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VALIDATION OF QUEUING TECHNIQUES FOR DETERMINING SYSTEM MANNING AND RELATED SUPPORT REQUIREMENTS

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FOREWORD

This report was prepared by Radio Corporation of America, Camden, New Jersey. It was prepared for the Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. The study was made under Contract No. AF33(657)-11607. The period of performance was from February 1964 to October 1964. The principal investigator was Mr. R. E. Purvis.

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This technical report has been reviewed and is approved.

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ABSTRACT

A program was conducted to establish the validity and reliability of a technique of mathematical modeling for predicting manning requirements for weapon systems. The model was based on AMRL-TDR-64-21, "A Queuing Model for Determining System Manning and Related Support Requirements," and AMRL-TR-64-125, "Queuing Tables for Determining System Manning and Related Support Requirements." The technique was applied to two systems; the F105D fire control system (FCS), which presently is operational; and the C141 system, which is scheduled for operation in the near future. The model prediction for the FCS, using field data for parameter estimation, yielded good results when compared with operational performance. Moreover, it was shown that the operational performance could be achieved by 34% less personnel than the manning set by the table of organization. The model prediction for the FCS, using conceptual data, resulted in substantially the same manning for the maintenance shop as that developed from the measured data; but, because maintenance concepts had been changed in the field, the number of flightline airmen was larger than the measured data. The manning prediction for the C141 system, based on operational rates planned for the system and field data on the C130 system, resulted in a prediction of 819 airmen in the organizational maintenance squadron and 476 airmen in field maintenance squadron. With the predicted manning it could be expected that an operational readiness of 78% could be maintained.

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SECTION I

INTRODUCTION

1.1 Content of the Report

System manning has been a persistent problem with all industry and the services. It has been a particular problem with the Air Force because of the multitude of systems and personnel skills involved. The mathematical model to be validated here is based on finite cyclical queuing theory. Details of the model are contained in a previous report, "A Queuing Model for Determining System Manning and Related Support Requirements," (Ref. 1). (See also appendix I.)

This report has been organized with the intent to make the reading relatively independent of preceding program reports. The reader will find a general discussion of validity and reliability of prediction models followed by experimental design of the model validation test in this section. A detailed description of the manning model is discussed in section II.

The remainder of the report consists of application of the model to specific systems. Preliminary information required for model application is presented in the first model application in section III. This consists of the development of necessary conversion factors, and is not repeated in the second model application in section IV. Section V presents general conclusions and recommendations. References and appropriate appendices are called out for background.

1.2 Decision Methods

Before a decision is made that a predictive mathematical model is acceptable, a validation is needed. The ways in which a prediction model may not meet stated objectives are as follows:

a. The model may include superfluous, independent, variables which have no appreciable effect on the dependent (output) variable.

b. The model may omit significant independent variables.

c. The model may assert an inaccurate, incorrect, or inadequate functional relation between the dependent variables. This may be the case for only certain ranges of values of one or more of the independent variables.

d. A valid model apparently may fail due to inaccurate parameter predictions. That is, inaccurately predicted values of an independent variable, substituted into the model, may yield an incorrect value for the dependent variable; where accurate predictions would have yielded an acceptable value.

e. Every mathematical model of a real system is an approximation. An extremely accurate approximation is possible by taking many independent variables into account, and using accurate values for these variables. If some of the variables are neglected because of poor model construction, or because they are not measurable, the approximation can be inaccurate. Therefore, it is necessary to decide in advance what degree of accuracy will lead to model acceptability. In general, sophistication and refinement of models are subject to diminishing returns, so that each further improvement bought at the same cost in technical effort will yield a smaller improvement in accuracy. Accordingly, it is desirable to attempt model sophistication only commensurate with desired accuracy.

The points discussed above form the fundamental criteria used in the validation of the model evaluated for manning prediction capability undertaken in this program.

1.3 Test of Model Validity

Basically the most appropriate way of validating the manning model described in this report is to compare the operational readiness level predicted by the model, based on a certain manning level, with the measured readiness actually achieved by the system in the field when it is appropriately manned. However, since in fact the system chosen for test can not be expected to have the same manning as that predicted by the model, direct validation is not possible. Therefore, the test of validity of the model must be made based on secondary criteria, which in turn will lead to the manning.

Such secondary criteria are operational readiness, waiting times, percentage of time wait occurs, etc. For a given set of parameter data, the model produces these secondary criteria, which lead directly to the correct manning.

1.4 Test of Model Reliability

The test of reliability of a model lies in the ability to produce consistent results with different experimenters. Although this validation program did not formally test for reliability, several partial tests have been performed, and a method has been developed which gives a general procedure for achieving reliability.

1.5 Experimental Design of Model Validation

The validation experiment for the manning technique was designed in the following manner. Two systems were selected which would be manned using the technique under test. One of two systems selected (system A) possessed considerable data, while the other (system B) was selected such that only conceptual information was available.

This choice was made to enable detection of potential error sources, and the subsequent modifications to the technique, using first the system with existing operational data. Moreover, if the technique did not work for a system for which information did exist, it would not be expected to work for a system for which only limited information exists.

The two systems chosen were the F105D Fire Control Subsystem (F105D-FCS), which will be system A, and the C-141 system (system B).

The F105D-FCS was chosen as system A for the following reasons:

a. The availability of field studies reporting reliability and maintainability data. The predictions of these rates for the system could then be subsequently compared with these field studies.

b. The system is complex, requiring a diversity of skills.

c. The system consists predominately of removeable black boxes.

The C-141 was chosen as a test of the model, primarily because its stage of development is such that field validation may be conducted in the near future. The predictions of model parameter values for this system were based on a comparable, existing system, and were to be subjected to field evaluation.

For system B, item a. was estimated using work experience data from a comparable system. For item b., two basically different activity networks were evaluated. The operational rate, item c, was based on anticipated usage, and maximum achievable operational readiness.

Based on model parameter data and anticipated operational rates, manning was established for the two subject systems, A and B. For system A these manning predictions were compared with the actual manning and the predicted system operational performance. System B manning requirements were predicted and a proposed table of organization (T.O.) structure developed.

1.6 Technique Reliability

There are two major obstacles against the achievement of reliability for the technique when considered from the standpoint of uniform results. The obstacles are: (1) uniform techniques for predicting model parameters. This involves predicting the utilization factor (reliability, maintainability, and operational rate). (2) predicting the organization structure. This involves decisions relative to the types of skills, shops, activities to be made available, crew sizes, and task sequencing.

For (1) above, several variants of the parts count reliability prediction technique are popular, and all provide estimates within a factor of two. Accuracy in maintainability estimates, given adequate skills, can be held within ± 50%. For high levels of operational readiness, which is standard for military systems, the error output of the manning model is less than the aggregate error input in the model parameters.

For (2) above, the organization and activity structure should be based on the peculiarities of the particular system; that is, there is no best organization structure for all systems. However, there are methods applicable to bound personnel requirements, a technique which has been applied to system B.

SECTION II

THE SYSTEM MODEL

2.1 Introduction

The finite cyclical queue describes a process often encountered in military and commercial operations; specifically, where the operation involves electronic equipment, or repairable machines, with which a failure rate and a repair rate may be associated. Figure 1 illustrates the behavior of the system under finite cyclical queue conditions. The mathematics of the model is based on exponential failure and service channel rates. (See appendix I for derivation of the model.)

2.2 Queuing Tables

Tables have been prepared which permit rapid evaluation of personnel requirements in terms of independent maintenance teams or repair channels. A synopsis of the characteristics of the cyclical queuing system is given below in terms of "Queuing Tables for Determining System Manning and Related Support Requirements."[1]

2.2.1 Tabular Entries

C = Number of service channels

N = Maximum number of units which may demand service at a particular instant

S = Number of spare units which may replace units being serviced or awaiting service

P = Utilization factor (λ/μ)

where:

λ = Rate of demand of one unit (failure rate)

μ = Service rate of one channel

2.2.2 Output

Two quantities are the output of the tables as follows:

d = Mean number of failed units, per N, for which no spares (S) are available

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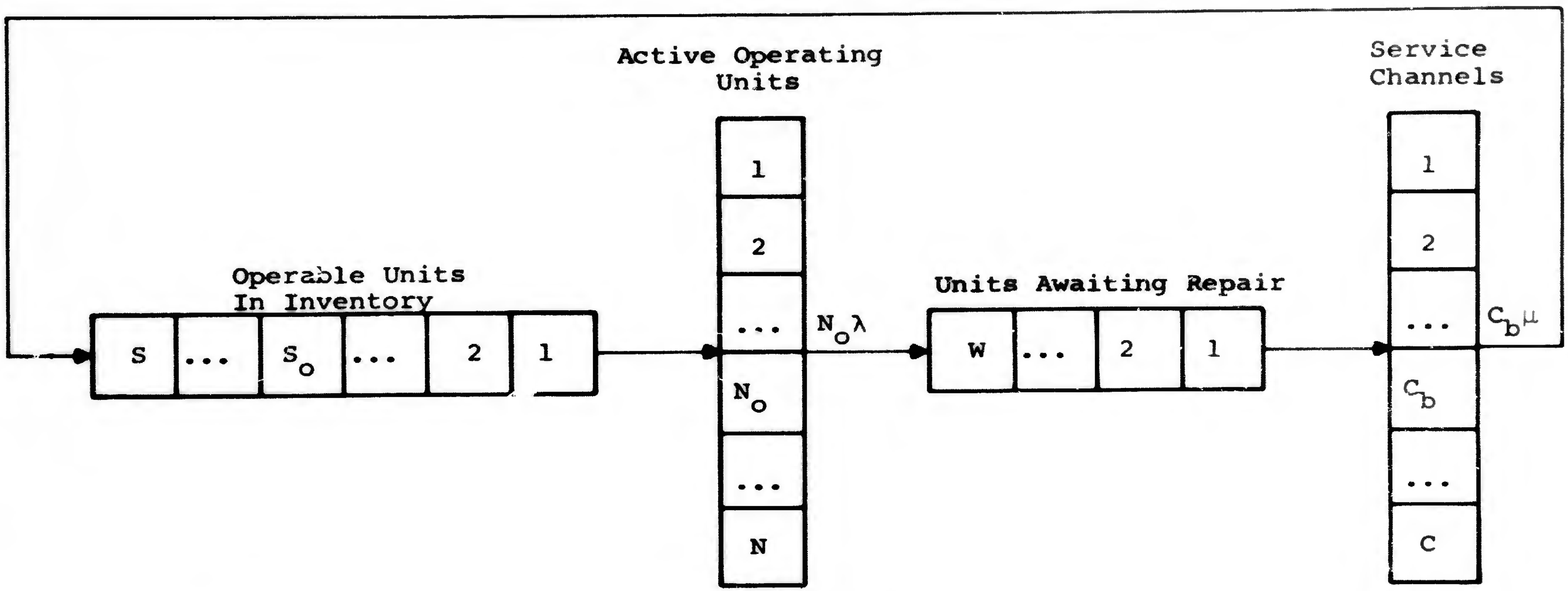
[1] Referred to as Tables in subsequent development.



N = Number of operational positions

N_o = Mean number of operational positions filled

S = Spare units

S_o = Mean number of operable spare units

C = Number of service channels

C_b = Mean number of busy channels

λ = Failure rate of operating unit

μ = Service rate of service channel

W = Mean number of units awaiting service

FIGURE 1. FINITE CYCLICAL QUEUE FOR A SYSTEM

$$= \sum_{n=S+1}^{N+S} (n-S)p_n/N \quad [2] \qquad (1)$$

n_d = Mean number of units, per N+S, either awaiting or undergoing service

$$= \sum_{n=1}^{N+S} np_n/(N+S) \qquad (2)$$

2.2.3 Derived Quantities

The following summarizes the various quantities that may be derived from the Tables, reduced to their tabular terms:

$$N_o = N(1-d) \qquad (3)$$

= Mean number of units operating

$$R = 1-d \qquad (4)$$

= Operational readiness

$$U = N(1-d)/(N+S) \qquad (5)$$

= Utilization of units

$$C_b = NP(1-d) \qquad (6)$$

= Mean number of busy channels

$$c = NP(1-d)/C \qquad (7)$$

= Utilization of service channels

$$W = n_d(N+S)-NP(1-d) \qquad (8)$$

= Mean number of units awaiting service

$$S_o = S+dN-n_d(N+S) \qquad (9)$$

= Mean number of units operable but not operating

$$t_w = [n_d(N+S)-NP(1-d)]/\lambda N(1-d), \text{ or} \qquad (10)$$

$$= [n_d(N+S)-NP(1-d)]/\mu NP(1-d) \qquad (11)$$

= Mean waiting time for service (in queue)

---

[2] See appendix I for definition of p_n - the steady state probability.

$$t_{ws} = n_d(N+S)/\mu NP(1-d) \quad (12)$$

= Mean waiting time in waiting and service

$$t_o = [S+dN+n_d(N+S)]/\mu NP(1-d) \quad (13)$$

= Mean waiting time for operable units before going into operation

SECTION III

F105D FIRE CONTROL SUBSYSTEM

3.1 Introduction

The F105D fire control subsystem (FCS or AN/ASG-19), known as "Thunderstick," is a combination of semi-automatic air to air and air to ground fire control, navigational aid, and automatic bomb delivery control. The three main operating subsystems of the FCS are as follows:

a. Radar (R14A)

b. Attack Display (AD)

c. Bomb Toss Computer (BTC)

There are some other subsystems providing inputs; however, most of the failures and the workload comes from these three subsystems.

3.1.1 Data Collection Program

The basic input data comes from several sources:

a. Reliability and maintainability field evaluation studies were conducted on the FCS by Republic Aviation Corporation (RAC), ARINC, and the USAF. All of the studies were summarized in RAC Document 1950 (Ref. 2). It was necessary for RCA Service Company (RCA) to perform an analysis of this document in order to extract time, failure data, and data on the repair of the FCS. (See appendix II).

b. A one week field trip was made to Seymour Johnson AFB (SJAFB) by the principal investigator where the following information was collected:

1. Time estimates of maintainability, intrabase travel time, waiting times, and time for maintenance tasks involving black boxes.

2. Level of spares, effective repair channels, and test equipment data.

3. Aircraft usage rates, operational readiness data, and personnel skill data.

3.1.2 FCS Maintenance at Seymour Johnson AFB (SJAFB)

Basically the maintenance support system consists of flightline personnel and Avionics and Electronics Shop (maintenance shop) personnel. (See appendix IV.)

3.1.2.1 Flightline Maintenance

Flightline maintenance on the FCS consists of three distinct types of activity:

a. The diagnostic team, consisting of 2 men of seven level for each 2 shifts in operation. The function of the team is to attend the debriefing of pilots and localize faults in the FCS. They then pass on this information to the regular flightline teams.

b. Regular flightline teams normally consist of 5 people, 2 five level and 3 three level. Only the 2 five level personnel are required for maintenance with the three level personnel engaged in on the on-the-job (OJT) training. There are approximately 55 men per shift - 2 shifts per day.

c. There are 2 peak-up stations with teams of 18 men each. Each team has 3 crews consisting of 1 five level man and 3 three level men; an extra 1 1/2 crew allows continuous operation, 24 hours a day, 7 days per week. Peak-up is based on a period of 100 hours of flying time and requires an average of 72 hours to perform.

The regular flightline teams are responsible for performing both unscheduled (random) and scheduled maintenance. The scheduled maintenance, not including peak-up, is performed as follows:

a. At the end of 50 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

b. At the end of 100 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

c. At the end of 200 flight hours, duration 16 hours, and a crew size of 6. The crew consists of 1 seven, 2 five, and 3 three levels of personnel. The FCS does not contribute to downtime since other subsystems have up to 5 days of downtime.

3.1.2.2 Maintenance Shop

The shop is divided into specialties as follows:

a. R14A and AD subsystems
b. BTC subsystem
c. Category II test equipment

Shop works a two shift operation.

Shift 1 7:30 - 4:30

Shift 2 4:30 - 12:30

Specific number of crews per shop breakout by shift.

Shift 1

<u>R14 and AD</u>

3 repair teams; each team consists of two personnel of levels 5 and 3.

One supervisor

<u>BTC</u>

3 repair teams; each team consists of two personnel of levels 3 and 5.

One supervisor

<u>Category II Test Equipment</u>

Repair teams (3); consisting of one man, one trainee, and
One supervisor

One general supervisor of 7 level.
One general administrator of 5 level.

Shift 2

R14 and AD

Same as Shift 1. One supervisor

BTC

Same as Shift 1. No supervisor

Category II Test Equipment

Second shift not assigned.

Personnel Complement by Grade

TSgt	1
SSgt	6
A1C	6
A2C	23
	36.

Two airmen of the 36 above were not available due to school, etc.

3.1.3 Queuing Processes

The FCS personnel support system contains four separate, but dependent, cyclical queuing processes; figure 2 shows these. Four critical elements in each of these are:

a. Demand per unit time per operational unit (failure rate - λ).

b. Rate of meeting these demands (service rate - μ).

c. Number of effective repair channels (C).

d. Number of standby repairable spares (S).

Since the basic mathematical model is based on continuous time, care must be taken to modify the failure rate for the fact that aircraft do not operate continuously. In establishing the service rate all significant time elements are to be added. That is, waiting time, intrabase travel time, documentation of reporting time, equipment set-up time, and the time required to effect the repair.

