simplified model. This section will discuss and explain many of these aspects and the reasoning behind the incorporation of each into the model.

A. PERMANENT LABOR FORCE

As a basis for all computations and comparisons, the authors have chosen the permanent worker. Three factors make up the definition of the permanent worker: (a) he works eight hours per day, forty hours per week; (b) he accrues two and one-half days of annual paid leave per week; and (c) he is eligible for severance pay if fired.

B. COST COMPUTATIONS FOR PERMANENT LABOR

The average hourly cost computations for the various trade skills used in the model development differ from NARFSD accounting methods. NARFSD computes the cost of government benefits (retirement, life insurance, health insurance, annual and sick leave, paid national holidays, and social security) as a factor above the base hourly wage of the worker. This factor is computed by summing the total cost of government benefits and the total cost of the quarterly projected workload including overtime and dividing by the cost of quarterly projected workload including overtime. The resultant facor (e.g. 127% was a recent NARFSD acceleration

factor for benefits) is then used to compute the cost of a permanent worker (i.e., acceleration factor times base hourly wage is equal to cost).

The base average hourly wages used for the sample problem and parametric studies were computed by using the on-board direct labor force mix of wage grades as of June 1971 and the base hourly wage schedule (Table IV).

TABLE IV. BASE HOURLY WAGE SCHEDULE AT NARFSD

GRADE	1st	2nd	3rd	GRADE	1st	2nd	3rd
1	3.00	3.13	3.26	9	4.24	4.42	4.60
2	3.16	3.29	3.42	10	4.40	4.58	4.76
3	3.31	3.45	3.59	11	4.55	4.74	4.93
4	3.47	3.61	3.75	12	4.70	4.90	5.10
5	3.62	3.77	3.92	13	4.86	5.06	5.26
6	3.77	3.93	4.09	14	5.01	5.22	5.43
7	3.93	4.09	4.25	15	5.16	5.38	5.60
8	4.08	4.25	4.42				

Since any given trade skill may be composed of from four to six wage grades and any one of three wage steps, averaging simplifies the model considerably,

while maintaining the concept of the average man. The base average hourly wages are shown in Table III.

For use in the model, government benefits were assumed to be associated with straight time wages only. To correct the base average wage for the cost of social security, health and life insurance, and retirement, a weighting factor of 1.083 (based on historical data at NARFSD) times the average wage was assumed. A value of 1.2 times this weighting factor is assumed to incorporate the effect of paid holidays and annual and sick leave (i.e., paid unproductive labor). Assuming that the average permanent worker will take all annual and sick leave available, management believes that this average worker will produce approximately 1740 hours of productive labor per fiscal year (2088 hours of straight time labor per year divided by 1740 productive hours per year = 1.2).

Several other costs were investigated in order to determine if they should be included in the straight time correction factors. Severance pay is a real dollar cost to NARFSD in the event that a permanent worker is fired. This cost varies directly with the trade skill and longevity of the fired worker. However, based on historical data concerning the number of firings of permanent workers for the period January 1969 to May 1971, this cost is less than one cent if reduced to an hourly rate.

The overtime costs were computed by multiplying the worker's base hourly wage by a factor of 1.5. This factor does not include government benefits, but by incorporating these factors into the straight time labor costs, a distinct difference in hourly cost is noted.

C. COST COMPUTATIONS FOR TEMPORARY LABOR

In line with present NARFSD policies, it has been assumed that no temporary worker will work overtime unless this individual can operate at 1.0 efficiency. The efficiency questionnaire indicates that .95 is the efficiency of the average temporary worker. Therefore, the temporary workers, as a group, will not work overtime and their base wage is assumed to be that of the permanent workers in the same skill category.

The temporary worker has an hourly wage acceleration factor of 1.054 vice the 1.2 factor used for the permanent worker. This factor is directly attributed to the fact that the temporary worker accrues no annual leave during the period that he is designated a temporary worker. This lack of annual leave leads to an increase of 240 hours of productive labor per year (2088/1980 = 1.054). All other benefits are equivalent to those enjoyed by the permanent labor force (i.e., 1.083 acceleration factor).

As discussed in CHAPTER III, the temporary worker is the least expensive worker to employ, even with a reduced efficiency factor of .95. One major item that is not included in the cost figures is the cost involved with training these temporary workers. NARFSD presently operates under a system of "norms," the standard time necessary to perform a specific task. Incorporated into the "norms" is a weighting factor that accounts for the loss of productive time while an individual is undergoing formal training. As a consequence, it is difficult to obtain a meaningful cost for this type of training.