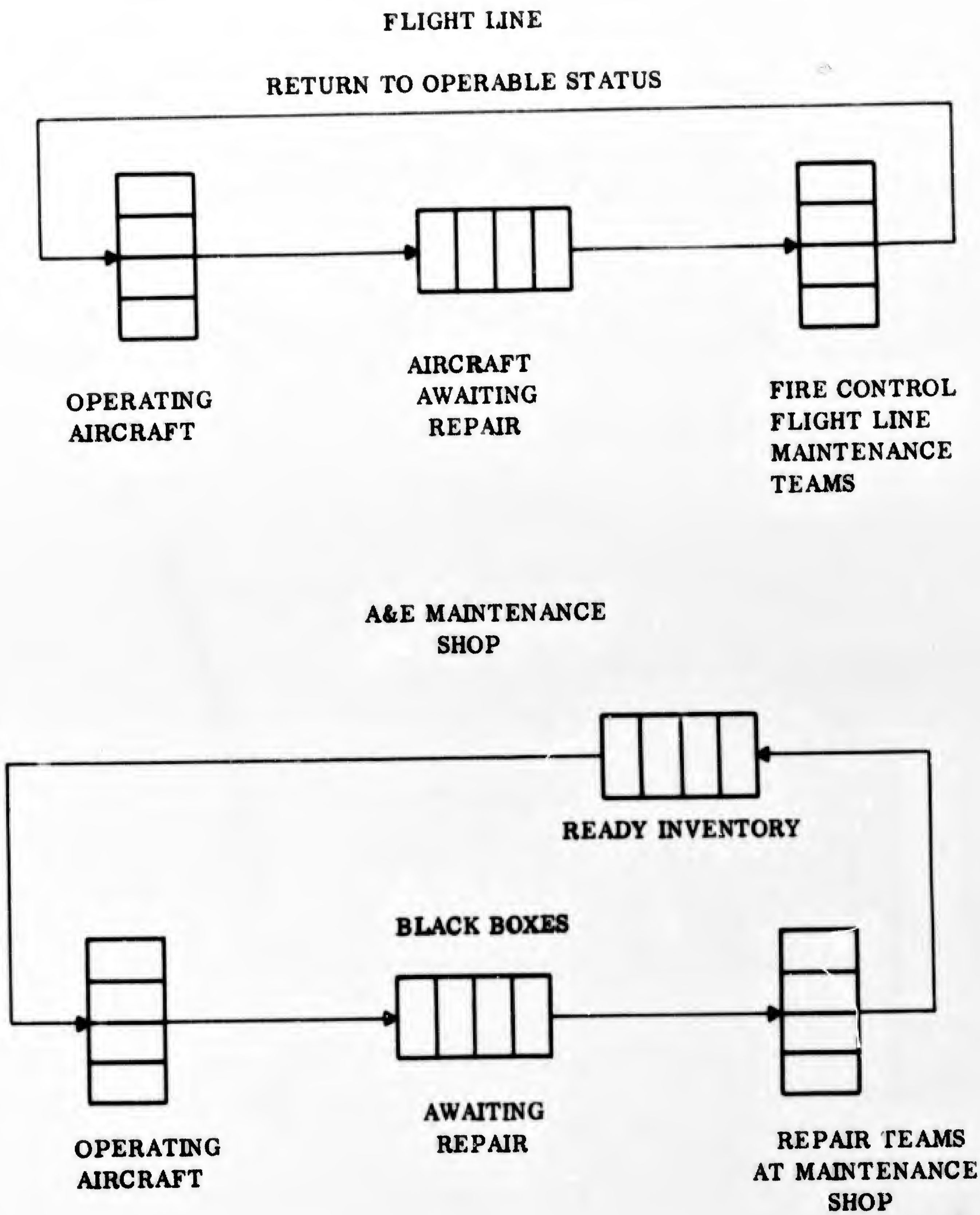
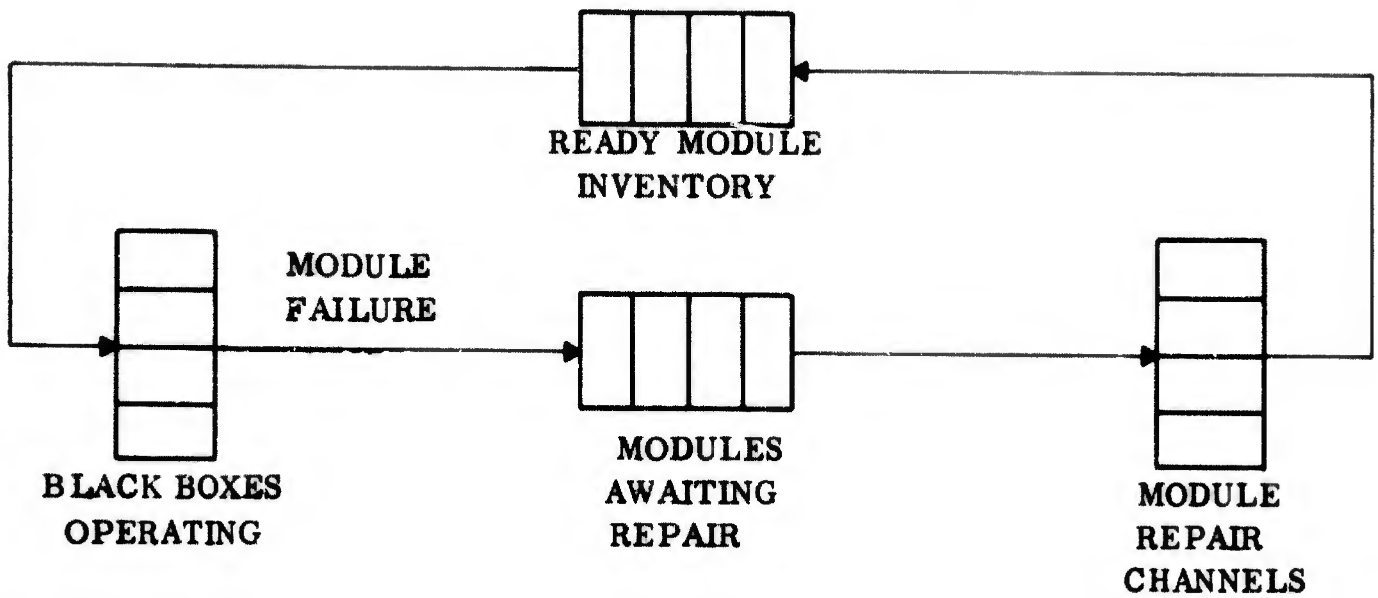


FIGURE 2. CYCLICAL QUEUES IN FCS SUPPORT SYSTEM

MODULE REPAIR OPERATION



CATEGORY II TEST EQUIPMENT
CALIBRATION AND REPAIR

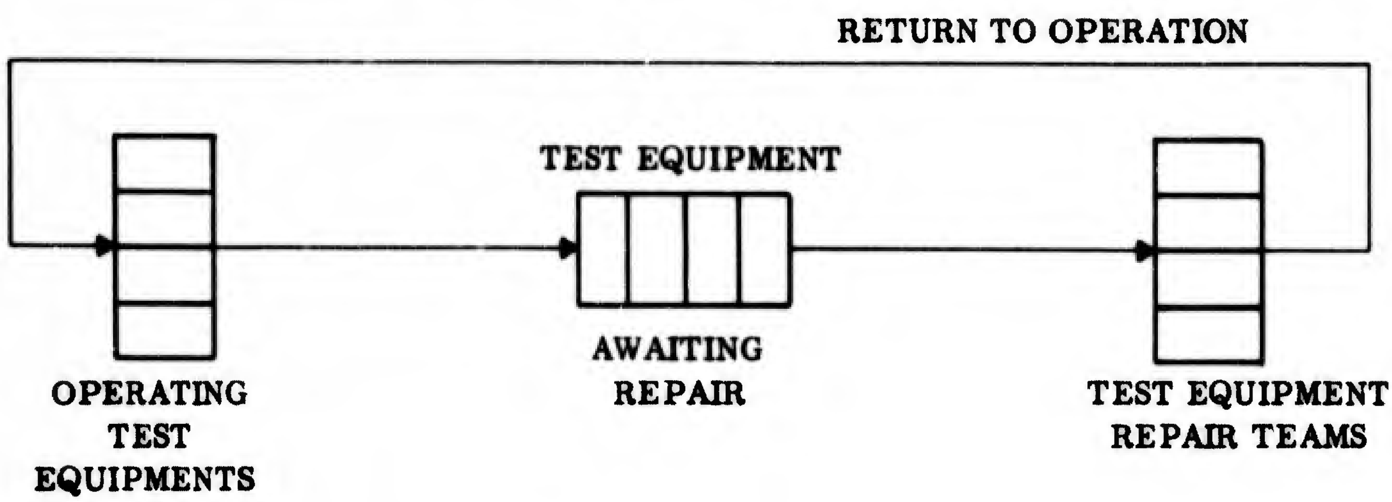


FIGURE 2. (CONT.) CYCLICAL QUEUES IN FCS SUPPORT SYSTEM

In establishing effective repair channels (maintenance teams) care must be taken to ensure that the teams are capable of performing all tasks independently. That is, they must have all auxiliary equipment necessary to function as a team. In establishing standby repairable spares, a spare refers to a set of black boxes which taken together form a subsystem.

3.2 Basic Model Parameter

The manning technique being evaluated depends on the reliability and the maintainability of the subsystem being manned. As part of this program both predicted and measured values of these parameters were developed. The results are discussed below.

3.2.1 Reliability of the FCS

3.2.1.1 Predicted

A reliability prediction was performed by RCA. The prediction was performed before the field evaluation results were known. The analysis was based on information available at the time of design of the FCS. (See appendix III for details of the reliability prediction.) Table 1 contains the summarized results of the prediction.

TABLE 1

PREDICTION RESULTS

Subsystem	Failure Rate λ (pt./hr.)	Mean Time Between Failure (MTBF-hr.)
Radar (R14A)	.049	20.5
Attack and Display (AD)	.003	320.0
Bomb Toss Computer (BTC)	.007	152.0
AN/ASG-19(FCS)	.059	17.1

3.2.1.2 Measured

There was no attempt to duplicate a field evaluation during this program. Instead reliance was placed on data which had previously been collected, as part of the overall F105D program, by RAC, ARINC, and USAF. (See appendix II). Table 2 contains the summarized measured results as follows:

TABLE 2

MEASURED RESULTS

Subsystem	MTBF (hr.)	λ (pt./hr.)
R14A	19	.053
AD	180	.006
BTC	130	.008
FCS	15	.067

3.2.1.3 Comparison of Predicted to Measured

The predicted reliability was based on catastrophic failures only. As it turns out, approximately 0.4 of the total failures are due to drift of part tolerances. (This also means a replacement black box is not required.) This estimate is based on an estimate by flightline personnel of SJAFB. The results of the reliability analyses are summarized and compared below in table 3.

TABLE 3

COMPARISON OF RESULTS

Sub-system	Predicted [3]		Measured	
	λ (pt./hr.)	MTBF (hr)	λ (pt./hr.)	MTBF (hr)
R14A	.068	15	.053	19
AD	.004	230	.006	180
BTC	.009	110	.008	130
FCS	.082	12	.067	15

3.2.1.4 Demand Per Unit Calendar Time Modification

In establishing the maintenance demands per unit calendar time, for modifying the failure rate, the following model is used:

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[3] Adjusted for drift failures.

Let

λ = failure rate/unit operational time
B = operational time/unit calendar time

Then the demand per unit calendar time (λ_B) becomes:

$$\lambda_B = B\lambda \tag{14}$$

Adjustment (B) must be made for non-flying days and non-working hours as follows:

$$B = T/(E-A)HN \tag{15}$$

where

N = number of units (aircraft, subsystems, etc.)

E = arbitrary time period in days, e.g., 1 month

T = total operational time, in hours, over a period of E days

A = number of days in E which are non-flying

H = hours during a day when work is performed

From SJAFB the following data is available for the period August 1963 to May 1964: [4]

T_{max} = 2155 hours/month
T_{mean} = 1648 hours/month
T_{min} = 1346 hours/month
N = 50 units
E = 30.42 average days/month
A = 8 days/month
H = 16 hours/day

Calculating B from the above data the following results are obtained:

B_{max} = .120
B_{mean} = .092
B_{min} = .075

---

[4] Monthly Maintenance Analysis Report, 4 TAC Fighter Wing, SJAFB, May 1964.

3.2.2 Maintainability of the FCS

Three sources of maintainability estimates on the FCS are available. They are:

a. Field evaluation of FCS maintenance task time. This is developed in appendix II.

b. Prediction based on the RADC-RCA technique (Ref. 3). Appendix III contains the details of the prediction. This appendix contains a prediction based on the technical orders on the equipments.

c. Estimates obtained at SJAFB. These estimates were obtained from maintenance shop and flightline personnel. (See appendix IV.)

Table 4 summarizes these results. The only significant difference between the estimates lies in the maintainability of the modules.

TABLE 4

FCS MAINTAINABILITY

Location	Level	Field Evaluation (hours)	Prediction (hours)	SJAFB (hours)
Flightline	FCS	-	1.5[5]	Adjustment 1.0[6] Pull Black Box 2.0[6]
Maintenance Shop	Black Box	2.0[5]	2.0[5]	2.0
	Module	-	1.0[5]	2.0

In establishing the service rate (μ), as differentiated from the maintainability, activity networks have been developed. (See appendix IV). These networks show the actual sequence of movements and associated time elements involved in a reported FCS failure. Table 5 summarizes the service rates:

---

[5] Adjusted to reflect active plus delay downtime and rounding to a whole or a half number.

[6] In the case SJAFB the time spent in adjustments, not requiring replacement of the black box, and the time spent in pulling the black box and replacing it with another, were estimated separately.

TABLE 5

FCS SERVICE RATES

Activity		Service Time (hour)	Service Rate-μ (per hour)
Flightline	Regular	3.2	.313
	Peak-up	72.0	.021
Maint. Shop	Black Box	2.0	.500
	Module	2.0	.500

3.2.3 Number of Repair Channels

Based on analysis at SJAFB the following observations were made:

a. Ninety percent of all repair time associated with aircraft malfunctions involves use of test equipment. Moreover, 65 percent of this time is spent acquiring an operable spare black box or awaiting the repair of the failed black box. Thus, the significant factors controlling aircraft downtime of the FCS are the extent of limitations to repair channels by test equipment availability, and the acquisition time of an operable unit.

b. The controlling factors of waiting at the maintenance shops are repairable spares and effective number of repair channels. Module repair does not constitute a significant delay problem because it is handled as fill-in work.

3.2.3.1 Test Equipment

For the FCS support system the availability of test equipment is the constraining factor in limiting the effective number of repair channels available. The critical items of test equipment for the Wing are tabulated below in table 6.

TABLE 6

CRITICAL TEST EQUIPMENT

Test Equipment Type	Number Assigned
Analyzer	12
Oscilloscopes	8
R14A and AD Mockup	3
BTC Mockup	3
Signal Generator (RAC)	2
Signal Generator (Dymac)	5
Module Tester (R14A)	1
Simulator	3

Flightline test equipment average allocation is as follows:

a. 4 analyzers
b. 2 oscilloscopes
c. 4 signal generators

Meeting the random demands at the flightline requires the following equipments:

a. Sixty percent of the demands require the complete test equipment requirements.

b. Thirty percent of the demands require the analyzer.

c. Ten percent of the demands require no test equipment.

Each flightline peak-up station has (or needs) the complete flightline test equipment.

Maintenance shop test equipment average allocation are divided between two shops.

a. R14A and AD shop
b. BTC shop

The allocation for the R14A and AD shop is as follows:

a. 1 signal generator,
b. 4 analyzers,
c. 3 oscilloscopes,
d. 1 module tester

with repair verification being made on any 1 of 3 mockups. The module tester performs the majority of module test requirements. However, it does not, in general, isolate a failure to the part level. This requires the use of a multimeter, etc.

The test equipment allocation is the BTC shop are as follows:

a. 3 simulators
b. 6 ratiometers
c. 1 oscilloscope
d. 3 BTC mockups

Table 7 summarizes the maintenance shop and flightline test equipment allocation information.

TABLE 7

TEST EQUIPMENT ALLOCATION

Test Equipment		Flightline		Maintenance Shops		
Type	Total Avail.	Random Demands	Peak-up	R14A and AD	BTC	Test Equip. Repair
Analyzer	12	4	2	4		2*
Oscilloscopes	8	2	2	3	1	
R14A and AD Mock-up	3			2		1*
BTC Mock-up	3				3	
Signal Generator	7	4	2	1		
Module Tester	1			1		
Ratiometer	6				6	
Simulator	3				3	

*Equipment down for repair

3.2.3.2 Determination of Effective Repair Channels

The determination of effective repair channels can now be made as follows:

a. Flightline-Random Demand. Effective repair channels are limited by the number of analyzers and signal generators and the tasks requiring them. There are 4 analyzers and 4 signal generators; thus, the normal flightline possesses an effective number of 4 independent repair channels.

b. Flightline Peak-up. There are 2 independent channels for scheduled maintenance.

c. R14A and Ad Maintenance Shop. Effectively this maintenance shop is working with 2 repair channels.

d. BTC Maintenance Shop. The effective number of independent repair channels is 3.

Although sequencing of test equipment usage is possible and under stress conditions probably takes place, the general rule is for personnel to stay with a black box until completely repaired (the exception is when an order to base supply or depot is made). Another thought is that test equipment may be transferred as needed between different operational areas. This does indeed occur. However, the increase in repair channels capacity at one location reduces proportionately repair channel capacity at the lending location.

3.2.4 Number of Spares

Spares are available, essentially, at one location, viz., the supply room connected with the maintenance shops. The inventory level at the supply room is controlled by space limitations. The level of spares is about an average of 2 for each black box in the FCS. The time required to fill a request from off the shelf is about .15 hours.

3.3 Operational Readiness

The operational readiness of the FCS and the F105D is now calculated, using the values developed in the preceding section for the FCS; and assumptions about the relation of the FCS to the other subsystems in calculating the overall F105D operational readiness. All calculations involving percent of units down in excess of spares (d), etc., are obtained from the Tables (Ref. 4). Specific tables used in all calculations in this report are contained in appendix V.

3.3.1 Flightline

The utilization factors P_R, associated with random demand flightline repairs, are found in table 8.

TABLE 8

PREFLIGHT RANDOM DEMAND UTILIZATION FACTORS

Value	Usage per Aircraft Hr	Failure Rate	Service Rate	Utilization Factor	Adjusted Fail. Rate
	B (per hr.)	λ (per hr.)	μ (per hr.)	P_R	λ_B (per. hr.)
Maximum	.120	.130	.313	.050	.0156
Mean	.092	.067	.313	.020	.0062
Minimum	.075	.032	.313	.008	.0024
Recommended	.120	.067	.313	.026	.0080

The total downtime for regular scheduled maintenance purposes is given in table 9. When divided by E (30.42 day/mo.) and a 2 shift operation per day (16 hr/day), this downtime numeric reduces to .372 aircraft down. The performance of scheduled maintenance requires test equipment used by the random demand people. The best way to treat this is by considering the scheduled maintenance as random in nature and using

TABLE 9

FLIGHTLINE SCHEDULED MAINTENANCE

T_{mean}	Scheduled Period	Number of Occurrences	Estimated Time	Downtime
(hr/mo.)	(hr.)	(per mo.)	(hr.)	(hr/mo.)
1648	50	32.96	1	32.96
1648	100	16.48	1	16.48
1648	200	8.24	16	131.84
Total				181.28

the relation

$$P_T = \sum_{i=1}^{n} p_n , \text{[7]} \qquad (16)$$

and for the specific case:

$$P_T = P_R + P_S \qquad (17)$$

where

P_R = random maintenance

P_S = scheduled maintenance

P_T = .372/50 = .007

Table 10, on the next page, presents this adjusted information.

There is one other flightline activity which is independent and therefore is not conducive to such treatment, viz., the peak-up activity. The information concerning the peak-up activity is summarized in table 11 on next page.

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[7] See AMRL-TDR-64-21 (Ref.1).

TABLE 10

FLIGHTLINE RANDOM DEMANDS ADJUSTED FOR SCHEDULED MAINTENANCE

N = 50 C = 4 S = 0

Value	P_R	P_S	P	d	Aircraft Down
Maximum	.050	.007	.057	.065	3.25
Mean	.020	.007	.027	.027	1.35
Minimum	.008	.007	.015	.015	.75
Recommended	.026	.007	.033	.033	1.65

TABLE 11

PEAK-UP MAINTENANCE

T_{mean} (hr/mo.)	Scheduled Period (hr.)	Number of Occurrences (per mo.)	Estimated Time (hr.)	Downtime (hr/mo.)
1648	100	16.48	72	1186.56

As was done with the scheduled maintenance, the downtime figure is converted into the number of aircraft down by dividing by the average number of days in the month (E) and, since the activity takes place around the clock, this operation yields a figure of 1.63 aircraft down. The number of aircraft down, due to peak-up, may be considered a constant.

Summarizing, the following procedure will take place:

a. Calculate the utilization factor (P_R) for random demands.

b. Determine the value of P_S for the scheduled maintenance from an analysis similar to that in table 9.

c. Perform the operation indicated in equation 17 ($P = P_R+P_S$).

d. From the Tables determine values d for the P, N, C, and S.[8]

e. Calculate the number of aircraft down $Nd_{(R+S)}$ because of random demands and scheduled maintenance.

f. Add the constant number of aircraft down (Nd_P) because of the peak-up activity.

g. Calculate the operational readiness (R) by means of the following formula:

$$R = (N - Nd_{(R+S)} - Nd_P)/N \quad (18)$$

Table 12 gives the summarized operational readiness.

TABLE 12

FCS OPERATIONAL READINESS

Value	$Nd_{(R+S)}$	Nd_P	Aircraft Down	R
Maximum	3.25	1.63	4.88	.902
Mean	1.35	1.63	2.98	.940
Minimum	.75	1.63	2.38	.952
Recommended	1.65	1.63	3.28	.934

In order to adjust the foregoing analysis to a five day week the values of P are multiplied by 1.40. (This constant corresponds to 7/5.) Table 13 presents the required adjustment. No adjustment is required of the peak-up activity which is 24 hours a day, 7 days a week.

TABLE 13

ADJUSTED FCS OPERATIONAL READINESS

N = 50 C = 4 S = 0

Value	Adj. P	$d_{(R+S)}$	$Nd_{(R+S)}$	Nd_P	Aircraft Down	R
Maximum	.080	.126	6.30	1.63	7.93	.841
Mean	.038	.039	1.95	1.63	3.58	.928
Minimum	.021	.021	1.05	1.63	2.68	.946
Recommended	.046	.049	2.45	1.63	4.08	.918

[8] S = 0 at flightline. (See appendix IV.)

3.3.2 Operational Readiness of F105D

The following assumptions are made concerning the operational readiness of the F105D:

a. Approximately 40% of the random demand downtime is attributed to the FCS.

b. 1.63 aircraft are down for peak-up of the FCS.

c. An average value of 2 aircraft are down for scheduled maintenance other than the FCS.

d. An average value of 1.5 aircraft are aircraft out of commission-parts (AOCP).

This information is summarized in table 14 below.

TABLE 14

F105D OPERATIONAL READINESS

Value	$Nd_{(R+S)}$	$2.5Nd_{(R+S)}$	Nd_P	Nd_{S-O}	Nd_{AOCP}	Aircraft Down	R
Maximum	6.30	15.75	1.63	2.00	1.50	20.88	.582
Mean	1.95	4.88	1.63	2.00	1.50	10.01	.800
Minimum	1.05	2.63	1.63	2.00	1.50	7.76	.845
Recommended	2.45	6.13	1.63	2.00	1.50	11.26	.775

The operational readiness is measured at 2400 hours daily at SJAFB and is .70 ± .02. (This is equivalent to 15 aircraft down ± 1 aircraft.) This number is compared with the various values of the predicted operational readiness in table 15.

TABLE 15

DIFFERENCE IN OPERATIONAL READINESS

Value	Predicted R	Measured R	Difference in % Meas. R
Maximum	.582	.700	-20
Mean	.800	.700	14
Minimum	.845	.700	21
Recommended	.775	.700	11

3.3.3 Sources of Error

The following are sources of error in all the calculations made above:

a. Insufficient knowledge of other subsystems and their relative contribution to downtime.

b. Fueling time is not included.

c. No consideration was given to the case of multiple flights, e.g., 2 aircraft land with failures in the FCS. An estimate of this would be on the average:

$$\Delta R = -.015$$

d. Downtime is measured from the time the flightline maintenance team goes into action. It does not include the action of the debriefing (diagnostic) team.

The error involved here is approximately .01 decrease in R.

3.3.4 Summary

Based on the preceeding analysis the error associated with the prediction technique, when dealing with R, is in the order of 11% before corrections are made. If more precise results are desired the error can be reduced to 7% (R = .750). The error is in the direction of overestimating the operational readiness.

3.4 Maintenance Shop Parameters

The utilization factors (P) are listed in table 16.

TABLE 16

MAINTENANCE SHOP UTILIZATION FACTORS

Shop	Value	B	1.4B*	λ**	λ_B	μ**	P
R14A & AD	Max.	.120	.168	.059	.0010	.5	.020
	Mean	.092	.129	.059	.0076	.5	.015
BTC	Max.	.120	.168	.008	.0013	.5	.0027
	Mean	.092	.129	.008	.0010	.5	.0020

* Correction for 5 day week
** Measured

3.4.1 R14A and AD Maintenance Shop

Based on the evaluation at SJAFB, the R14A and AD maintenance shop operates with 2 black box repair channels. The equivalent of 2 spare black boxes is available. The exception to the spare level is when a request is made on base supply but such a request is made only 5% of the time and therefore can be neglected. Thus, the parameters controlling waiting time, etc., are:

$N = 50 \quad C = 2 \quad S = 2$

$P_{max} = .020$ and $P_{mean} = .015$

The corresponding values in the Tables for units down (Nd) and units down in excess of spares $(N+S)n_d$ are listed in table 17.

TABLE 17

UNITS DOWN AND UNITS DOWN IN EXCESS OF SPARES

(R14 and AD Maintenance Shop)

Value	P	d	Nd	n_d	$(N+S)n_d$
Max	.020	.006	.30	.025	1.30
Mean	.015	.004	.20	.018	.94

Other parameters which can be derived from the values in table 17 are as follows:

a. For P_{max}

(1) $C_b = N_o P_{max}$ (19)

$= (49.70)(.020)$

$= .994$

(2) $W = (N+S)n_d - C_b$ (20)

$= 1.30 - .994$

$= .306$ units

(3) $t_w = W/C_b\mu$ (21)

$= .306/(.994)(.5)$

$= .616$ hours

(4) $t_d = Nd/C_b\mu$ (22)

$= .30/(.994)(.5)$

$= .604$ hours

It is desirable to find a number for those that have to wait ($\bar{t}_d$). The value of $\bar{t}_d$ must account for the presence in R14A of a unit (synchronizer) for which repair is always awaited. This synchronizer comprises 42.19% of the total failure rate of the R14A.[9] This adjustment is made by solving the following formula:

$$\bar{t}_{d-adj} = t_d + \lambda_{syn}/\mu \tag{23}$$

$$= .604 + .422/.5$$

$$= 1.448 \text{ hours}$$

This number compares with an estimate of 1.5 hours obtained from flightline personnel.

b. For P_{mean}

(1) C_b = .747

(2) W = .553 units

(3) t_w = 1.481 hours

(4) t_d = .535 hours

(5) $\bar{t}_{d-adj}$ = 1.379 hours

The module repair is predominantly fill work and as such does not affect aircraft downtime. Module repair time is estimated at an average of 2 hours.

3.4.2 BTC Maintenance Shop

Based on the evaluation at SJAFB the BTC maintenance shop operates with 3 effective repair channels and 2 spares. The corresponding values in the tables for units down (Nd) and units down in excess of spares [$(N+S)n_d$] are listed in table 18.

Other parameters which can be derived from the values in Table 18 are as follows:

a. For P_{max}

(1) C_b = .135

(2) W = .025 unit

(3) t_w = .370 hours

(4) t_{d-B} = .741 hours

---

[9]Predicted

TABLE 18

UNITS DOWN AND UNITS DOWN IN EXCESS OF SPARES

(BTC Maintenance Shop)

$N = 50 \quad C = 3 \quad S = 2$

Value	P	d*	Nd*	n_d*	$(N+S)n_d$*
Max.	.0027	.001	.05	.003	.16
Mean	.0020	.001	.05	.002	.10

*These quantities are upper bounds. Based on the Tables the decrease in d and n_d for C>1 and S>1 is negligable

From the above calculations the mean time to acquire an operable spare from either of the two maintenance shops is:

$$t_{os} = (\bar{t}_{d-adj})P_R + t_{d-B}(1-P_R) \qquad (24)$$

where

P_T = mean time to acquire a spare from either shop

P_R = proportion of failure rate of R14A and AD maintenance shop

$(1-P_R)$ = proportion of failure rate of BTC

$= (1.448)(.891)+(.741)(.119)$

$= 1.378$ hours

b. For P_{mean}

(1) C_b = .100

(2) W = .090 units

(3) t_w = 1.800 hours

(4) t_{d-B} = 1.000 hours

3.5 Subsystem Manning

From sections 3.3 and 3.4 the number of personnel required to perform work, such that the operational readiness levels are achieved, can be determined. This count is based on personnel available and must be modified in two ways:

a. Adjustment for sick leave, furlough, etc., this adjustment factor is .20 of the direct manpower by skill level.

b. Adjustment for on the job training for replacement personnel. The rationale and justification for these stable system adjustments are fully developed in appendix VI. Although a very brief treatment of stable system considerations was included, its detailed development was not included. The linear programming model presented in appendix VI represents an approximation to the true situation. This model has not been validated.

The adjustments above must be applied to specific skills and proficiency levels. In the case of flight line personnel, all personnel of a given skill level may be combined and the adjustment made to the aggregate quantity. Whereas in the case of shop maintenance, the adjustments are based on specific maintenance shops, e.g., BTC maintenance shop. The rationale behind this is: that there is sufficient differences in these areas and that specific training (OJT) is required, viz., personnel are not interchangeable between shops at the same level of efficiency.

3.5.1 Personnel Training and Phaseover; Backup Data

The following personnel data are applicable to SJAFB FCS personnel.

a. Basic training cycle requires approximately 54 weeks - this includes basic training, basic electronics training and leave.

b. Approximately 3 months of on the job training (OJT) is required for upgrading to level three airman.

c. Upgrading to level five airman required additional 13 months.

d. Effectively no further increase in level can take place within first hitch.

e. Second hitch personnel require approximately 14 additional months to obtain seven level classification.

Other data are:

a. Retention of first hitch personnel is approximately 12%.

b. Approximately 85% of first hitch level five personnel leave service.

c. The average airman (F105D FCS) will spend 13 months as a productive three level and 19 months as a productive five level airmen.

d. It is estimated that approximately 60% of the seven level personnel leave the USAF due to retirement, discharge as undesirable, and conventional discharge.

e. The level nine personnel do not appear to present a problem since they generally come from outside the FCS technical field and the responsibility is less technical.

Table 19 contains the current status of personnel at SJAFB.

TABLE 19

FCS CURRENT PERSONNEL

Skill Level	Table of Organization	Assigned	Projected Requirements
9	14	3	14
7	48	22	51
5	106	83	97
3	26	123	24
Total	194	231	186

3.5.2 Determination of Personnel Requirements - Flightline

Table 20, on next page, presents the requirements for flightline personnel.

TABLE 20

REQUIREMENTS FOR FCS FLIGHTLINE MANNING

Shift	Category	Activity: Random Demand and Scheduled Maintenance	Peak-up	Debriefing Diagnosis	Test Equipment Control
I	Workers	4(2) [5,5]*	2(4) [5,3,3,3]	1(2) [7,7]	1(2) [5,5]
	Supervisors	1(1) [7]	1(1) [7]		
II	Workers	4(2) [5,5]	2(4) [5,3,3,3]	1(2) [7,7]	1(2) [5,5]
	Supervisors	1(1) [7]	1(1) [7]		
III	Workers		2(4) [5,3,3,3]		1(2) [5,5]
	Supervisors		1(1) [7]		
Extra**	Workers		2(4) [5,3,3,3]		
	Supervisors		1(1) [7]		

Total Number of People by Skill Level

	7 level	5 level	3 level	Total
Activity less Peak-up	6	22		28
Backup Adjustment***	1	4		5
Peak-up ****	4	8	24	36
Total	11	34	24	69

*The first number designates the number of crews; the second, in parenthesis, the number of people in a crew; and the third, in brackets, designates the skill level.

**Permits 24 hours, 7 days a week operation.

***Rounded up or down, the backup adjustment is .2 times the number of men in the activity.

****Peak-up activity is already adjusted.

Table 21 presents the adjusted requirements for a stable personnel system.

TABLE 21

FCS ADJUSTED FLIGHTLINE PERSONNEL

Level	Predicted	Required Adjustment for Stable Personnel Subsystem*
7	11	11
5	34	34
3	24	34
1	0	16**
Total	69	95

*See appendix VI

**These personnel are not assigned to the system. They should be in training as replacements for level three personnel.

3.5.3 Determination of Personnel Requirement-Maintenance Shops.

Table 22, on next page, lists the maintenance shops proposed manning. Table 23 presents the adjusted requirements for a stable personnel subsystem in the maintenance shops.

TABLE 23

FCS ADJUSTED MAINTENANCE SHOPS PERSONNEL

Level	Predicted	Adjusted
7	4	4
5	14	14
3	10	14
1	0	12
Total	28	44

3.5.4 Total Manning

Table 24 presents the final results of the manning prediction and compares it with the number of people assigned by the T.O.

TABLE 22

REQUIREMENTS FOR FCS MAINTENANCE SHOPS MANNING

Shift	Category	Activity			
		R14 and AD			
		Mockups	Module Repair	BTC	Special Test Equipment Repair
I	Workers	2(2)[5,3]	1(2)[5,3]	1(2)[5,3]*	2(1)[5] 1(1)[5] 1(1)[7]
	Supervisory	1(1)[7]			
II	Workers	2(2)[5,3]	1(2)[5,3]	1(2)[5,3]*	
	Supervisory	1(1)[7]			

Total Number of Personnel by Skill Level

	7 level	5 level	3 level	Total
Activity	3	11	8	22
Backup Adjustment	1	3	2	6
Total	4	14	10	28

*See note on table 18. For manning prediction purposes C=1

TABLE 24

MANNING PREDICTION

Level	Maintenance Shops	Flightline	Total Predicted	Table of Organization	% T.O.
7	4	11	15	48	-69
5	14	34	48	106	-51
3	14	34	48	26	+50
Sub-Total	32	79	111	180	-34
1	12	16	28	0	
Total	44	95	139	180	-18

Table 25, presents the data arranged by activity.

TABLE 25

MANNING PREDICTION BY ACTIVITY

Activity	Predicted	T.O.	% T.O.
Normal Flightline (7,5,3)	43	108	-60
Peak-up (7,5,3)	36	36	0
Maintenance Shops (7,5,3)	32	36	11
Total	111	180	-34

In addition to the personnel determined above, the practice at SJAFB is to have a central control monitoring and status evaluation center which draws personnel from the FCS personnel subsystem. There is one man assigned, per shift, to this position. Adjusting manning for this position would increase the personnel requirements by 2 additional level five people; raising the total number of personnel required to 113.

3.6 Manning Prediction Using Conceptual Information

A manning prediction was performed for the F105D using only conceptual information. The following postulates were made based on the predictions contained in appendix III.

a. A preflight and postflight inspection would be performed for each flight. At Johnson AFB these inspections are not being performed. However, these inspections may be performed at other F105D wings.

b. A 100 hour periodic would be performed for each aircraft. This corresponds to the peak-up inspection at Johnson AFB.

c. The maintenance shop was divided into three skill specialties: 1) AD, 2) R14A, 3) BTC. At Johnson AFB the maintenance shop is divided into two specialties: 1) AD and R14A, 2) BTC.

d. It was assumed that category II test equipment would be maintained off site. This assumption was not valid for SJAFB.

The flightline maintenance activity network was assumed the same as that ovserved at Johnsom AFB. (See appendix IV.) No time however was assigned for travel to and from the aircraft or for travel to and from the maintenance shops.

Since the time to service a flightline failure depends upon the waiting time that will be incurred at the maintenance shops, the manning alternatives at the shop was first determined. The waiting time for repairable spares was then added to the predicted MTTR of the flightline maintenance crew.

3.6.1 Predicted Parameter Values for FCS Maintenance Shops

The arrival rate at each shop is obtained from subdivision of FCS predicted failure rate. This is:

$$\lambda = \lambda_R + \lambda_{BT} + \lambda_{AD} = .082 \text{ pt./hr.} \qquad (25)$$

where

λ_R = R14A failure rate = .068 pt./hr.

λ_{BT} = BTC failure rate = .009 pt./hr.

λ_{AD} = AD failure rate = .004 pt./hr.

For each shop failure rate there is an associated repair rate, μ_R, μ_{BT}, μ_{AD}. The value of these parameters were predicted using the methods discussed in appendix III.

The utilization factor for each skill shop per maintenance channel becomes:

$$P_R = (\lambda_R/\mu_R)\,B \tag{26}$$

$$P_{BT} = (\lambda_{BT}/\mu_{BT})\,B \tag{27}$$

$$P_{AD} = (\lambda_{AD}/\mu_{AD})\,B \tag{28}$$

B is an adjustment factor discussed previously and a modified equation is given by B = EF/(E-A)H where E, A, H, are defined as before and F represents the operational time per day accumulated on the FCS.

Manning was determined for two values of F, viz., two and four hours per day of operation. The two hour estimate corresponds essentially to that experienced at SJAFB.

The mean waiting time encountered from shop maintenance is given by

$$t_d = (\lambda_R t_{dR} + \lambda_{BTC} t_{d\text{-}BTC} + \lambda_{AD} t_{d\text{-}AD}) / (\lambda_R + \lambda_{BT} + \lambda_{AD}) \tag{29}$$

where the general form of the waiting time (t_{d-i}) is given by

$$t_{d-i} = N d_i / C_b \mu_i \tag{30}$$

$$C_b = N_o P \tag{31}$$

Table 26 contains various combinations of repair channels and repairable spares and consequent waiting times. The combinations indicated by arrow have been selected for comparison purpose.

The data in table 26 are translated into personnel requirement using the technique discussed in section 3.5, the results are summarized and presented in table 27 (A and B).

Comparison of the results of table 27, A and B, with those obtained in table 23 show that the manning requirement difference lies in the organization breakout. The predicted breakout consisted of three skill specialties.

It is of interest to note that the waiting encountered for a spare are .33 hr. and .39 hours for manning of table 27, A and B respectively, for this organizational structure, compared to .6 for the actual organization. Note that the time spent waiting in the radar shop constitutes essentially all waiting time.

TABLE 26

TABULAR VALUES

1. Radar Shop

B = .17, λ = .068, μ = .5, P = .023

C	S	d	t_d
3	0	.020	2.2
3	1	.008	.7
3	2	.003	.26

B = .34, λ = .068, μ = .5, P = .046

C	S	d	t_d
3	0	.033	3.4
3	1	.018	.78
3	2	.009	.4

2. Attack and Display

B = .17, λ = .004, μ = .5, P = .0014

C	S	d	t_d
1	0	.002	3.48
1	1	.001	.75

B = .34, λ = .004, μ = .5, P = .0027

C	S	d	t_d
1	0	.003	4.
1	1	.001	.71

TABLE 26 (cont'd.)

3. Bomb Toss Computer

$B = .17,\ \lambda = .009,\ \mu = .5,\ P = .003$

C	S	d	t_d
1	0	.003	4
1	1	.001	.67

$B = .34,\ \lambda = .009,\ \mu = .5,\ P = .006$

C	S	d	t_d
1	1	.002	.67
2	1	.001	.33

TABLE 27

PERSONNEL REQUIREMENTS

Table A

Conceptual Manning Prediction

F = 2 flying hours per day per AC

Skill Level	Radar	AD	BTC	Backup Adj	Total
5	6	2	2	2	12
3	6	2	2	2	12
7	1 each shift			1	3
Total	14	4	4	5	27

Table B

Conceptual Manning Prediction

F = 4 flying hours per day per AC

Skill Level	Radar	AD	BTC	Backup Adj	Total
5	6	2	4	3	15
3	6	2	4	3	15
7	1 each shift			1	3
Total	14	4	8	7	33

3.6.2 Prediction of Flightline Manning

Let μ_1, μ_2, represent the rate of performance of preflight and postflight maintenance respectively. Let μ_{rf} represent the rate of performing random failure maintenance, λ the failure rate per operational hour of the system, and t_d represents the waiting time for acquisition of a repairable spare.

Let C represent the frequency of flights per day and G the mean duration per flight. The utilization factor, P, is given by

$$P = [(1/\mu_1+1/\mu_2)+GC\lambda(1/\mu_{rf}+t_d)]B' \quad (32)$$

where B' is the time conversion factor.

The parameter values for the equation above are given below. The values were predicted based on methods contained in appendix III.

μ_1 = 2 hrs. μ_2 = .67 hrs.

C = 1, 2 flights per day, G = 2 hrs. (duration of flight)

λ = .082 $\frac{\text{failures}}{\text{hour}}$, T_{rf} = 2 hours

B' = E/(E-A)H (conversion factor defined in section 3.6.1 less the multifying factor F) = .0848

P = .2

The utilization rate P is approximately the same for two or four hours of operational time per aircraft per day. This is due to the overriding contribution from the scheduled maintenance ($1/\mu_1$ and $1/\mu_2$).

The operational readiness (FCS only) and the associated repair teams are shown below in table 28 for these parameter values.