To take into consideration any constraints on the physical capacities of a shop, it has been assumed that the temporary labor force in any specific shop will not exceed a figure equivalent to seven percent above the shop's permanent labor force. This constraint further assumes that an increase of the shop force by seven percent will not adversely effect the overall shop efficiency. The authors realize that this figure is an arbitrary choice, but discussions with NARFSD management led to the conclusion that this figure is reasonable.

D. COST COMPUTATIONS FOR OUT-OF-SKILL LABOR

As with temporary labor, it has been assumed that the out-of-skill labor will not work overtime. In conversations with management personnel, the authors came to the conclusion that the use of an out-of-skill labor force would reduce the overall overtime efficiency factor and morale would be lowered to a point at which the overtime would become too expensive for the resulting productive labor.

It is further assumed that the hourly cost of the out-of-skill labor force is equal to that of the permanent labor force in the same designated trade skill. The out-of-skill labor force will suffer no reduction in hourly wages, even though they may be performing in a skill which is less costly. If this policy is changed, the change might have an adverse effect on the morale and motivation of the effected worker, thereby reducing any positive effect caused by using this labor force.

In defining the out-of-skill labor force, it is assumed that there is no formalized cross-training program. Any cross-training that a skill possesses is obtained solely by direct association with, or having similar background requirements to,those of the skill using this out-of-skill labor. As an example, an electronics mechanic and an electrician both require basic knowledge of electricity, a common factor that accounts somewhat for their relatively high out-of-skill efficiency factors.

E. OTHER RESTRICTIONS ON OUT-OF-SKILL LABOR

Several other restrictions and assumptions have been placed on the out-of-skill labor force. Any skill that is unable to work out-of-skill at an efficiency factor of at least .70 was assumed to not be used as a part of this work type. This figure equates to 5.6 hours of productive labor per eight-hour day, a figure management personnel felt was the minimum acceptable.

One area of concern that is a real problem, even though it is not present in this model, is the fact that the local labor unions in the San Diego area restrict the time a worker may work out-of-skill to four months. If utilization model is used for long range planning of more than four months, this restriction should definitely be incorporated into the model.

F. EFFICIENCY QUESTIONNAIRE

One of the major problems involved in a variable workload situation is the difficulty in measuring labor efficiency. In a typical production line, labor efficiency could be measured in terms of units produced per hour or hours necessary to perform an assigned task. Such is not the case at NARFSD where labor may perform several tasks per day, each different than the day before. Therefore, in an attempt to measure the relative efficiency of the various trade skills, the authors developed an efficiency questionnaire (Figure 9).

The basic idea was to question an individual who had firsthand knowledge of the various trade skills, but was also involved in mangement planning. It was hoped that these individuals could see the merits of this type of questionnaire and would therefore provide reasonably accurate data in response to the questions presented. The individuals selected had, on the average, twenty-five years of experience at NARFSD or other similar facilities. Many of these individuals started their careers as members of the direct labor force and were promoted to their present positions.

After defining nineteen major trade skills (i.e., those trade skills composed of at least fifteen workers) and designing the questionnaire format, the questionnaire was distributed to the twenty-five shop supervisors. The supervisors were asked to read the questionnaire and discuss it with other shop personnel. They were further instructed not to fill in

We are attempting to obtain a feeling for efficiency of direct labor in the following four categories:

1. Career employee working in his designated trade (straight time).

2. Temporary employee working in his designated trade (one year limited, straight time).

3. Career employee working in a job outside his designated trade but closely related (90 day limited straight time).

4. Career employee working overtime in his designated trade.

Definition of terms:

1. "In designated trade" - working in the trade or craft or skill in which he is trained, experienced and designated.

2. "Outside designated trade" - working in a trade or craft or skill other than that in which he is trained, experienced and designated.

3. "Efficiency" - generally demonstrated effectiveness in accomplishing the workload assigned to his category.

In completing the following survey, assume that:

1. In the case of a career employee, assume that he has the necessary training and experience to qualify him to work in the position in which he will be rated.

2. In the case of a temporary employee, assume that he already possess the basic knowledge of his trade and has completed a short indoctrination (2-4 weeks).

3. In the case of a career employee working out of his trade, assume only that he has already completed a short indoctrination (2-3 weeks).

FIGURE 9a. EFFICIENCY QUESTIONNAIRE (Page 1)

Because we need a point on the scale to which we can relate, we shall assign Category 1 personnel an efficiency index of 1.0. Other categories of personnel should be rated up or down relative to this base, from zero to as high as is considered appropriately descriptive.

Examples:

a. A rating of 0.5 indicates that Category (x) accomplishes, in general, half as much as Category 1.

b. A rating of 2.0 indicates twice as much.