TABLE 28

PREDICTED OPERATIONAL READINESS

C	R
8	.758
9	.797
10	.817
11	.826
12	.830
13	.832

The personnel that would be required to support an operational readiness, say, of .817 is given below in table 29.

TABLE 29

PREDICTED FLIGHTLINE PERSONNEL

Skill Level	Base Personnel	Backup	Adjustment for Stable Manning	Total
7	2	1	-	3
5	40	8	-	48
3	-	-	48	48
Total	42	9	48	99

The reason that a higher level of operational readiness (see table 13) is obtained with fewer effective maintenance airmen (see table 24) at SJAFB) is that neither preflight nor postflight is performed. Specifically, postflight is obviated through a debriefing operation with the pilot. This procedure eliminates effort spent in checkout of operable systems.

3.7 Summary

3.7.1 General

In general, the technique clearly establishes the validity of the finite cyclical queuing process as an accurate discription of the F105 FCS support subsystems. The resultant manning estimation has not, in fact, been tested even through good agreement has been achieved between predicted and measured parameters of operational performance behavior. Only by changing the manning and observation of the performance of the support system with respect to operational readiness, et al, could real validity be established.

The effective manning and skill requirements established in this study is predicted on the concept of a combined wing. If each squadron of the wing were required to possess self sufficiency, viz., possess its own maintenance flightline and shop personnel, the wing would require more maintenance personnel than predicted - in particular, the number of seven level personnel would more than double. Self-sufficiency requirements were not evaluated in this study. It is pertinent to note that existing personnel requirements, viz., the T.O., would be incompatible with test equipment limitations, if self-sufficiency were to be adopted as a policy for the FCS at SJAFB.

3.7.2 Technique Validity

The justification for the above conclusion is the following:

a. Failure rates and repair rates predicted possess excellent agreement with measured values.[10]

b. Implicit in the model is the concept of independent repair channels. One of the key observations made at SJAFB was that there was insufficient test equipment to utilize available personnel (this condition existed at both flightline and in the shops). Further, the utilization of personnel on a specific task generally diminishes rapidly as personnel is increased. An over-manned task possesses value, usually via on-the-job-training. Overmanning of tasks results from insufficient test equipment to make independent repair channels. Thus, the model provides a means of establishing total needs (rather than only personnel) to insure personnel can be used effectively. (See reference 4 for methods of test equipment-personnel cost trades.)

c. Task analysis may be applied to establish the required number and types of personnel for assignment per task. This is done in appendix III. It should be noted that different organizational, or structural (skill subsystem) breakouts can be used to achieve the same operational readiness. Usually there are several feasible breakouts, but one will usually offer greater operational readiness with fewer personnel invested. A case in point is the predicted organization structure as opposed to that at SJAFB.

d. The output of the model is waiting times, with inputs being P, N, C, and S. This calculated waiting time was in excellent agreement with the estimated waiting time, for specified model inputs. The predicted total service time at flightline was in good agreement with the calculated service time using the model waiting time outputs.

e. The contribution to aircraft down due to FCS peak-up maintenance, along with other contributions, was assessed to establish total unreadiness.

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[10] The errors made in prediction of failure and repair rates may be compensated for by using the maximum anticipated value of the operational rate.

f. The waiting time determined at the FCS maintenance shop was added to other service time elements to establish the total maintenance time per failure for the flightline teams. This was then used to establish the number of aircraft down as a result of random demands from the FCS.

g. The calculated operational readiness was within 7 percent of the readiness observed.

The above points a through g demonstrate the validity of the technique.

3.7.3 Technique Reliability

Reliability of a technique is a measure of consistent reproduction of results; i.e., will two people using the same data produce the same predictions? For the technique evaluated in this program reliability may be a source of difficulty or perhaps an advantage.

The difficulty arises in that if different organizational structures and/or activity networks are used, generally different manning requirements will result. (Working with different activity networks amounts to working on different problems.)

The advantage arises from the recognition that among different feasible support organizations, one will be superior. The technique possesses the ability to evaluate, quantitatively, the alternates and thus produce the most advantageous one.

This characteristic of the technique is sharply brought out by comparing the manning predictions of the FCS as follows:

a. The maintenance skill specialties were broken out differently. Essentially the same manning and skill distribution were required. Further, category II test equipment maintenance was assumed away. The category II equipment was not always maintained at the FCS shop. Maintenance of category II test equipment at the shop evolved from an availability of personnel in conjunction with the need for increased test equipment availability.

b. The flightline procedures simply did not operate as anticipated. Preflight and postflight were not performed. The results of the manning analysis yielded manning requirement equivalent to the actual assignment - which were shown to be over-manned from the point of achieving the readiness being experienced. However, it was also found that the personnel assigned to flightline simply could not be utilized due to insufficient test equipment.

These discrepancies may be due to the inexperience of the investigators or the result of the fact that insufficient test equipment necessitated an alternate (and superior) flightline maintenance procedure; specifically, the debriefing of pilot to determine the operability of the FCS. Using this debriefing, in lieu of going through postflight checkout, eliminated the time spent in checkout of operable systems.

3.7.4 Technique Accuracy

The output of the model, number of personnel, possesses less error than contained in the predicted parameter values. In some cases manning is not changed even when the utilization factor is varied by as much as an order of magnitude; whereas, a worst case is an approximation to linear proportionality. This characteristic of the model may be examined through parametric analysis of the specific situation.

A logical source of error is the implicit model assumption that a subsystem may be considered as a single black box. In fact, a subsystem consisting of two or more black boxes, one of each type spared, should demonstrate a waiting time significantly less than that of a subsystem having the same aggregate demand rate consisting of only one black box. The complete theoretical structure of this problem has not yet been formulated.

Two significant findings, which were not uncovered in the prediction of service time and failure rate, weighed heavily in the results of the model evaluation. These were as follows:

a. The sensitivity of the FCS to the R14A synchronizer unit. This fact required adjustment of the waiting time to compensate for maintenance shop repair of the synchronizer while the flightline crew waited.

b. Malfunctions not involving catastrophic failures were underestimated. This resulted in an experienced failure rate higher than anticipated. This problem is related to the problem above in that the system is very sensitive to timing adjustments.

3.7.5 Improvement of Operational Readiness at SJAFB

The following are potential sources of improvement:

a. Increase test equipment complements.

(1) Make category II testing and calibration a two shift operation.

(2) Purchase additional test equipment. If this is done, it must be in conjunction with 1 or 2; otherwise, additional test equipment will end up in a waiting line.

b. Move the spares to the flightline. This would reduce total travel time per failure. (This presumes that off-shelf items are operable.)

3.7.6 Recommended Procedure

For each maintenance activity, a probabilistic activity network should be developed which contains estimators of time elements from which the total service time estimate may be derived. This particular device of the technique is fundamental to achievement of technique reliability. In general any differences in results of technique application will be traceable to the basic activity network. Further, the improvement potential, by changes in activity networks, is a necessary part of system analysis for optimization.

The following parameter estimation procedure should be used:

a. Flightline

(1) Use 1.5 times the predicted value of failure rate. The reason for this is that crabs, non-verified, and adjustments are not encompassed in the prediction technique.

(2) Use maximum operational usage rate.

(3) Use RADC maintainability technique for prediction of active repair time. (See Ref. 3.)

b. Shop Repair

(1) Use maximum operational usage rate.

(2) Use predicted failure rate. Generally, only catastrophic failures reach the shop.

(3) Use twice the predicted repair time. The actual time to repair is approximately twice the predicted active repair time for shop maintenance. (See Ref. 3.)

SECTION IV

THE C141 SYSTEM

4.1 Introduction

The C141 aircraft is a follow on version of the C130 with many of the subsystems carried over directly. The principal differences are:

a. Size - the C141 is about one third larger than the C130.

b. Engines - the C141 is equipped with fan jet engines, while the C130 is driven by turboprop engines.

c. Capacity - the C141 can lift a load 1.7 times the load lifted by the C130.

The detailed design of the C141 is very simple and completely conventional; it is held within the state-of-the-art in all areas.

4.1.1 Background

It is anticipated that the C141 will be operated with Tactical Air Command (TAC) and from Military Air Transport Services (MATS) bases where maintenance facilities are now established for 4 engine transport aircraft of comparable size. Essentially all basic model parameter estimates are based on USAF experience gained on the C130. The primary source of information is the C141 Proposal by Lockheed Corporation (Ref. 5).

4.1.2 Scope of Manning Prediction

The manning and skill prediction is limited to those subsystems of the C141 that are directly related to the operational readiness of the aircraft and which fall into the direct maintenance category. No attempt is made to establish personnel requirements which are independent of workload, viz., command, administrative, flight operations, and supply [11] functions.

The application of the manning technique to C141 system invoked the following rules:

a. The number of personnel assigned to each activity was such that additional personnel would not produce a measureable increase in operational readiness.

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[11] Supply is essential to operational readiness to the extent that they provide spares; however, no attempt is made to man a supply facility.

b. For field maintenance shops manning was assigned, using the rule above, for zero repairable spares except where specifically covered. If the equivalent of the number of units in waiting at each shop is assigned as repairable spares to the respective shop the result is: no waiting time due to lack of spares. Consequently, there will be no effect on the operational readiness at the flightline.

4.2 Operational Plan

The operational plan assumes the existence of two organizations as follows:

a. Organizational maintenance squadron
b. Field maintenance squadron

The assumptions which must be made concerning these squadrons are contained in the following paragraphs.

4.2.1 Organizational Maintenance Squadron Assumptions

a. Organizational maintenance performs the following tasks:

(1) Turnaround inspection - flightline
(2) Daily preflight - flightline (See table 30.)
(3) 100 hour postflight - docks (See table 30.)
(4) 300 hour periodic - docks

The personnel in organizational maintenance are assumed to have an AFSC 431X1-Aircraft Mechanic.

b. Organization maintenance is made up of teams as follows:

(1) Turnaround inspection - 3 men
(2) Daily preflight - 13 men
(3) 100 hour postflight - 19 men
(4) 300 hour periodic - 19 men

The flightline teams act independently while the dock teams perform the postflight and the periodic interchangeably. One seven level technician manages each of the shifts of turnaround inspection. One senior technician (7 level) is included on each of the reams as called out in 2, 3, and 4.

TABLE 30

ORGANIZATIONAL MAINTENANCE - PREFLIGHT AND POSTFLIGHT

Inspection Activity	Flightline				Docks			
	Preflight				100 hour Postflight			
	Insp. Time (hr.)	Unsch. Time (hr.)	Total Time* (hr.)	Men	Insp. Time (hr.)	Unsch. Time (hr.)	Total Time* (hr.)	Men
Insp. Preparation	.58	.87	1.45	1	.87	1.31	2.18	1
Airframe Int. and Ext.	.67	1.01	1.68	2	1.00	1.50	2.50	2
Landing Gear	.53	.80	1.33	1	1.00	1.50	2.50	1
Flight Control	.75	1.13	1.88**	1	.62	.93	1.55	2
Engines and APU	.72	1.08	1.80	1	1.03	1.55	2.58**	5
Air Cond. Pres. Anti Ice	.42	.63	1.05	1	.75	1.13	1.88	2
Electric Power and Light	.47	.71	1.18	1	.47	.71	1.18	1
Hydraulics	.27	.41	1.68	1	.33	.50	.83	1
Fuel System	.58	.87	1.45	1	.47	.71	1.18	1
Misc. Utilities	.33	.50	.83	1	.42	.63	1.05	1
Inst. and Auto Pilot	.37	.56	.93	1	.63	.95	1.58	1
Comm. and Nav.	.53	.80	1.33	1*	.87	1.31	2.18	2***

*Does not include .5 hours team time for travel time, test equipment acquisition, etc.

**Greatest mean activity time.

***Supplied by maintenance shop.

c. The organizational maintenance occurrence rates (equivalent to the failure rate - λ) are as follows:

(1) Turnaround - λ_1 = .1250
(2 inspections per 16 hour day per aircraft)

(2) Preflight - λ_2 = .0625
(1 inspection per 16 hour day per aircraft)

(3) Postflight - λ_3 = .0031
(3 inspections per 60 - 16 hour days per aircraft)

(4) Periodic - λ_4 = .0010
(1 inspection per 60 - 16 hour days per aircraft)

d. The total downtime for organizational maintenance inspections plus non-scheduled maintenance (random) plus team delay time (.5 hours) equals as follows:

1. Turnaround - 1.0 hour (μ_1 = 1.0)
2. Preflight - 2.4 hours (μ_2 = .42)
3. Postflight - 3.1 hours (μ_3 = .32)
4. Periodic - 10.0 hours (μ_4 = .10)

e. Preflight, postflight, and periodic inspections of Comm-Nav subsystems will be provided from the appropriate maintenance shop.

4.2.2 Field Maintenance Squadron Assumptions

a. The work provided for the maintenance shops is directly related to the amount of work performed in organizational maintenance as outlined in table 20.

b. The standard crew size is 2 men.

4.3 <u>Organizational Maintenance Squadron Manning</u>

4.3.1 Flightline Maintenance

For this category, as in the remaining ones, the Tables are used to obtain the appropriate numbers of crews. A basic parameter of the Tables, P, must be calculated for the flightline personnel.

4.3.1.1 Turnaround

Turnaround personnel requirements are based on an anticipated wing strength of 48 aircraft being given two turnaround inspection per day. Calculating as follows:

$\lambda_1 = .1250 \quad \mu_1 = 1.0 \quad P_1 = .125$

the other parameters are

$N = 48 \cong 50 \quad S = 0$

It is desired to find C in the Tables, for the above parameters, which will yield the smallest useful value of d, hence the largest value of operational readiness (R).

$C = 10 \quad d = .112 \quad R = .888$

The mean channel utilization (c) is

$c = .6$

The 3 member crew consists of 2 level five and 1 level three men. With C = 10 the manning information is summarized below:

Team Composition	3[5,5,3]	
Two Shift Total	40[5]	20[3]
Adjustment at .2	8	4
	48	24
Total Pers.	72	
Senior Tech 2 [7]	2	
	74	

4.3.1.2 Preflight

For the preflight inspection the same process is followed as for the turnaround inspection, viz., list the known parameters and find the number of channels which will give the maximum useful operational readiness (R). The following are the known parameters:

$\lambda_2 = .0625 \quad \mu_2 = .42 \quad P = \lambda_2/\mu_2 = .149$

$N = 50 \quad S = 0$

Entering the Tables: the number of channels (C) required

$C = 10$

for which

$d = .138 \quad R = .862$

and channel utilization (c) is

$c = .75$

The Tables indicate that 10 repair teams are needed each shift for two shifts, or a total of 20 crews. Based on the assumed crew composition stated above. Table 31 below, gives a breakout of requirements for the preflight. The 20% adjustment for backup is also included.

TABLE 31

PREFLIGHT MAINTENANCE

Skill Levels	3	5	7	Total
20 Crews	20	220	20	260
Back-up (20%)	4	44	4	52
Total	24	264	24	312

4.3.2 Dock Maintenance

It is supposed that postflight and periodic maintenance will be performed at the docks by the same personnel. In both cases the team composition will be essentially the same. Periodic can be accomplished by a team of 32 men in five hours. In order to make the periodic and postflight teams compatible in number this has been adjusted to a team of 19 men with a work duration of 10 hours. (See table 30 for a breakdown of the postflight inspection.)

The quantity P is calculated as follows:

	λ_i	μ_i	P
Postflight	.0031	.32	.010
Periodic	.0010	.01	.010
Total			.020

From the Tables for:

$N \cong 50$ $P = .020$ $S = 0$

it is seen that for

$C = 3$ $d = .020$ $R = .980$

and channel utilization is

$c = .256$

but with

$C = 2 \quad d = .025 \quad R = .975$

and channel utilization

$c = .385$

Since the operational readiness (R) is not significantly affected and there is an improved channel utilization, the choice is C = 2. Table 32 below, gives the breakout of requirements for a 2 shift operation.

TABLE 32

DOCK MAINTENANCE

Skill Level	3	5	7	Total
4 Crews	4	68	4	76
Back-up	1	14	1	16
Total	5	82	5	92

4.3.3 Summary of Organizational Maintenance Manning

Table 33 summarizes the requirements for organizational maintenance manning. Table 34 gives the requirements for a stable personnel system for organizational maintenance.

4.4 Field Maintenance Squadron Manning

4.4.1 General

In order to use the Tables for calculating the manning requirements the parameter P must be calculated. To obtain P_i for a specific subsystem the following procedure is used.

a. λ_2 is divided by the repair rate (μ_{2i}) of the specific activity of the preflight.

b. λ_3 is added to λ_4 then the whole is divided by the repair rate (μ_{3i}) of the specific activity of the postflight and multiplied by 2.[12]

c. a, above, is added to b, above, then divided by the standard crew size (2) to obtain P_i of the specific activity of the subsystem.

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[12] P of the periodic is equal to P of the postflight at organizational maintenance.

TABLE 33

ORGANIZATIONAL MAINTENANCE MANNING

AFSC	Flightline						Docks			Total		
	Turnaround			Preflight			Postflight & Periodic					
	Total	Adj.	Adj. Tot.	Total	Adj.	Adj. Tot.	Total	Adj.	Adj. Tot.	Total	Adj.	Adj.Tot.
43171	2	0	2	20	4	24	4	1	5	26	5	31
43151	40	8	48	220	44	264	68	14	82	328	66	394
43131	20	4	24	20	4	24	4	1	5	44	9	53
Totals	62	12	74	260	52	312	76	16	92	398	80	478

TABLE 34

STABLE ORGANIZATIONAL MAINTENANCE MANNING

AFSC	Adj. Total *	Stable Total **
43171	31	31
43151	394	394
43131	53	394
Total	478	819

* Manpower figures that have been adjusted for sick leave, furlough, etc. (see 3.5)

** Manpower adjustments for on the job training for replacement personnel (see 3.5 and appendix VI)

Example:

$\lambda_2 = .0625$ $\lambda_3 = .0031$ $\lambda_4 = .0010$

μ_2 of the engine and auxiliary power unit shop = 1/1.80 = .5556

μ_3 of the same shop = 1/(5) (2.58) = .0775

The table below works out the example:

λ_i	μ_i	λ_i/μ_i	Std. Crew	P_i
.0625	.5556	.1124		
2(.0041)	.0775	.1058		
		.2182	2	.109

Table 35 below, contains the values of P for the various subsystems.

TABLE 35

FIELD MAINTENANCE UTILIZATION FACTORS

Maintenance Shop	P_i
Airframe Repair	.126
Land Gear and Flight Controls	.120
Engines and Auxiliary Power Unit	.109
Airborne Utilities	.103
Electrical	.042
Fuel System	.050
Instruments and Auto Pilot	.036
Comm-Nav	.059

4.4.2 Subsystem Manning

Now that all of the parameters, except C and S have been obtained, subsystem manning can begin. The quantity C will be that which has a value of d as small as possible. The manning is arrived at without consideration of sparing (S) for all subsystems; except the engine shop and the Comm-Nav shops, for which the possibility of maintaining repairable spares is more evident.

The empirical workload data is presumed to include waiting time encountered for repairable spares. However, the actual allocation of spares to the subsystem is not known. Hence, in order to insure at least that these waiting times are achieved, spares (by subsystem complement) have been allocated such that the percentage of subsystems down in excess of spares is less than .001 per subsystem. With this condition achieved, adequate protection against waiting exceeding those encountered in C130 maintenance activity is assumed.

The various shops are manned as follows: (The value of d in general corresponds to subsystems down, not aircraft down.)

a. Air Frame Repair, AFSC 533X0, 534X0

$N = 48 \cong 50$ $S = 0$ $P = .126 \cong .13$

then

$C = 10$ with a value of $d = .116$

Team composition 2[5,3]

Team composition 2[5,3]

	5 level	3 level
Two shift total	20	20
Adjustment at .2	4	4
Total	24	24
Senior technician (7 level)	2	
Total personnel	50	

b. Flight Controls, AFSC 422X1, 422X2 Landing Gear

$N = 48 \cong 50$ $S = 0$ $P = .123 \cong .12$

then

$C = 10$ $d = .108$

Team composition 2[5,3]

	5 level	3 level
Two shift total	20	20
Adjustment at .2	4	4
Total	24	24
Senior technician (7 level)	2	
Total personnel	50	

c. Engines and Auxiliary Power Unit, AFSC 432X0

$N = 48 \cong 50$ $S = 0$ $P = .10$

then
$C = 9$ $d = .091$

Team composition 2[5,5]

	5 level
Two shift total	36
Adjustment at .2	8
Total	44
Senior technician (7 level)	2
Adjustment for trainees	44[3]
Total personnel	90

As previously indicated (see section 4.1.2 and 4.4.2) this manning level may be decreased through the introduction of spares. A proper balance between repair crews and spare engines is feasible for various contributions of the engines to the overall readiness of the aircraft.

Table 36 below shows the combinations of maintenance teams (C) and sets of engines (4 engines) spares (S) corresponding to various downtime contributions (d) no greater than .025.

TABLE 36

ENGINE REPAIR

S	C	d
7	6	.022
8	6	.021
9	6	.017
7	7	.012
9	7	.006
9	8	.003
10	8	.002
11	8	.001

Table 36 shows that the smallest value of d corresponds to a manning of 8 engine repair crews and 11 spare sets (44 engines). The maintenance operation in the engine shop requires two men teams (level 5). When considering the 20% adjustment factor for sick leave, etc., and the additional conditions imposed for a stable personnel system (see appendix VI), the following manning results for minimum contribution to aircraft downtime:

$N = 48 \cong 50$ $S = 11$ $P = .10$

then

$C = 8$ $d = .001$

Team composition 2[5,5]

	5 level
Two shift total	32
Adjustment of .2	7
Total	39
Senior technician (7 level)	2
Adjustment for trainees	39
Total personnel	80

d. Airborne Utilities, AFSC 421X2, 422X1

$N = 48 \cong 50$ $S = 0$ $P = .103 \cong .10$

then

$C = 9$ $d = .091$

Team composition 2[5,3]

	5 level	3 level
Two shift total	18	18
Adjustment at .2	4	4
Total	22	22
Senior technician (7 level)	2	
Total personnel	46	

e. Electrical, AFSC 42ↄX0

$N = 48 \cong 50$ $S = 0$ $P = .042 \cong .04$

then

$C = 5$ $d = .039$

Team composition 2[5,3]

	5 level	3 level
Two shift total	10	10
Adjustment at	2	2
Total	12	12
Senior technician (7 level)	2	
Total personnel	26	

f. Fuel System, AFSC 424X0

$N = 48 \cong 50$ $S = 0$ $P = .05$

then

$C = 6$ $d = .048$

Team composition 2[5,3]

	5 level	3 level
Two shift total	12	12
Adjustment at .2	3	3
Total	15	15
Senior technician (7 level)	2	
Total personnel	32	

g. Instruments and Auto Pilot, AFSC 422X0, 423X3

$N = 48 \cong 50$ $S = 0$ $P = .036 \cong .04$

then

$C = 5$ $d = .039$

Team composition 2[5,3]

	5 level	3 level
Two shift total	10	10
Adjustment at .2	2	2
Total	12	12
Senior technician (7 level)	2	
Total personnel	26	

h. Communication - Navigation Shop

The manning calculation for the Comm-Nav shop was handled in a slightly different fashion than the other subsystems in other maintenance categories. On the flightline, and in the docks, the same people perform the tasks associated with both the navigation and the communication subsystems. In the shop, however, these systems are sufficiently complex to warrant establishing separate shops.

The total workload coming into the Comm-Nav shop has been broken out according to their relative failure rates, with P calculated separately for each, and the Tables entered as usual.

(1) Communications Shop AFSC 301X0, 301X1

$N = 48 \cong 50$ $S = 0$ $P = .023 \cong .02$

then

$C = 3$ $d = .02$

Team composition 2[5,3]

	5 level	3 level
Two shift total	6	6
Adjustment of .2	2	2
Total	8	8
Senior technician (7 level)	2	
Total personnel	18	

(2) Navigation Shop AFSC 301X0, 301X1

$N = 48 \cong 50$ $S = 0$ $P = .034 \cong .03$

then

$C = 4$ $d = .03$

Team composition 2[5,3]

	5 level	3 level
Two shift total	8	8
Adjustment at .2	2	2
Total	10	10
Senior technician (7 level)	2	
Total personnel	22	

If these shops were manned at the above levels, the downtime contributions would be d = .02 and d = .03 for communication and navigation respectively. By maintaining repairable spares in these shops, this downtime may be reduced; or alternatively, traded off with crew size. Table 37 below illustrate these trade-offs.

(3) Comm-Nav Flightline AFSC301X0, 301X1

The Comm-Nav men perform their own preflight inspection independently as detailed below:

λ_2	μ_{2i}	P
.0625	1.0	.0625

$N = 48 \cong 50$ $S = 0$ $P = .0625 \cong .06$

Then C = 6 with a value of d = .058

Team composition 2[5,3]

	5 level	3 level
Two shift total	12	12
Adjustment at .2	3	3
Total	15	15
Senior technician (7 level)	2	
Total personnel	32	

TABLE 37

COM-NAV SHOP TRADE-OFFS

Communications

S	C	d
0	3	.02
1	3	.008
1	2	.012
2	3	.003
2	2	.006
3	3	.001

Navigation

S	C	d
0	4	.03
1	4	.015
1	3	.018
2	4	.006
2	3	.009
2	2	.027
3	4	.002

(4) Comm-Nav Dock Personnel, AFSC 301X0, 301X1. The personnel in the Comm-Nav shop perform their own postflight and periodic inspections, independently as detailed below:

	λ_i	μ_i	λ_i/μ_i
Postflight	.0031	.4587	.0014
Periodic	.0010	.2000	.0002
Total P			.0016

$N = 48 \cong 50$ $S = 0$ $P = .0016 \cong .002$

then C = 1 with a value of d = .002

Team composition 1[5,5]

	5 level
Two shift total	4
Adjustment at .2	1
Total	5
Adjustment for trainees	5 [3 level]
Total personnel	

Table 38, on the next page, presents a stable field maintenance squadron manning.

Table 39 shows maintenance manning figures for those personnel who contribute to the maintenance workload of the total system; but which may not be directly traceable to any of the subsystems through its failure rate, e.g., the many pieces of ground support equipment that must be maintained and serviced requiring trained personnel.

The data in table 39 are based on current C-130 aircraft whose requirements relative to this type of maintenance are assumed comparable to the C141.

TABLE 39

MANNING - OTHER SKILLS

Function Title	AFSC	Manning
Machinist	531X0	4
Metal Processing Specialist	532X0	5
Painters	522X0	4
Ground Support Equipment	421X3	31
Repair & Reclamation	431X1	46
Total		90

4.5 Operational Readiness

4.5.1 General

All operational unreadiness may be considered to be generated only at either flightline or the docks. In the analysis performed in this study, the data used did not permit development of a direct relation between the field maintenance shops and flightline (organizational). However, implicit in the data (unscheduled maintenance at flightline) is the effect of organizational maintenance on flightline time. Hence, the values used should be representative of total maintenance effects.

TABLE 38

STABLE FIELD MAINTENANCE MANNING

Maintenance Shop	533X0	534X0	53470	422X1	422X2	42271	432X0	43270	421X2	42172	423X0	42370	424X0	42470	422X0	423X3	42373	301X0	301X1	30170	30171	Total
Airframe Repair	24	24	2																			50
Flight Control and Landing Gear				24	24	2																50
Engines and APU							78	2														80
Airborne Utilities				22					22	2												46
Electrical											24	2										26
Fuel System													30	2								32
Instruments and Auto Pilot															12	12	2					26
Comm-Nav Shop																						
Maintenance Shop																		18	18	2	2	40
Flightline																		15	15	1	1	32
Docks																		5	5			10
Total	24	24	2	46	24	2	78	2	22	2	24	2	30	2	12	12	2	38	38	3	3	392

For shop maintenance, the value for subsystems down in excess of spares (N+S)d, represents, in fact, the workload awaiting repair on the average. For all other shops, subsystem spares have not been included. This means that generally less units down in excess of spares can be expected - since spares will be available. The value of d still will represent a good approximation to tasks awaiting service.

4.5.2 Dock Maintenance

It has been assumed that both periodic and postflight will be performed by the same teams. The data available does not permit an explicit evaluation of the aircraft down for periodic maintenance. Based on essentially postflight only, on the average there will be 1/2 aircraft down. This estimate may be in error by a factor of 4. In summary, manning beyond that presented in this analysis would result in essentially no increase in operational readiness.

4.5.3 Calculation of Operational Readiness

The operational readiness for the C141 based on manpower established in this analysis is summarized in table 40.

TABLE 40

OPERATIONAL READINESS

Activity	d
Preflight	.138
Dock	.020
Comm-Nav - Flightline	.058
Comm-Nav - Dock	.002
Total	.218
$R = 1-d_{TOTAL} =$	.782

4.5.4 Sources of Error

The sources of error are anticipated to affect the value of operational readiness achievable but not affect the manning established. The following points are made:

a. The time for performance of preflight is based on adjustment to the longest time required. Other simultaneous tasks may actually exceed this task time. (See appendix III AMRL-TDR-64-21 (Ref. 1), and appendix VII this report.)

b. As in the case of multiple flights for the F105D discussed previously, waiting may occur.

c. It is presumed that adequate shop spares will be available (equivalent level to the C130) to assure no increase in unscheduled maintenance time. If the level is increased beyond that of the C130, unscheduled time may be reduced.

4.6 Summary

Table 41 summarizes the stable manning data developed above by skill level.

TABLE 41

STABLE MANNING - BY SKILL LEVEL

Level	Organizational Maintenance	Field Maintenance	Total
7	31	22	53
5	394	227	621
3	394	227	621
Total	819	476	1295

SECTION V

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The manning technique evaluated in this program has been demonstrated to be a valid and reliable technique for predicting manning requirements for weapons systems. The technique has been found to be relatively easy to apply, and is compatible with existing methods for predicting reliability and maintainability parameters. The model is based on random processes approximating field conditions, and produces valid results using state-of-the-art reliability and maintainability techniques.

The prediction for the FCS, using field data as sources for parameter estimation, yielded good results when compared with operational performance and existing manning. The results of the FCS analysis also verified the fact that, as with any technique, the validity of this technique depends upon the accuracy of the inputs. There is also evidence, among the results of the program, that the technique provides a means for seeking out sources of inefficient personnel utilization and sparing procedures.

The reliability of a model has been agreed upon to lie in the ability to produce consistent results with different experimenters. The validation program did not formally test for reliability, However, a method was developed which establishes a general procedure for achieving reliability. This procedure was found to be quite sensitive to, and dependent on, methods for estimating parameter values and organizational structure of the support system.

One of the more serious problems existing in the Air Force is the development of requist skills to maintain a complex system. In the manning analysis developed in this program it has been assumed that a five level technician could perform at the predicted repair rates. This presumed that the personnel have been associated with the F105D FCS during his maintenance training. For example, in general 5 level technician without F105D FCS experience could not, in general, achieve predicted maintenance rates. A conservative estimate is that a six month familiarization with the F105D FCS is required for 5 level technician to achieve the maintenance rates predicted.

It is recommended that:

a. A field program or analysis of existing data, if available, be conducted to validate the total operational readiness of the F105D in order to validate the finding in this program.

b. The C141 system should be evaluated with respect to the validity of manning requirements based on existing manning assignments, and tested for:

(1) operational readiness achieved

(2) effective number of repair channels as determined by test equipment limitations

(3) adequacy of repairable spares

(4) compatibility of the results above with the predicted manning requirements.

c. The manning technique be employed as a device for evaluating support organizations. The validity and ease of application of the queuing model suggest that the technique may be profitably used to evaluate the performance of existing support organizations for potential improvement. Additionally, the model may be used to search out problem areas and suggest optimum improvement methods.

d. Standard shop activity networks be developed. The availability of a manual consisting of standard networks would facilate employment of the queuing model. Further, standard time estimates could be established for network activity elements. With variance estimates this would permit model application with minimum parameter research. Also, it would permit sensitivity analysis of the results due to parameter error estimates.

e. Uniform documentation procedures, forms, and data dimensions which are consistant with manning information requirement be developed. Information (estimates) should be made available to military manpower analysts no latter than the program definition phase in the weapon system development cycle.

f. General personnel backup factors, to achieve manning stability, be determined. One aspect of manning which weighs heavily in the total manning is the requirement for total personnel-skill stability. The requirement for a single seven-level person necessitates, in general, several 5 level and 3 level personnel. This comes about simply as a matter of promotional policy and rates of discharge. In the case of the F105D FCS at SJAFB, ratios of the skill levels (7, 5, and 3) for stable manning were computed for the FCS personnel, and are reasonably accurate. It is recommended that:

(1) These backup factors be calculated and continuously updated for all skill categories to further improve quantitative analysis of manning requirements.

(2) A research program be conducted to establish ways in which discharge rates of five level personnel could be reduced. A first step in such a program would be to establish, quantitatively, the economical return per incremental change in the discharge rate.

(3) A personnel-system phaseover analysis be implemented, to better capitalize on existing skills in the services, and reduce backup personnel to achieve manning stability (see appendix VI).

g. The interface between personnel requirements, repairable spares provisioning, and system operational performance be utilized. Provisioning and manning analysis are strongly correlated parameters of system effectiveness, and, such manning analysis and provisioning should be jointly performed rather than independently performed. Further, manning and repairable spares should be considered commonly in terms of cost and traded with operational readiness.

h. Test equipment-skill-packaging trade-off be studied. The techniques evaluated in this program permit quantitative analysis of general and special test equipment in conjunction with skill requirements and packaging techniques. A particular problem is the prevalence of either an inadequate supply of special test equipment, or the existance of expensive test equipment which is either not used, or useful, and which requires special skill for maintenance with its concomitant sparing problems.

APPENDIX I

MATHEMATICAL MODEL

The formal name of the mathematical model is: "Mathematical Model of Finite Cyclical Queues for Systems with Repairable Spares." Suppose that a system consists of identical units (N+S), and that, at most, N_o of the N+S units must be operational. The S units are provided as repairable spares. Further, the system has a service facility consisting of independent service channels (C).

At any time the system must be in one of N+S+1 possible states (n), i.e.,

$$0 \geq n \geq (N+S) \qquad \text{(I-1)}$$

where if n = (N+S) all units are down and if n = 0 all units are up. The probability that the system is in a state n is p_n. Two cases must be considered:

Case 1. Number of channels exceeds the number of spares, viz., $C > S$

Case 2. Number of channels is less than or equal to the number of spares, viz., $C \geq S$

<u>Probability State Equations</u>

The quantity p_n may be explicitly expressed in terms of measurable parameters; these parameters and associated symbols are as follows:

N = Maximum number of units operating

S = Spares, units in excess of N

λ = Failure rate of a single operating unit

μ = Repair rate of a single service channel

C = Number of repair channels

n = Number of units actually operating

p_o = Probability that all units are operating

P = Utilization factor (λ/μ)

For case 1 (C>S) the equations for p_n are given as follows:

$$p_n = \frac{(NP)^n}{n!} p_o \qquad n<(S+1), n<C \qquad \text{(I-2)}$$

$$p_n = \frac{N!}{(N+S-n)!} \cdot \frac{N^S P^n}{N!} p_o \qquad n\geq(S+1), n\leq C \qquad \text{(I-3)}$$

$$p_n = \frac{N!}{(N+S-n)!} \frac{N^S C^C P^n}{C!C^n} p_o \qquad n>C \qquad \text{(I-4)}$$

For case 2 (C≤S) the equations for p_n are given as follows:

$$p_n = \frac{(NP)^n}{n!} p_o \qquad n<C \qquad \text{(I-5)}$$

$$p_n = \frac{C^C (NP)^n}{C!C^n} p_o \qquad n\leq(S+1),\ n\geq C \qquad \text{(I-6)}$$

$$p_n = \frac{N!}{(N+S-n)!} \cdot \frac{N^S C^C P^n}{C!C^n} p_o \qquad n>(S+1) \qquad \text{(I-7)}$$

Since at any one time, one and only one state may exist, the sum of their probabilities must equal one

$$\sum_{n=0}^{N+S} p_n = 1 \quad . \qquad \text{(I-8)}$$

Noting that p_o is an explicit factor of each p_n the ratio

$$k_n = p_n/p_o \text{ [13]} \qquad \text{(I-9)}$$

the expression

$$p_o \sum_{n=0}^{N+S} k_n = 1 \qquad \text{(I-10)}$$

---

[13] k_n in equation I-2, for instance, would equal $[(NP)^n]/n!$

is obtained. From this p_o can be determined

$$p_o = 1/\left[\sum_{n=0}^{N+S} k_n\right] \qquad \text{(I-11)}$$

Knowing p_n the following measures may be derived.

The mean number of units awaiting service or undergoing service is

$$N_d = \sum_{n=1}^{N+S} np_n \text{ [14]} \qquad \text{(I-12)}$$

The mean number of units down in excess of spares is

$$D = \sum_{n=S+1}^{N+S} (n-S)\ p_n \text{ [14]} \qquad \text{(I-13)}$$

The mean number of service channels busy is

$$C_b = \sum_{n=1}^{C} np_n + C \sum_{n=C+1}^{N+S} p_n \qquad \text{(I-14)}$$

The mean number of units awaiting service is

$$W = \sum_{n=C+1}^{N+S} (n-C)\ p_n \qquad \text{(I-15)}$$

The mean number of units operating is

$$N_o = N - \sum_{n=S+1}^{N+S} (n-S)\ p_n \qquad \text{(I-16)}$$

The mean number of units operable but not operating is

$$S_o = \sum_{n=0}^{S} (S-n)\ p_n \qquad \text{(I-17)}$$

Of the six equations above (I-12 to I-17) only two equations, viz., I-12 and I-13 are independent; the others may be derived from them.

---

[14] The output entries (n_d, d) are per unit, via., $n_d = N_d/T$ and $d = D/N$

Derived Quantities

It may be noted that all of the measures just defined above are all expressed in terms of the basic state probabilities. It is possible to extend these measures to other system characteristics which are not described explicitly as probabilities.

Four identities listed below are the basis for derivation of other pertinent quantities, necessary to establish system efficiency measures. They are as follows:

a. $N_d = W+C_b$ I-18

This identity states that the mean number of units either awaiting or undergoing service (down) are either waiting (W) or undergoing service (C_b).

b. $N_u = N_o+S_o$ I-19

This identity states that the number of operable units (N_u) are either operating (N_o) or awaiting operation (S_o).

c. $N+S = N_d+N_u$ I-20

This identity states the total number of units in the system (N+S) is the sum of units down (N_d) and units up (N_u).

d. $C_b = N_oP$ I-21

This identity states that the mean number of busy channels (C_b) is equal to the mean number of units operating (N_o) multiplied by consideration of the following:

(1) In a steady state there exists a finite queue length.

(2) In order to maintain a stable mean queue length, the number of units entering the queue must be equal to the number of units leaving the queue.[15] The mean number of units arriving to the queue is equal to $N_o\lambda$.

(3) Also, for steady state, the mean number leaving service (μC_b) must be equal to the mean number of units leaving the queue. Thus:

$$\mu C_b = N_o\lambda \quad \text{I-22}$$

or:

$$C_b = N_oP \quad \text{I-23}$$

---

[15] Some suitable time base is assumed to form a rate.

The following quantities can now be derived using the four identities established above.