In all cases, consider that you are rating a class or a category, not an individual; or you may consider that you are rating a theoretical individual who is representative of his class or category.

Overall Ratings.

Category	Type Time	Type Employee	In Trade	Rating
1	Straight	Career	Yes	1.0
2	Straight	Temporary	Yes	
3	Straight	Career	No	See next page
4	Overtime	Career	Yes	

Trade(s) Being Rated: ______________________________

____

(Please use additional sheets if you wish to distinguish between trades).
Now go to last sheet for Category 3 ratings, then return here for Category 4.

Overtime Ratings.

We are now looking at overtime efficiency indices as a function of three different time scales; i.e., hours of a day, days of a week and number of weeks. Please use extra sheets to distinguish between trades, if necessary.

Trade(s) Being Rated: ______________________________

____

FIGURE 9b. EFFICIENCY QUESTIONNAIRE (Page 2)

Overtime Ratings.

1. Efficiency ratings of overtime hours in a single day (assume that this is the first day of overtime).

	Hour of work								
	1-8	9	10	11	12	13	14	15	16
Rating	1.0								

2. Efficiency ratings of continuous days in a single week against continuous weeks of overtime.

	Continuous Weeks									
Continuous 8 Hr Days	1	2	4	6	8	10	12	14	16	18
5	1.0									
6										
7										
Continuous 9 Hr Days										
5										
6										
7										
Continuous 10 Hr Days										
5										
6										
7										
Continuous 12 Hr Days										
5										
6										
7										

General Questions.

1. What is your background trade? ____________________

2. Do you feel that this survey is a fairly accurate method of efficiency? ____________________

FIGURE 9c. EFFICIENCY QUESTIONNAIRE (Page 3)

DESIGNATED SKILL / OUT-OF-SKILL ASSIGNMENT	A/C Electrician	A/C Engine Mechanic	A/C Instr. Mechanic	A/C Metalsmith	Ordnance Mechanic	Electronics Mechanic	Machinist	Instrument Mechanic	A/C Mechanic	Painter	Bearing Reconditioner	Metal Cleaner	Upholsterer	Sandblaster	Electroplater	Buffer and Polisher	Plastic/Fiber-glass Worker	Toolmaker	Welder
A/C Electrician																			
A/C Engine Mechanic																			
A/C Instrument Mech.																			
A/C Metalsmith																			
Ordnance Mechanic																			
Electronics Mechanic																			
Machinist																			
Instrument Mechanic																			
A/C Mechanic																			
Painter																			
Bearing Reconditioner																			
Metal Cleaner																			
Upholsterer																			
Sandblaster																			
Electroplater																			
Buffer and Polisher																			
Plastic/Fiberglass Wkr																			
Toolmaker																			
Welder																			

FIGURE 9d. EFFICIENCY QUESTIONNAIRE (Page 4)

the questionnaire except in the presence of the authors. This afforded the authors an opportunity to monitor the supervisors as they filled in the questionnaire and to prevent any misinterpretation of what was requested by the questionnaire. It also afforded the authors the opportunity to judge the supervisors' attitude toward the questionnaire.

As rating progressed, the authors found that they had to continually remind the supervisors to rate the average man, instead of a specific individual. An area of concern to the supervisors was what incremental value to use when numerical responses were required. The authors recommended that .05 increments be used; several supervisors felt that this figure was too detailed and responded in increments of .10.

The supervisors were also asked to specify an efficiency cutoff figure below which they felt the use of the out-of-skill individual was too expensive for the labor produced. The opinion of the majority was that a factor of .70 was the lowest figure that should be considered.

Twenty forms were returned in complete enough detail for use in computing average efficiencies. In tabulating the final efficiency factors (Table X) a simple averaging technique was used on those skills in which more than five responses were recorded. Two examples are the use of aircraft engine mechanic as an ordnance mechanic (with a total of thirteen responses, seven below and six above the .70 cutoff), resulting in an average of .75; and the aircraft mechanic used as a metal cleaner (with six responses, all within $\pm$ .05 of each other), resulting in an average of .95.