W = Mean number of units awaiting service

$$= N_d - C_b \qquad \text{I-24}$$

S_o = Mean number of units operable but not operating

$$= S + D - N_d \qquad \text{I-25}$$

t_w = Mean waiting time for service (in queue)

$$= W/\mu C_b \qquad \text{I-26}$$

t_{ws} = Mean waiting time in waiting and service

$$= t_w + 1/\mu \qquad \text{I-27}$$

t_o = Mean waiting time for operable units before going into operation

$$= S_o/\mu C_b \qquad \text{I-28}$$

APPENDIX II

REVIEW OF RAC DOCUMENT 1950

1. INTRODUCTION

1.1 Purpose

The Republic Aircraft Corporation (RAC) document number 1950 (Ref. 2) was reviewed for the following purposes:

a. To extract the time and failure data for the AN/ASG-19 subsystem.

b. To extract data on repair of the AN/ASG-19 subsystem.

1.2 Method

The method of obtaining the reliability estimate is a straight-forward evaluation and includes all applicable data. The method of obtaining the repair data involves a number of assumptions and all are documented.

No statistical tests are made in comparing the data with the predicted result. Instead, a range of values is set up corresponding to various degrees of failure, since the value predicted is so close to the value given by the data that statistical comparison is meaningless.

2. RELIABILITY ANALYSIS

Table 42, "Summary of Failure and Crab Information," shows all the reliability data from RAC and USAF sources contained in RAC No. 1950. It is divided between, and subtotaled, RCA and USAF. The subtotals show 18 hours MTBF for the data accumulated by RAC with a total of 10,013 hours accumulated and 545 failures for the AN/ASG-19 subsystem. The USAF data shows a MTBF of 13 hours with approximately 7500 hours accumulated and 613 failures. Combining the sources of data yields a MTBF of 15 hours for the AN/ASG-19. The predicted value was 17 hours which was quite close to the observed value. Data was available on the individual components (black boxes) at PACAF and in general it was in agreement with the prediction done by RCAS. However, there was too small a time sample involved for definite verification of the prediction at the black box level. On the other hand verification at the three main equipment level means that the predicted figures for the black boxes can be accepted since nothing unusual was involved in the production of AN/ASG-19, e.g., advances in the state of the art.

TABLE 42
SUMMARY OF FAILURE AND CRAB INFORMATION

		RAC				USAF				ALL
		139 A/C	50 A/C	PACAF 15 A/C	Sub-Total	PACAF 15 A/C	ARINC NELLIS	EGLIN	Sub-Total	Total
Radar	Pred. MTBF									21
	Hours	6720	2546	747	10013	2783	1602	3700	8085	18,098
	Failures	318	125	35	478	73	150	236	459	937
	MTBF	21	20	21	21	38	11	16	18	19
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					146			146	146
	MFTBVC					9.3			9.3	9.3
Sight	Pred. MTBF									320
	Hours	6720	2546	747	10013	2783	1602	3700	8085	18,098
	Failures	23	10	2	35	8	31	24	63	98
	MTBF	290	250	370	290	350	43	150	130	180
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					19			19	19
	MFTBVC					71			71	71
BTC	Pred. MTBF									150
	Hours	6720	2546	747	10013	2783	1602	1720	6105	16,118
	Failures	25	6	1	32	10	32	49	91	123
	MTBF	240	420	750	310	280	38	31	67	130
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					13			13	13
	MFTBVC					100			100	100
AN/ASG-19	Pred. MTBF									17
	Hours	6720	2546	747	10013	2783	1602	3129	7547	17,550
	Failures	366	141	38	545	91	213	309	613	1,158
	MTBF	18	18	20	18	31	7.5	10	13	15
	Flt. Hrs.					1352			1352	1,352
	Ver. Crab					178			178	178
	MFTBVC					7.6			7.6	7.6

At PACAF the value for the MTBF of AN/ASG-19 was 31 hours, almost exactly two times the value of 15. At PACAF a record was kept of flight crabs which yields a mean flying time between verified crab (MFTBVC) of 7.6 hours, almost one half of the MTBF of 15 hours.

3. MAINTAINABILITY ANALYSIS

Table 43, "Mean Active Repair Time (MART)," shows the repair data. There were a number of problems in dealing with this data, viz., "other" category of removal, "bench time," and "repair manhours" are not clearly identified. Thus it is necessary to make some assumptions which are based on actual field data.

The following is a detailed procedure of how the data were modified:

a. Bench time was divided by two. Roughly one half of the time is spent in active time and one half is spent on delay time.

b. Repair manhours is divided by two for the reason cited above and is divided again by 1.5 on the theory that half of the tasks are accomplished by one man and the other half is accomplished by two men. The overall divisor is three (3 x 1.5).

c. The sum of these two (ABT + ARMH) is an estimate of total active repair time (ART).

d. Some adjustment is needed for the other removals. This is guessed at one half hour per other removal. The adjustment is shown in the AART column.

e. The mean active repair time (MART) is found by dividing the AART by the sum of failures (F) and non-verified failures (NV). The sum is used on the theory that just as much time is spent on the average, in checking an NV as an F.

f. The (MART) is listed for purposes of comparison to see the effect of removing the others. This is the quotient of ART divided by total removals (T). The figures are approximately the same.

g. Finally the predicted MART is listed. For purposes of round off the predicted time for each major part of the AN/ASG-19 subsystem were predicted as listed. The value MART predicted for the AN/ASG-19 subsystem was arrived at by considering the relative probability of failure of the three major parts of the AN/ASG-19.

TABLE 43

MEAN ACTIVE REPAIR TIME (MART)

System	Failures (F)	Non-Ver Fail. (NV)	Sub-Total (F+NV)	Other (O)	Total Removal (T)
R14A	73	59	132	23	155
AD	8	7	15	12	27
BTC	10	24	34	43	77
AN/ASG-19	91	90	181	78	259

System	Bench Time (BT)	Repair Man Hours (RMH)	$\frac{BT}{2}$	$\frac{RMH}{2x1.5}$	Active Repair Time (ART)	Adj. ART [ART-.5(O)] (AART)	$\frac{AART}{F+NV}$ (MART)	$\frac{DT}{T}$ (MART)	Pred-icted (MART)
R14A	217	231	108.5	77.0	185.5	174.0	1.3	1.2	1.0
AD	27	32	13.5	10.7	24.2	18.2	1.2	0.9	1.0
TBC	75	42	37.5	14.0	51.5	30.0	0.9	0.7	1.0
AN/ASG-19	319	305	159.5	101.7	261.2	222.2	1.2	1.0	1.2

It can be seen that the values shown in the last three columns in Table 43 are all of the same magnitude. Further, it is believed that the values are realistic estimates of the mean active repair time.

APPENDIX III

RCA PREDICTIONS OF RELIABILITY AND MAINTAINABILITY

1. INTRODUCTION

To establish the workload for the FCS, a reliability and maintainability analysis was performed. This appendix gives the results of this analysis.

2. RELIABILITY

The objective was to assign a failure rate to each black box in the FCS. To achieve this a gross part count was performed on each box with the assignment of mean reliability figures of merit on standard parts.

a. The reliability figures are representative of the 1959-60 state-of-the-art and were derived from the following:

   1. RCA TR59-416-1 (Reliability Stress Analysis for Electronic Equipment) (Ref. 6)

   2. Military Standardization Handbook MIL-HDBK-217 (Reliability Stress and Failure Rate Data for Electronic Equipment) (Ref. 7)

b. Failure rates represent average stress levels (between 20% and 30% of rated) and are based on 60% confidence limit.

c. Only true random catastrophic failures are considered in the analysis. Not included in this type of failure are:

   1. Wear-out failures
   2. Performance deterioration
   3. Design changes
   4. Workmanship errors
   5. Non-operational defects

Failures of this type should be eliminated either through good design, proper derating of components and/or efficient preventive maintenance scheduling. (Results are in Table 44.)

3. MAINTAINABILITY

The objective was to establish mean repair times for:

a. Each basic maintenance action (preventive, corrective)

TABLE 44

RELIABILITY PREDICTION

THUNDERSTICK FIRE CONTROL SYSTEM, AN/ASG-19 (FCS)

Radar (R14A)	Failure Rate (λ) %/1000 Hours
Antenna Unit	192.40
Automatic Frequency Control	12.35
Electronic-Control Amplifier	384.80
Post IF Amplifier	841.75
Radar-Flight Indicator	336.70
Synchronizer	2188.55
Low Voltage P.S.	456.95
Transmitter	325.00
Radar-Calibration Control	24.05
Wave Guide Coupling	24.05
Flexible Wave Guide	24.05
Clearance Plan Indicator	48.10
Ferrite-Load Isolator	16.25
	λ_1 = 4875.00

Attack and Display (AD)	
Sight Head	107.3410
Gyro Lead Computer	46.956
Sight Amplifier	86.008
Erase Control & Power Supply	6.539
Missile Launch Computer	27.287
Display Tube Amplifier	38.272
	λ_3 = 312.40

Bomb Toss Computer (BTC)	
Power Supply	30.2445
Amplifier	114.1790
Comparator	45.7210
Angle Position Drive	164.7880
Roll Angle Repeater	74.0610
Time & Range Drive Assembly	41.9900
Angle Function B	52.0650
Angle Function A	43.1145
Angle Function E	21.9895
Drift Angle and Range Wind	71.5390
	λ_2 = 695.69

Composite Failure Rate of FCS

$$\lambda_T = \lambda_1+\lambda_2+\lambda_3$$

$$= 4875.00 + 659.69 + 312.40 = 5847.09\%/1000 \text{ hours.}$$

b. Maintenance level (flightline, maintenance shop)

3.1 Basic Procedure

The estimates for corrective maintenance were obtained with a sampling technique where various levels of equipment repair were analyzed using check lists provided with RADC-TDR-63-85, Volume II (Ref. 3). For the preventive maintenance figures, a combination of interviews was employed.

a. Airmen now at work on century series fighter aircraft.

b. The experience of RCA Service Company field engineers who had worked on complex FCS in aircraft.

Table 45 gives the preventive maintenance time, while Table 46 gives estimates of corrective maintenance time broken down to the various levels of maintenance. The times are based on the presence of the number of personnel stated as a minimum.

TABLE 45. ESTIMATES OF MEAN PREVENTIVE MAINTENANCE TIME

	Procedure	AN/ASG-19
	Preflight	2 Men - 1/2 Hr.
	Postflight	2 Men - 1 1/2 Hr. - System
	Squadron 50 Hr. PM	4 Men - 16 Hr. - System
Field Maintenance	100 Hr. PM	4 Men - 24 Hr. - System
Field Maintenance	500 Hr. PM	4 Men - 24 Hr. - System
Field Maintenance	1000 Hr. PM	4 Men - 24 Hr. - System

TABLE 46. ESTIMATES OF MEAN CORRECTIVE MAINTENANCE TIME

Procedure	AN/ASG-19		
	R14A	A&D	BTC
Preflight	If the system fails the checks outlined in the preflight procedures of F105D the system reverts to postflight maintenance times.		
Postflight (Component Replacement)	45* 2 Men	60 2 Men	30 2 Men
Squadron Maintenance (Minor Component Repair)	60 2 Men	30 2 Men	30 2 Men
Field Maintenance - Component Repair	60 2 Men	60 2 Men	60 2 Men
Field Maintenance - Module Repair	30 1 Man	30 1 Man	30 1 Man

*All times in minutes

APPENDIX IV

ACTIVITY NETWORKS

SEYMOUR JOHNSON AFB (SJAFB)

1. FCS Maintenance at Seymour Johnson AFB (SJAFB)

Basically, the maintenance support system consists of flightline personnel and Avionics and Electronics Shop (maintenance shop) personnel.

2.1 FLIGHTLINE MAINTENANCE

Flightline maintenance on the FCS consists of three distinct types of activity:

a. The diagnostic team, consisting of 2 men of seven level for each 2 shifts in operation. The function of the team is to attend the debriefing of pilots and localize faults in the FCS. They then pass on this information to the regular flightline teams.

b. Regular flightline teams normally consist of 5 people, 2 five level and 3 three level. Only the 2 five level personnel are required for maintenance with the three level personnel engaged in on the on-the-job (OJT) training. There are approximately 55 men per shift - 2 shifts per day.

c. There are 2 peak-up stations with teams of 18 men each. Each team has 3 crews consisting of 1 five level man and 3 three level men; an extra 1 1/2 crew allows continuous operation, 24 hours a day, 7 days per week. Peak-up is based on a period of 100 hours of flying time and requires an average of 72 hours to perform.

The regular flightline teams are responsible for performing both unscheduled (random) and scheduled maintenance. The scheduled maintenance, not including peak-up, is performed as follows:

a. At the end of 50 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

b. At the end of 100 flight hours, duration 1 hour, and a crew size of 5. The crew consists of 2 five level and 3 three level personnel.

c. At the end of 200 flight hours, duration 16 hours, and a crew size of 6. The crew consists of 1 seven, 2 five, and 3 three levels of personnel. The FCS does not contribute to downtime since other subsystems have up to 5 days of downtime.

The peak-up effort and the scheduled maintenance activity may be assumed to have rigid scheduling. The random maintenance, on the other hand, is sufficiently variable to make an activity network desirable. Figure 3 presents the activity network for random demands.

2.2 Expected Time of Flight Line Team Per Call.

The expected value (mean) of time for the flight line team per call is as follows:

$$E = p_1[t_2+p_2(t_{10}+t_{12})+(1-p_2)(t_{10}+t_4+t_{11})] + (1-p_1)[t_2+t_3+t_4+p_3t_{12}+p_4(t_5+t_6+t_7+t_8) + p_5t_{11}]+t_9 \quad \text{(IV-1)}$$

The aircraft downtime

$$A_d = E+t_1-t_9 \quad \text{(IV-2)}$$

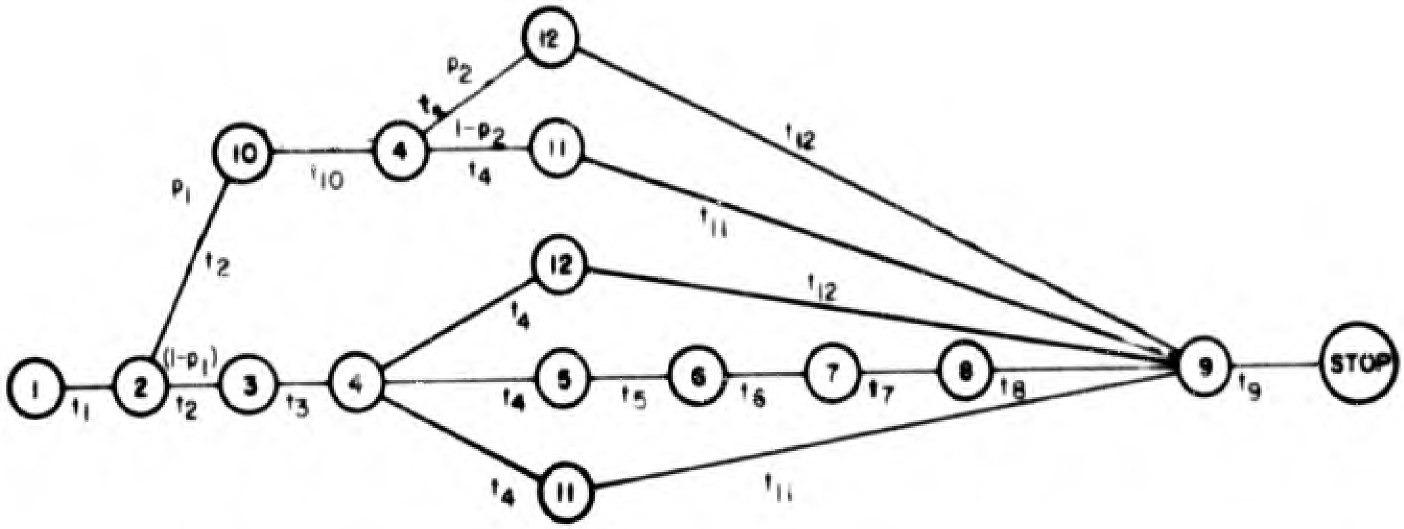
Using the value of figure 3

$E = 3.2$ and
$A_d = 3.5$[16]

2.3 Sources of Data

All of the estimates above were obtained directly from flight-line personnel at SJAFB. A sample of approximately 100 measurement of aircraft downtime was used in establishing the downtime per FCS failure. The mean of the sample was calculated directly from maintenance reports at flightline and was calculated to be 3.5. The measured times were separated into two types, those involving replacement of a black box and those requiring only adjustment or alignment. Approximately sixty percent of the malfunctions involved black box replacement. Those requiring a black box as a replacement had a restore to operation time of 4.5 hours, those not requiring a replacement black box average 2.5 hours. All other time estimates were obtained from flightline personnel and based directly on their experience. The estimates are verified (not statistically) by compatibility provided with other times at the FCS squadron maintenance shop.

[16] It may reasonably be assumed that time estimates are accurate to within .25 hour. Further, invoking the statistical rule for estimation of combined errors leads to assumption that the aggregate error will be less than .25 of the maximum time element estimate involved.



Activity	Estimated Values (hours)
t_1 =debriefing diagnostics	.5
t_2 =notify central control/dispatch crew	0
t_3 =get required test equipment	.2
t_4 =verify malfunction	.3
t_5 =isolate and remove black box	.5
t_6 =get black box at maintenance shops [17]	2.0
t_7 =return to flight line	.3
t_8 =replace box and checkout	.5
t_9 =return point of operation	.2
t_{10}=test equipment not required	.1
t_{11}=perform adjustment	1.5
t_{12}=not verified malfunction	1.5

Probability of Occurrence	(probability)
p_1	.2
$1-p_1$	.8
p_2	.05
$1-p_2$	.95
p_3	.05
p_4	.6
p_5	.35

[17]See detail network in paragraph 2.3

FIGURE 3. FLIGHTLINE ACTIVITY NETWORK

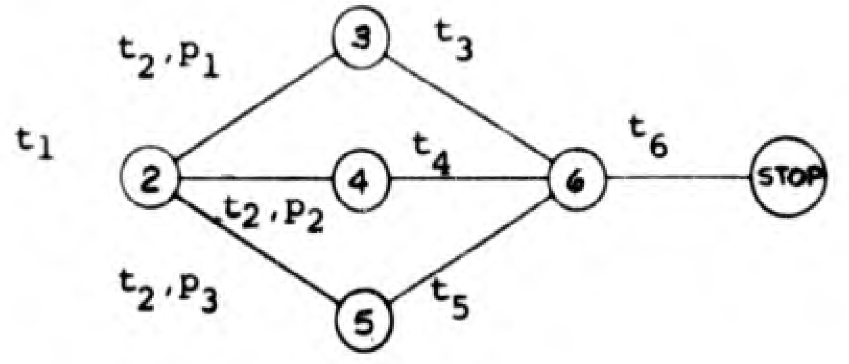
The following observations are pertinent:

a. The RCA maintainability (active time to repair) estimates corresponds exactly to the flightline estimate, viz., t_5+t_8 = 1 hour. But, of course, does not compensate for noncatastrophe failures.

b. The proportion of failures experienced in the radar section of the FCS is essentially that predicted (90%).

2.4 <u>Detail Network of Event (6)</u>

In obtaining the black box several routes are possible; the possible routes are shown below.



The estimated values for these events of the activity network are:

Activity	Estimated Values (hours)
t_1=travel to maintenance shop	.3
t_2=place faulty box in repair line	.2
t_3=take box from ready inventory	.1
t_4=await repair	1.5
t_5=obtain box from base inventory	4.0
t_6=return to aircraft	.35
p_1=probability of occurrence	.35
p_2=probability of occurrence	.60
p_3=probability of occurrence	.05

The expected time duration spent in acquiring the black box is:

$$E_{bb} = t_1+t_2+p_1t_3+p_2t_4+p_3t_5+t_6$$

$$= 2.0 \text{ hours}$$

The rule for determining the course of action is least time. Generally, 60% of the time repair is awaited; 35% of time the box is in ready inventory; 5% of time box cannot be repaired due to lack of parts and is replaced through base inventory. The time for tapping base inventory is 4 hours (this includes uncrating, calibration, travel).

3.1 Maintenance Shop

The shop is divided into specialties as follows:

a. R14A and AD subsystems
b. BTC subsystem
c. Category II test equipment

Shop works a two shift operation.

Shift 1 7:30 - 4:30

Shift 2 4:30 - 12:30

Specific number of crews per shop breakout by shift.

Shift 1

<u>R14 and AD</u>

3 repair teams; each team consists of two personnel of levels 5 and 3.

One supervisor

<u>BTC</u>

3 repair teams; each team consists of two personnel of levels 3 and 5.

One supervisor

<u>Category II Test Equipment</u>

Repair teams (3); consisting of one man, one trainee.

One supervisor

One general supervisor of 7 level.
One general administrator of 5 level.

Shift 2

R14 and AD

Same as Shift 1. One supervisor

BTC

Same as Shift 1. No supervisor

Category II Test Equipment

Second shift not assigned.

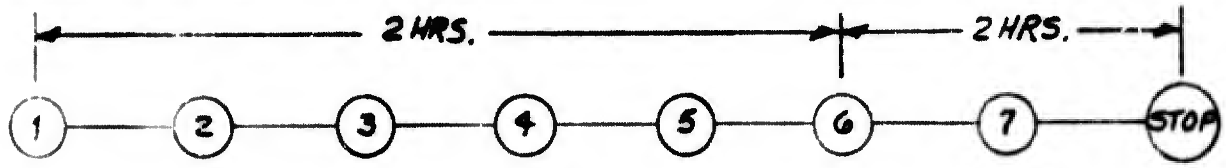
Personnel Complement by Grade

TSgt	1
SSgt	6
A1C	6
A2C	23
	36

Two airmen of the 36 above were not available due to school, etc.

3.2 Radar and Attack and Display Subsystem Activity

The following is the activity network for the R14A and AD maintenance shop.



t_1=item entered in repair shop.

t_2=item assigned (or assignment assumed by) to repair channel.

t_3=setup for fault verification of item. (Requires test complement.)

t_4=faulty module in black box is isolated.

t_5=module is replaced and black box is checked out. (Requires mock-up.)

t_6=item entered into ready inventory.

t_7=faulty module is repaired.

Faulty module repair is fill in work. A module test-isolation set is required. All R14A and AD modules are repairable at maintenance shop. All the time estimates above were obtained from supervisory personnel at the maintenance shop.

3.3 Bomb Toss Computer Subsystem Activity

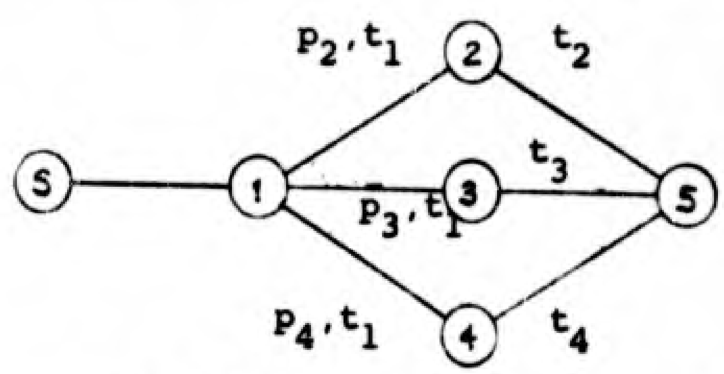
The activity network for the BTC subsystem shop is equivalent to the Radar activity network. The approximate time required to process a failed unit through this shop is 2 hours. BTC modules are not repaired at site due to the problem of isolation to part level because of epoxy coating requiring special processing equipment. Supply of replacement modules is adequate and downtime of aircraft is not experienced from modules.

3.4 Category II Test Equipment Activity

This activity performs calibration and maintenance of all special test equipment associated with the FCS. The critical equipment is the analyzer since this equipment experiences the greater use and is most in demand. Also serviced by this activity is mock-ups (both types). This activity is also specialized, viz., 2 people on mock-up and 2 on analyzer. The average number of analyzers down is 2 (estimate) either for failure or calibration. These units undergo calibration every thirty days or at failure, whichever came first.

3.5 Ready Inventory Link

This ready inventory link corresponds to event 6 of the flightline activity network. The activity network follows:



Activity	Estimated Values (hours)
s=request for aircraft repair	-
t_1=request for spare comes from FCS maintenance shop	-
t_2=fill request from off shelf	.1-.2
t_3=order from base supply cycle	4
t_4=order from depot cycle	in excess of 30 days
t_5=satisfy request	
P_2=probability of taking this route	$\geq .95$
P_3=probability of taking this route	$\leq .05$
P_4=probability of taking this route	$\leq .01$

Expected time in ready inventory link

$$E = p_2t_2+p_3t_3+p_4t_4$$
$$= (.95)(.15)+(.05)(4)+0$$
$$= .35 \text{ hr}$$

p_4t_4 can be neglected because personnel would not wait.

Inventory level is controlled by space at supply room. Repairable spares average two black boxes. About 100 base requests per month are made. High valued items are constantly monitored, low valued items periodically monitored.

Units which must be sent outside base (to depot, etc.) involve a pipeline time in excess of 30 days. One to two aircraft are constantly down, due to all subsystems, waiting for depot spares.

APPENDIX V

SELECTED QUEUING TABLES

This appendix contains a set of selected queuing tables which were extracted from the complete set of tables published in AMRL-TR-64-125, "Queuing Tables for Determining System Manning and Related Support Requirements," dated December 1964 (Ref. 4.)

These tables were developed to satisfy the need for a method to quantitatively predict manning requirements of various system designs, and to depict the probable interplay between such system elements as personnel, operational performance, and logistic support.

The tables are directly applicable to characteristics of military systems having quantitative spares, personnel, component failure rates, and operational readiness performance requirements. The tables provide a ready means of estimating the performance capability of a complex system which depends upon capabilities of distinct support units.

The tables also provide a manual means of performing tradeoff analyses between personnel, logistic support components, test equipments, component reliability and maintainability, and the number of systems to be supported.

The tabular format is based on anticipated use of tables. Two parameters, (N) and (P) are required to locate each specific table within the range covered. Within each specific table are two additional locators: service channels (C - columns) and spare units (S - rows). For combinations of C and S there are two output entries; these are d, the fraction of units inoperable in excess of spares and n_d, the fraction of the total number of units down.

The effect on the output entries (d, n_d) of changing either C for a given S or S for a given C may be read directly in sequential order; viz., across a row for C and down a column for S. A particular advantage is that for a specified combination (C,S) the maximum rate of change in the d, n_d may be immediately determined from the difference in value between present value of d and n_d and that obtained from the adjacent row and column. The format of the basic tabular entries follows:

Basic Tabular Entry Format

N =   P =

S \ C	1	2	3	...
0				
1		d= n_d =		
2				
...				

N= 50 P= .00300

S \ C	1	2
0	.003	
	.003	
1	.001	
	.003	

N= 50 P= .00400

S \ C	1	2
0	.005	
	.005	
1	.001	
	.005	

N= 50 P= .00500

S \ C	1	2
0	.007	.005
	.007	.005
1	.002	.001
	.006	.005

N= 50 P= .00600

S \ C	1	2
0	.008	.006
	.008	.006
1	.002	.001
	.008	.006
2	.001	
	.008	

N= 50 P= .00700

S \ C	1	2
0	.010	.007
	.010	.007
1	.004	.001
	.010	.007
2	.001	
	.010	

N= 50 P= .00800

S \ C	1	2
0	.013	.008
	.013	.008
1	.005	.002
	.013	.008
2	.002	
	.013	
3	.001	
	.013	

N= 50 P= .00900

S \ C	1	2
0	.015	.009
	.015	.009
1	.007	.002
	.016	.009
2	.003	
	.015	
3	.001	
	.015	
4	.001	
	.015	

N= 50 P= .01000

S \ C	1	2
0	.019	.010
	.019	.010
1	.009	.003
	.019	.010
2	.005	.001
	.019	.010
3	.002	
	.019	
4	.001	
	.018	
5	.001	
	.018	

N= 50 P= .02000

S \ C	1	2	3
0	.105	.025	.020
	.105	.025	.020
1	.095	.012	.003
	.111	.025	.020
2	.087	.006	.003
	.117	.025	.020
3	.080	.003	.001
	.123	.025	.020
4	.074	.002	
	.129	.024	
5	.069	.001	
	.135	.024	

N= 50 P= .03000

S \ C	1	2	3	4
0	.334	.052	.033	.030
	.334	.052	.033	.030
1	.333	.037	.018	.015
	.347	.053	.033	.030
2	.333	.027	.009	.006
	.359	.054	.033	.029
3	.333	.020	.004	.002
	.371	.055	.032	.029
4	.333	.015	.002	.001
	.383	.056	.032	.029
5	.333	.011	.001	
	.394	.056	.031	
6	.333	.008	.001	
	.405	.056	.031	
7	.333	.006		
	.415	.056		
8	.333	.005		
	.425	.056		
9	.333	.003		
	.435	.056		
10	.333	.003		
	.444	.055		
11	.333	.002		
	.454	.055		

N= 50 P= .04000

S \ C	1	2	3	4	5
0	.500	.111	.049	.041	.039
	.500	.111	.049	.041	.039
1	.500	.100	.033	.024	.022
	.510	.116	.050	.041	.039
2	.500	.091	.022	.013	.011
	.519	.122	.050	.041	.039
3	.500	.083	.014	.006	.005
	.528	.128	.051	.040	.038
4	.500	.077	.009	.003	.002
	.537	.134	.051	.040	.038
5	.500	.071	.006	.002	
	.545	.139	.050	.039	
6	.500	.066	.004	.001	
	.554	.145	.050	.039	
7	.500	.062	.003		
	.561	.151	.050		
8	.500	.059	.002		
	.569	.156	.049		

N= 50 P= .05000

S	C 2	3	4	5	6
0	.217	.075	.054	.049	.048
	.217	.075	.054	.049	.048
1	.213	.060	.037	.032	.031
	.229	.077	.054	.049	.048
2	.211	.048	.023	.018	.017
	.240	.080	.054	.049	.048
3	.208	.038	.014	.010	.008
	.252	.081	.054	.049	.047
4	.207	.031	.009	.005	.004
	.264	.083	.054	.048	.047
5	.205	.025	.006	.002	
	.276	.085	.054	.048	
6	.204	.021	.003	.001	
	.287	.086	.053	.047	
7	.203	.017	.002	.001	
	.298	.087	.053	.046	
8	.203	.014	.001		
	.309	.087	.052		
9	.202	.011	.001		
	.320	.088	.051		
10	.202	.009	.001		
	.331	.088	.050		
11	.201	.008			
	.341	.088			
12	.201	.006			
	.352	.088			
13	.200	.005			
	.361	.087			
14	.200	.004			
	.375	.087			
15	.200	.004			
	.385	.087			

N= 50 P= .06000

S	C 2	3	4	5	6
0	.335	.118	.070	.060	.058
	.335	.118	.070	.060	.058
1	.333	.106	.054	.043	.040
	.347	.123	.072	.061	.058
2	.333	.096	.040	.028	.025
	.359	.129	.073	.061	.058
3	.333	.087	.029	.017	.014
	.371	.134	.073	.061	.057
4	.333	.080	.021	.010	.007
	.383	.140	.074	.060	.057
5	.333	.074	.016	.006	.004
	.394	.145	.074	.060	.056
6	.333	.069	.012	.004	.002
	.405	.151	.074	.059	.055
7	.333	.065	.009	.002	.001
	.415	.156	.074	.058	.054
8	.333	.061	.006	.001	
	.425	.162	.074	.057	
9	.333	.057	.005	.001	
	.435	.167	.073	.057	
10	.333	.054	.004		
	.444	.172	.073		
11	.333	.051	.003		
	.454	.177	.072		

N= 50   P= .07000

S \ C	3	4	5	6	7
0	.182	.094	.073	.068	.066
	.182	.094	.073	.068	.066
1	.175	.078	.056	.050	.048
	.191	.096	.074	.068	.066
2	.170	.065	.041	.034	.032
	.201	.099	.074	.068	.066
3	.165	.054	.028	.022	.019
	.211	.101	.075	.068	.066
4	.162	.045	.019	.013	.011
	.221	.103	.075	.067	.065
5	.159	.038	.013	.007	.006
	.231	.106	.075	.067	.064
6	.156	.032	.009	.004	.003
	.242	.108	.075	.066	.064
7	.154	.027	.006	.003	.001
	.252	.109	.074	.065	.063
8	.152	.023	.005	.001	
	.262	.111	.074	.064	
9	.151	.020	.003	.001	
	.272	.112	.073	.063	
10	.150	.017	.002		
	.282	.113	.072		
11	.149	.015	.002		
	.292	.114	.071		
12	.148	.013	.001		
	.302	.114	.070		
13	.147	.011	.001		
	.311	.114	.069		
14	.146	.010	.001		
	.321	.115	.068		
15	.146	.008			
	.330	.115			
16	.146	.007			
	.339	.115			
17	.145	.006			
	.348	.114			

N= 50 P= .06000

S \ C	3	4	5	6	7	8
0	.259	.126	.089	.079	.075	
	.259	.126	.089	.079	.075	
1	.257	.114	.073	.061	.058	.056
	.271	.131	.090	.079	.076	.075
2	.255	.102	.057	.045	.041	.040
	.284	.136	.092	.079	.076	.074
3	.254	.093	.045	.031	.027	.026
	.296	.141	.093	.080	.076	.074
4	.253	.085	.034	.021	.017	.015
	.308	.146	.094	.080	.075	.074
5	.252	.078	.027	.014	.010	.008
	.319	.152	.095	.079	.075	.073
6	.252	.073	.021	.009	.006	.004
	.331	.157	.096	.079	.074	.072
7	.251	.068	.016	.006	.003	
	.342	.162	.096	.078	.073	
8	.250	.063	.013	.004	.002	
	.353	.168	.096	.077	.072	
9	.250	.060	.010	.003	.001	
	.364	.173	.096	.076	.071	
10	.250	.056	.008	.002	.001	
	.375	.178	.096	.075	.070	
11	.250	.053	.007	.001		
	.385	.182	.095	.074		
12	.250	.051	.005	.001		
	.395	.187	.095	.073		
13	.250	.048	.004	.001		
	.405	.192	.094	.072		
14	.250	.046	.003			
	.414	.196	.093			
15	.250	.044	.003			
	.423	.201	.093			

N= 50 P= .09000

S \ C	4	5	6	7	8
0	.170	.109	.091	.085	.083
	.170	.109	.091	.085	.083
1	.161	.094	.074	.068	.065
	.177	.112	.092	.086	.084
2	.154	.080	.058	.051	.048
	.186	.114	.093	.086	.084
3	.147	.068	.044	.036	.034
	.194	.117	.094	.086	.083
4	.142	.057	.032	.024	.022
	.203	.120	.094	.086	.083
5	.138	.049	.024	.016	.013
	.212	.122	.094	.085	.082
6	.134	.042	.017	.010	.007
	.221	.125	.095	.085	.082
7	.131	.037	.013	.006	.004
	.230	.127	.094	.084	.081
8	.129	.032	.010	.004	.002
	.239	.129	.094	.083	.079
9	.126	.028	.007	.003	.001
	.248	.131	.093	.082	.078
10	.125	.025	.005	.002	
	.257	.132	.093	.081	
11	.123	.022	.004	.001	
	.266	.134	.092	.080	
12	.121	.019	.003	.001	
	.275	.135	.091	.079	
13	.120	.017	.002		
	.284	.136	.090		
14	.119	.015	.002		
	.293	.137	.089		
15	.118	.013	.001		
	.302	.137	.088		
16	.117	.012	.001		
	.310	.138	.087		
17	.117	.011	.001		
	.319	.138	.085		

N= 50 P= .10000

S \ C	4	5	6	7	8	9
0	.223	.135	.105	.096	.093	.091
	.223	.135	.105	.096	.093	.091
1	.218	.122	.089	.079	.075	.074
	.234	.139	.107	.096	.093	.092
2	.215	.110	.074	.062	.058	.056
	.245	.144	.109	.097	.093	.092
3	.211	.099	.060	.047	.042	.041
	.256	.149	.110	.098	.093	.091
4	.209	.090	.048	.034	.029	.027
	.267	.154	.112	.098	.093	.091
5	.207	.083	.038	.024	.019	.017
	.278	.159	.113	.098	.092	.090
6	.206	.077	.031	.017	.012	.010
	.289	.164	.114	.098	.092	.090
7	.205	.071	.025	.012	.007	.006
	.300	.169	.115	.097	.091	.089
8	.204	.066	.021	.008	.005	.003
	.311	.174	.116	.096	.090	.087
9	.203	.062	.017	.006	.003	.002
	.321	.179	.116	.096	.089	.086
10	.202	.059	.014	.004	.002	
	.332	.184	.116	.095	.087	
11	.202	.055	.011	.003	.001	
	.342	.188	.116	.094	.086	
12	.201	.052	.009	.002	.001	
	.352	.193	.116	.092	.085	
13	.201	.050	.008	.002		
	.362	.198	.116	.091		
14	.200	.047	.006	.001		
	.372	.202	.115	.090		
15	.200	.045	.005	.001		
	.385	.206	.114	.089		
16	.200	.043	.004	.001		
	.394	.210	.114	.088		
17	.200	.042	.004			
	.403	.215	.113			

N= 50   P= .11000

S	C 4	5	6	7	8	9	10
0	.280 .280	.167 .167	.123 .123	.108 .108	.102 .102	.100 .100	
1	.278 .292	.157 .174	.108 .125	.091 .109	.065 .102	.062 .100	
2	.277 .305	.148 .181	.094 .128	.075 .110	.068 .103	.065 .100	
3	.276 .317	.140 .188	.081 .131	.060 .111	.052 .103	.049 .100	.048 .099
4	.275 .328	.134 .196	.069 .134	.046 .111	.038 .103	.035 .100	.034 .099
5	.274 .340	.128 .204	.060 .137	.036 .112	.027 .103	.024 .100	.022 .099
6	.274 .351	.124 .212	.052 .139	.027 .113	.018 .103	.015 .099	.014 .098
7	.273 .362	.120 .220	.045 .142	.021 .113	.012 .102	.009 .098	.008 .097
8	.273 .373	.116 .228	.040 .144	.016 .113	.009 .101	.006 .097	.005 .095
9	.273 .384	.113 .236	.035 .147	.013 .112	.006 .100	.003 .096	
10	.273 .394	.111 .244	.031 .149	.010 .112	.004 .099	.002 .094	
11	.273 .404	.109 .253	.028 .150	.008 .111	.003 .098	.001 .093	
12	.273 .413	.107 .261	.025 .152	.006 .111	.002 .097	.001 .092	
13	.273 .423	.105 .269	.022 .153	.005 .110	.001 .095		
14	.273 .432	.104 .277	.020 .154	.004 .109	.001 .094		
15	.273 .441	.102 .285	.018 .155	.003 .108	.001 .093		
16	.273 .449	.101 .293	.016 .156	.002 .106			
17	.273 .457	.100 .301	.015 .157	.002 .105			