TABLE X. OUT-OF-SKILL EFFICIENCY FACTORS

OUT-OF-SKILL ASSIGNMENT \ DESIGNATED TRADE	A/C Electrician	A/C Engine Mechanic	A/C Instr. Mechanic	A/C Metalsmith	Ordnance Mechanic	Electronics Mechanic	Machinist	Instrument Mechanic	A/C Mechanic	Painter	Bearing Reconditioner	Metal Cleaner	Upholsterer	Sandblaster	Electroplater	Buffer and Polisher	Plastic/Fiber-glass Worker	Toolmaker	Welder
A/C Electrician	1.0		.70		.70	.90		.70	.70										
A/C Engine Mechanic		1.0		.70	.70		.70		.80										
A/C Instrument Mech.	.80		1.0			.80		.95											
A/C Metalsmith				1.0			.75											.70	.70
Ordnance Mechanic		.75			1.0	.75			.80										
Electronics Mechanic	.80					1.0		.75											
Machinist							1.0											1.0	
Instrument Mechanic	.75		.95			.85		1.0											
A/C Mechanic	.70	.85		.75	.80		.70	.70	1.0									.75	
Painter									.70	1.0							.70		
Bearing Reconditioner	.80	.95	.90	.70	.80	.80	.90	.90	.85	.80	1.0	.75				.70	.70	.90	
Metal Cleaner	.70	.85		.95	.80		.90		.95	1.0	.80	1.0	.80	.90	.85	.80	.85	.90	.85
Upholsterer													1.0						
Sandblaster	.70	.85		.85	.75		.90	.85	.80	.80	.85	.80	.70	1.0	.80	.80	.70	.70	.80
Electroplater	.70														1.0				
Buffer and Polisher		.80	.80	.85	.90	.85	.85	.75	.80	.85	.90	.80		.90	.95	1.0	.80	.90	.90
Plastic/Fiberglass Wkr		.70		.80	.75					.80	.70						1.0		
Toolmaker							.85											1.0	
Welder																			1.0

Included within the efficiency questionnaire were several queries whose results did not figure prominently in the model development, but might be useful for future reference. Typical of these was the question concerning the maximum amount of overtime an individual could work before the overtime efficiency drops off severely (Figure 9c).

Because the authors felt that some of the supervisors might show preferential treatment to their trade skill background, a question was included to determine each supervisor's trade skill experience (Figure 9b). This bias appeared to be present in only very isolated cases. (Note: the overall results of the efficiency questionnaire have been studied by NARFSD Methods and Standards' personnel and the general reaction has been that the results are reasonable.)

G. MISCELLANEOUS ASPECTS OF THE PROBLEM

NARFSD has historically experienced a normal attrition of approximately 150 workers per quarter, of which nearly 100 were members of the permanent, direct labor force (January 1969 to May 1971). Several reasons for this attrition are death, retirement, family problems, and change of routine, all factors that no manager can control. The model developed to solve the utilization problem does not include an activity to replace these attrited workers. Instead, it assumes that the attrited worker is replaced on a one-for-one basis by an equally trained worker. In specific instances, this assumption is not valid, for it is a "no cost"

method of reducing the labor force. In the event that the labor force must be reduced, the managers do realize that this means can be used.

In conjunction with the assumption of a constant workload per quarter for this model, assumptions concerning the hire-fire procedures to be used were made. By using the temporary labor in the model, the authors have, in fact, included a hiring procedure. There is, however, no fire activity listed for or shown in the network.

As previously mentioned, the workload requirements for the upcoming quarter are reached at the previous mid-quarter conference. This allows management approximately six weeks in which to obtain a labor force capable of performing this workload. It is assumed that this model would be used by management prior to the start of a quarter to determine the optimal utilization of the labor force and the related costs of various options. In using the model, the number of workers to be fired for this optimal allocation is obtained by comparing the sum of the flow in the straight time and out-of-skill arcs to corresponding M_s values. If M_s is the larger, the difference is considered to have been fired. If this model is needed for long range planning, then firing should be incorporated into the network.

It is interesting to note the .95 efficiency given to temporary labor. The authors felt that the temporary worker would be considerably less efficient than the permanent worker. However, conversations with senior management personnel revealed two possible explanations for the seemingly high figure of .95. The first reason was the fact that the San Diego area

is composed of a highly skilled labor force, encompassing all trade skills employed at NARFSD. Another reason is that the temporary employee works more diligently, knowing that a job well-done could lead to permanent worker status and its related benefits.

Morale and motivation are two factors toward which man has allocated much time and effort in the search for definitions and costs which are meaningful. In the discussion of hourly costs, only real dollar costs were included. At the present time, it is extremely difficult to place a dollar value on morale and motivation, but the two factors do have a definite effect on the worker's ability to perform. An unhappy worker, a worker with a "poor" attitude, or the worker with no hope of job security is admittedly less efficient than the contented worker.

NARFSD is presently attempting to minimize any negative cost due to morale or motivation by placing strong emphasis on having a constant labor force with a minimum turnover in personnel. In keeping with this emphasis, the authors felt that the time spent investigating the out-of-skill labor was not wasted. In the event DOD restrictions reduce present NARFSD labor force limits, the out-of-skill work force may become a valuable management tool in maintaining a constant labor force.

V. SUGGESTED AREAS OF FURTHER STUDY

A. SENSITIVITY STUDIES

The use of sensitivity analysis is a valuable means of identifying key factors in network flow problems. The optimal solution obtained as a result of the use of network solution techniques is dependent on many data inputs and constraints, and often a slight change in one or more of these factors will have a major effect on the final solution. Through the use of sensitivity analysis, those factors which, when changed slightly, have the greatest effect on the final solution may be identified. Once the most sensitive of these factors is determined, a reappraisal of their current values can be made. Sensitivity studies may also be conducted to determine the effect of various combinations of, or the addition of, constraints to the problem.

The parametric studies conducted on the sample problem emphasize several "sensitive" parameters. These are the hourly wage of the temporary labor and the efficiencies of the temporary and out-of-skill labor. The hourly wage cost assigned to the temporary labor should be investigated, especially to determine the effect of excluded costs. Because they are based on subjective judgement, the efficiency factors of the temporary and out-of-skill labor should be reexamined prior to their use to insure that they are as accurate as possible.

B. USE OF A SHOP CONCEPT

The model is concerned primarily with trade skills, rather than shops which are comprised of several trade skills. In adapting this model to a labor situation such as that at NARFSD, the model could be expanded to incorporate these shops in the form of subnetworks within a larger network. This larger network could represent a division from which a master network of NARFSD could be developed.

One of the advantages of the "shop" over the "skill" concept is that shops are composed of several fairly small skill forces. As such, the averaging technique used to obtain hourly costs and efficiencies would result in more accurate estimates. In addition, shop managers could determine various out-of-skill efficiencies among the same skill force within the shop. As an example, there are certain electricians who could conceivably perform as an electronics mechanic at an efficiency of .95, while a second group might perform at an efficiency of .30. With these figures, the out-of-skill labor force which is available in any skill could be considered as several distinct groups.

C. DEVELOPMENT OF A CONSTANT WORKLOAD

In developing the model, the authors made the assumption that the workload was constant. At the present time, the workload is constant only in conjunction with short range planning. Historical data demonstrates a 98% accuracy for a one-quarter projection. This accuracy decreases approximately 5% per quarter for longer range planning.

There appear to be three methods of creating a more constant workload. The first of these is to develop a system for more accurately predicting workload. This could be accomplished by using historical data on aircraft to determine the total "par" time per aircraft rather than the present method of using "norms" to obtain expected time an aircraft will take to complete the par cycle.

The second means for determining a better estimate of the amount of work each aircraft should require is to develop field teams consisting of members from each major trade skill. These teams could inspect each aircraft prior to delivery to NARFSD and advise the rework facility of their estimate of expected work required as an input to update prior estimates. A trial period of this field team concept could be implemented to study the effect on time stimates and the associated costs.

A third approach would be to set up a queue of aircraft waiting rework and repair. These aircraft would be scheduled to arrive at NARFSD within some specified time period prior to induction into the rework cycle. This would allow time for careful inspection of the aircraft and an updating of workload projections to reflect unexpected damage and modifications.

D. EXTENSIONS OF THE MODEL

The "network with gains" algorithm developed by Jewell utilizes the primal-dual method of solution, which requires all lower bounds to be zero. In the case of the sample problem, the few non-zero lower bounds

encountered were adjusted with little difficulty to allow the use of Jewell's algorithm. If, however, non-zero lower bounds were imposed on most of the arcs in the model, a more sophisticated algorithm which does not require zero lower bounds would be advantageous. This would alleviate the need for a large number of preliminary calculations to adjust lower bounds.

An algorithm such as the "Out-of-Kilter" algorithm of Ford and Fulkerson (1962) is capable of solving not only those minimal cost flow problems which the primal-dual algorithm can solve, but as well, problems which contain non-zero lower bounds. With the appropriate adjustments to include gains, it could become an improved solution technique for the utilization problem.

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13. ABSTRACT

The management personnel at the Naval Air Rework Facility, North Island Naval Air Station, San Diego, California, are currently faced with two difficult planning problems inherent in any large industrial concern. These are the inability to smooth the workload so that it may be considered constant over a specific period of time and the determination of the optimal utilization of the direct labor force in order to produce the workload at minimum dollar wage cost. Assuming a constant workload, a mathematical model of this utilization problem, incorporating constraints and restrictions placed upon NARFSD by various agencies, is developed which can be solved as a minimal cost flow-with-gains network problem. By varying the constraint and restriction limits, several alternative manpower utilization options and their related costs are examined. Finally, various methods of smoothing variable workloads are suggested.

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