N= 50 P= .12000

S \ C	5	6	7	8	9	10
0	.206	.144	.121	.112	.109	.106
	.206	.144	.121	.112	.109	.108
1	.199	.131	.105	.095	.091	.090
	.215	.148	.122	.113	.109	.106
2	.193	.118	.089	.076	.074	.073
	.224	.152	.124	.113	.109	.108
3	.188	.107	.075	.063	.058	.056
	.234	.156	.126	.114	.110	.108
4	.184	.097	.062	.048	.043	.041
	.244	.161	.127	.115	.110	.108
5	.181	.088	.051	.036	.031	.029
	.254	.166	.129	.115	.110	.107
6	.179	.081	.042	.027	.021	.019
	.264	.171	.131	.115	.109	.107
7	.176	.075	.034	.020	.014	.012
	.274	.176	.132	.115	.108	.106
8	.175	.070	.029	.015	.009	.007
	.285	.181	.133	.115	.107	.105
9	.173	.065	.024	.011	.006	.004
	.295	.185	.134	.114	.106	.103
10	.172	.061	.020	.008	.004	.003
	.305	.190	.134	.113	.105	.102
11	.171	.058	.017	.006	.003	.002
	.315	.195	.135	.112	.104	.100
12	.170	.055	.014	.004	.002	
	.324	.199	.135	.111	.102	
13	.170	.052	.012	.003	.001	
	.334	.204	.135	.110	.101	
14	.169	.049	.010	.003	.001	
	.343	.208	.134	.109	.100	
15	.169	.047	.009	.002	.001	
	.353	.212	.134	.107	.098	
16	.168	.045	.007	.001		
	.362	.216	.134	.106		
17	.168	.043	.006	.001		
	.371	.220	.133	.105		

N= 50   P= .13000

S \ C	5	6	7	8	9	10	11
0	.249	.169	.136	.123	.118	.116	
	.249	.169	.136	.123	.118	.116	
1	.245	.158	.121	.107	.101	.099	
	.260	.175	.138	.124	.118	.116	
2	.242	.148	.107	.090	.084	.081	
	.271	.181	.141	.125	.119	.116	
3	.239	.139	.093	.075	.068	.065	.064
	.282	.187	.144	.126	.119	.117	.116
4	.237	.131	.081	.061	.053	.050	.048
	.293	.194	.146	.127	.120	.117	.115
5	.236	.124	.070	.048	.040	.036	.035
	.305	.201	.149	.128	.120	.116	.115
6	.234	.119	.061	.038	.029	.025	.024
	.316	.208	.152	.129	.120	.116	.114
7	.234	.114	.054	.030	.021	.017	.015
	.327	.216	.155	.130	.119	.115	.113
8	.233	.110	.048	.024	.015	.011	.009
	.337	.223	.158	.130	.119	.114	.112
9	.232	.106	.042	.019	.011	.007	.006
	.348	.230	.160	.130	.118	.113	.111
10	.232	.103	.038	.015	.008	.005	.003
	.358	.238	.162	.130	.117	.112	.110
11	.231	.101	.034	.012	.005	.003	.002
	.368	.245	.164	.129	.116	.110	.108
12	.231	.098	.031	.010	.004	.002	
	.380	.253	.166	.129	.114	.109	
13	.231	.096	.028	.008	.003	.001	
	.389	.260	.168	.128	.113	.107	
14	.231	.094	.025	.006	.002	.001	
	.399	.268	.170	.127	.112	.106	
15	.231	.093	.023	.005	.001		
	.408	.275	.171	.126	.110		
16	.231	.091	.021	.004	.001		
	.417	.282	.172	[illegible]	.109		
17	.231	.090	.019	[illegible]	.001		
	.426	.290	.173	[illegible]	.107		

N= 50 P= .15000

S \ C	6	7	8	9	10	11	12
0	.231	.174	.148	.138	.133	.132	
	.231	.174	.148	.138	.133	.132	
1	.225	.162	.133	.121	.116	.114	
	.241	.176	.150	.139	.134	.132	
2	.221	.151	.119	.105	.100	.097	
	.250	.184	.153	.140	.134	.132	
3	.216	.141	.105	.090	.083	.081	.080
	.261	.189	.155	.141	.135	.132	.131
4	.213	.132	.092	.075	.068	.065	.063
	.271	.195	.158	.142	.135	.132	.131
5	.210	.124	.081	.062	.054	.050	.049
	.281	.202	.161	.143	.135	.132	.131
6	.208	.117	.071	.050	.041	.037	.036
	.292	.208	.164	.144	.136	.132	.130
7	.206	.112	.062	.040	.031	.027	.025
	.302	.215	.167	.145	.136	.131	.130
8	.205	.107	.055	.033	.023	.019	.017
	.313	.222	.170	.146	.135	.131	.129
9	.204	.103	.049	.026	.017	.013	.011
	.323	.228	.172	.146	.135	.130	.127
10	.203	.099	.044	.022	.012	.009	.007
	.333	.235	.175	.146	.134	.128	.126
11	.203	.096	.040	.016	.009	.006	.004
	.343	.242	.177	.146	.133	.127	.124
12	.202	.093	.036	.014	.007	.004	.003
	.353	.249	.179	.146	.132	.125	.123
13	.202	.091	.032	.012	.005	.003	.002
	.363	.256	.181	.145	.130	.124	.121
14	.201	.089	.030	.010	.004	.002	
	.372	.263	.183	.145	.129	.122	
15	.201	.087	.027	.008	.003	.001	
	.381	.269	.185	.144	.127	.121	
16	.200	.085	.025	.007	.002	.001	
	.390	.276	.186	.143	.126	.119	
17	.200	.084	.023	.006	.002	.001	
	.403	.283	.187	.142	.124	.117	

N= 50   P= .16000

S \ C	6	7	8	9	10	11	12	13
0	.266	.197	.163	.149	.142	.140	.139	
	.266	.197	.163	.149	.142	.140	.139	
1	.263	.187	.150	.133	.126	.123	.121	
	.277	.203	.166	.150	.143	.140	.139	
2	.260	.178	.136	.118	.109	.106	.104	
	.288	.210	.170	.152	.144	.140	.139	
3	.257	.171	.124	.103	.093	.089	.088	
	.299	.217	.173	.153	.144	.141	.139	
4	.256	.164	.112	.089	.078	.074	.072	
	.311	.225	.177	.155	.145	.141	.139	
5	.254	.158	.102	.076	.064	.059	.056	
	.322	.233	.181	.157	.146	.141	.139	
6	.253	.153	.093	.064	.051	.045	.043	.042
	.333	.241	.186	.159	.147	.141	.139	.138
7	.252	.149	.085	.054	.040	.034	.031	.030
	.344	.250	.190	.160	.147	.141	.138	.137
8	.252	.145	.078	.046	.031	.025	.022	.021
	.354	.258	.195	.162	.147	.140	.137	.136
9	.251	.142	.073	.039	.025	.018	.015	.014
	.365	.267	.199	.163	.147	.140	.136	.135
10	.250	.140	.068	.034	.019	.013	.010	.009
	.375	.276	.203	.165	.147	.139	.135	.133
11	.250	.138	.063	.029	.015	.009	.007	.005
	.385	.284	.208	.166	.146	.138	.134	.132
12	.250	.136	.060	.025	.012	.007	.004	.003
	.395	.293	.212	.166	.146	.136	.132	.130
13	.250	.135	.056	.022	.009	.005	.003	
	.405	.302	.216	.167	.145	.135	.130	
14	.250	.133	.053	.019	.008	.004	.002	
	.414	.310	.220	.167	.144	.133	.129	
15	.250	.132	.051	.017	.006	.003	.001	
	.423	.319	.224	.168	.142	.132	.127	
16	.250	.131	.048	.015	.005	.002		
	.432	.327	.228	.168	.141	.130		
17	.250	.130	.046	.013	.004	.001		
	.440	.336	.232	.168	.140	.128		

N= 50 P= .19000

C	7	8	9	10	11	12	13
18	.263	.160	.075	.028	.010	.004	.002
	.458	.373	.264	.213	.174	.156	.147
19	.263	.160	.073	.026	.008	.003	.001
	.466	.382	.269	.214	.173	.154	.145
20	.263	.160	.072	.024	.007	.002	.001
	.474	.390	.295	.216	.172	.152	.143
21	.263	.159	.070	.022	.006	.002	.001
	.481	.398	.301	.217	.171	.151	.142
22	.263	.159	.069	.020	.005	.001	
	.488	.406	.307	.218	.170	.149	
23	.263	.159	.068	.019	.005	.001	
	.495	.414	.312	.219	.168	.147	
24	.263	.158	.067	.018	.004	.001	
	.502	.421	.318	.219	.167	.145	
25	.263	.158	.066	.017	.003	.001	
	.509	.439	.323	.220	.166	.144	
26	.263	.158	.065	.016	.003	.001	
	.515	.446	.329	.221	.164	.142	
27	.263	.158	.064	.015	.002		
	.522	.453	.334	.221	.163		
28	.263	.158	.064	.014	.002		
	.528	.460	.340	.222	.161		
29	.263	.158	.063	.013	.002		
	.534	.467	.345	.222	.160		

N= 50 P= .20000

S \ C	8	9	10	11	12	13	14	15
0	.242	.203	.183	.174	.170	.168		
	.242	.203	.183	.174	.170	.168		
2	.229	.181	.156	.144	.138	.135	.134	
	.258	.212	.188	.177	.171	.169	.167	
4	.219	.162	.130	.114	.107	.103	.102	
	.276	.224	.194	.180	.173	.169	.168	
6	.212	.146	.108	.088	.076	.073	.071	.070
	.296	.236	.202	.183	.174	.170	.168	.167
8	.207	.134	.089	.065	.053	.047	.044	.043
	.315	.250	.209	.187	.176	.170	.167	.166
10	.205	.126	.076	.046	.035	.028	.025	.023
	.335	.265	.217	.190	.176	.169	.166	.164
12	.203	.120	.066	.037	.023	.016	.013	.011
	.354	.280	.225	.193	.176	.168	.163	.161
14	.202	.116	.058	.029	.015	.009	.006	.005
	.373	.295	.233	.195	.175	.165	.160	.158
16	.201	.112	.052	.023	.010	.005	.003	.002
	.391	.310	.240	.196	.173	.162	.156	.154
18	.200	.110	.047	.018	.007	.003	.002	
	.408	.325	.247	.197	.171	.158	.153	
20	.200	.108	.043	.014	.005	.002	.001	
	.429	.339	.254	.197	.168	.155	.149	
22	.200	.106	.040	.012	.003	.001		
	.444	.354	.260	.196	.165	.151		
24	.200	.105	.037	.009	.002	.001		
	.459	.368	.267	.195	.162	.147		
26	.200	.104	.034	.008	.002			
	.474	.382	.272	.194	.158			
28	.200	.103	.032	.006	.001			
	.487	.395	.278	.192	.155			
30	.200	.103	.030	.005	.001			
	.500	.408	.283	.190	.152			
32	.200	.102	.028	.004	.001			
	.512	.421	.289	.188	.148			
34	.200	.102	.027	.003				
	.524	.433	.293	.186				

N= 50 P= .24000

S \ C	9	10	11	12	13	14	15	16	17	18
0	.278	.238	.216	.204	.199	.196	.194			
	.278	.238	.216	.204	.199	.196	.194			
2	.268	.220	.192	.176	.168	.165	.163			
	.296	.250	.223	.208	.200	.197	.195			
4	.261	.205	.169	.150	.139	.134	.131	.130		
	.316	.264	.231	.213	.203	.198	.196	.194		
6	.256	.193	.150	.125	.111	.104	.101	.099		
	.336	.279	.241	.218	.206	.199	.196	.195		
8	.254	.164	.134	.104	.086	.077	.072	.070	.069	
	.356	.296	.252	.225	.209	.201	.197	.195	.194	
10	.252	.179	.122	.086	.066	.054	.048	.045	.044	
	.376	.313	.264	.232	.213	.202	.197	.194	.193	
12	.251	.175	.114	.074	.050	.037	.030	.027	.025	
	.395	.331	.276	.239	.216	.203	.196	.193	.191	
14	.250	.172	.108	.064	.039	.026	.019	.015	.013	.012
	.413	.348	.289	.246	.218	.203	.194	.190	.188	.186
16	.250	.170	.103	.057	.031	.018	.012	.008	.006	
	.432	.365	.302	.253	.220	.202	.192	.187	.184	
18	.250	.169	.099	.051	.025	.013	.007	.005	.003	
	.449	.382	.316	.259	.222	.200	.189	.183	.179	
20	.250	.168	.096	.046	.021	.009	.005	.003		
	.464	.398	.329	.266	.222	.198	.185	.178		
22	.250	.168	.094	.042	.017	.007	.003	.001		
	.479	.414	.342	.272	.223	.195	.181	.174		
24	.250	.167	.092	.039	.014	.005	.002	.001		
	.493	.429	.354	.278	.222	.192	.177	.170		
26	.250	.167	.091	.036	.012	.004	.001			
	.507	.452	.367	.283	.222	.189	.173			
28	.250	.167	.089	.034	.010	.003	.001			
	.519	.466	.379	.289	.221	.186	.169			
30	.250	.167	.088	.032	.008	.002				
	.531	.479	.392	.294	.219	.182				
32	.250	.167	.087	.030	.007	.001				
	.543	.492	.403	.298	.218	.178				
34	.250	.167	.087	.028	.006	.001				
	.554	.504	.415	.303	.216	.175				

APPENDIX VI

PERSONNEL REQUIREMENTS AND SYSTEM PHASEOVER

1. INTRODUCTION

The purpose of this discussion is to present a technique which will permit computation of personnel requirements and scheduling of training manpower resources in the Air Force. Specifically, the method developed describes:

a. training in terms of time necessary to achieve a specified skill capability;

b. the phasing-in of new systems and the consequent demands for retraining on available skills;

c. the phasing-out of old systems and the concomitant availability of skills; and

d. the relation of manpower, phasing into and out of personnel inventory due to enlistment and discharge, to:

   1. scheduling of training,
   2. scheduling of new entries in the personnel inventory, and
   3. total manning requirements of active systems.

1.1 General

In most technical fields, there is a series of skill levels, viz., 1, 3, 5, 7, and 9, representing increasing amounts of skill, knowledge, and responsibility. Typically, the technician advances a level at a time to the highest level, with training and the passage of time being prerequisites for each step. Consequently, in order to have men continuously in the highest level there must be a steady upward flow from the lower skill levels to replace those discharged. Only a small portion of the qualified men starting out in a field reach its high skill levels; concomitant with this progression is a progression in grade (rank), pay, and privileges.

2. MODEL DEVELOPMENT

In the succeeding analysis, the concern is to establish the total number of personnel required in personnel inventory in order to maintain a specified number of qualified assigned personnel for a given system.

The personnel lost per year in a specific skill field (i) and skill level (j) consists of the following:

a. Discharged (D_{ij})

b. Retired (R_{ij})

c. Promoted (P_{ij})

d. Transferred (T_{ij})[18]

The total personnel leaving a skill designation (ij) per year can be presented as:

$$L_{ij} = D_{ij}+R_{ij}+T_{ij}+P_{ij} \qquad \text{(VI-1)}$$

2.1 <u>Steady State Personnel Required by a Specific System</u>

For designation (ij) all personnel leaving this designation must be replaced through promotion from:

$$P_{i,j-1} = D_{ij}+R_{ij}+T_{ij}+P_{ij} \qquad \text{(VI-2)}$$ [19]

Let:

N_j = personnel required in each skill level, for a given field, as determined by manning analysis to achieve system operational requirements.

l_j = the yearly rate per person of personnel leaving this skill level (j).

Then:

$$l_j = L_j/N_j \qquad \text{(VI-3)}$$

and:

$$p_j = P_j/N_j \qquad \text{(VI-4)}$$

the rate per person of personnel being promoted from the j skill level per year.

Suppose a system manning analysis establishes that the Table of Organization (TO) for personnel requires N_4, N_3, and N_1 personnel in the respective skill levels. To have a self sustaining personnel system, viz., one that produces sufficient

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[18] T_{ij} can represent either a gain or loss to the system.

[19] Using this basic relationship, the recurrence equation for a specific skill field becomes:

$$P_j = P_o - \sum_{k=1}^{k=j} (D_k+R_k+T_k)$$

The significance of P_o is that it represents the number of personnel to be brought into basic training to support the personnel of a given system.

skilled personnel from a level to replace those leaving the next in highest skill level, the equation

$$N_j l_j = N_{j-1} p_{j-1} \qquad \text{(VI-5)}$$

must be satisfied. In general, these equations will not be satisfied for a given system. Thus, in general:

$$N_j l_i \neq N_{j-1} p_{j-1} \qquad \text{(VI-6)}$$

If:

$$N_j l_j > N_{j-1} p_{j-1} \qquad \text{(VI-7)}$$

this requires that somewhere in personnel inventory there must be ΔN_{j-1} additional personnel such that:

$$N_j l_j = (N_{j-1} + \Delta N_{j-1}) p_{j-1} = N'_{j-1} p_{j-1} \qquad \text{(VI-8)}$$

transposing and adding to subscripts:

$$N'_j = (l_{j+1} N_{j+1})/p_j \qquad \text{(VI-9)}$$

and:

$$N'_j = (l_{j+1} N'_{j+1})/p_j \qquad \text{(VI-10)}$$

and so forth, stopping at each primed N_j which yields the largest number. Therefore, in establishing <u>total</u> system personnel requirements the number of people charged to the system in any skill level will be greatest value of N_j and the primed N_j's, starting with the manning analysis as represented by the TO.

2.1.1 Example 1

Let N_4, N_3, N_2, and N_1 designate the required skill complement as determined by a work analysis. The total number of people needed to fill these requirements will be determined from equations 9 and 10.

Suppose the following data is available:

$N_4 = 20$	$l_4 = 0.30$	$p_4 = 0.00$
$N_3 = 40$	$l_3 = 0.40$	$p_3 = 0.30$
$N_2 = 100$	$l_2 = 0.85$	$p_2 = 0.10$
$N_1 = 30$	$l_1 = 0.98$	$p_1 = 0.95$
$N_0 = 0$	$l_0 = 0.99$	$p_0 = 0.98$

and applying:

$$N'_j = (l_{j+1}N_{j+1})/p_j \qquad \text{(VI-11)}$$

the results are:

$N'_4 =$		$N_4 =$ (20)
$N'_3 = 20$		$N_3 =$ (40)
$N'_2 =$ (160)	as opposed to	$N_2 = 100$
$N'_1 =$ (90)		$N_1 = 30$
$N'_0 =$ (30)		$N_0 = 0$

The larger number of people is circled. Then applying equations 9 and 10 successively and always choosing the largest number of people the following data is obtained:

	Work Analysis	To be Supplied
	$N_4 = 20$	$N_4 = 0$
	$N_3 = 40$	$N_3 = 0$
	$N_2 = 100$	$N'_2 - N_2 = 60$
	$N_1 = 30$	$N''_1 - N_1 = 114$
	$N_0 = 0$	$N'''_0 - N_1 = 144$
Total	190	318

Or stated in words: for every 190 people assigned to the system 318 have to be supplied outside the system. Therefore, the total number of people to man the system actually is 508.

2.1.2 Example 2

The following rates are representative of an existing Communications and Electronics Squadron:

$N_4 = 14$	$l_4 = 0.08$	$p_4 = 0.00$
$N_3 = 48$	$l_3 = 0.15$	$p_3 = 0.08$
$N_2 = 106$	$l_2 = 0.45$	$p_2 = 0.05$
$N_1 = 26$	$l_1 = 0.50$	$p_1 = 0.40$
$N_0 = 0$	$l_0 = 0.99$	$p_0 = 0.98$

and using the TO as a basis for calculation:

N_4	= 14		N_4	= 14
N_3	= 48		N_3	= 48
N_2	= 106	as opposed to	N_2'	= 144
N_1	= 26		N_1''	= 162
N_0	= 0		N_0'''	= 83
Total	194			451

Roughly, the personnel system requires twice as many personnel as can be actively employed.

Two fairly obvious features are: (1) reduction in level three and level four capability has a significant effect upon level two personnel. It is indicative of the fact that the higher skill level are most likely not to be filled; (2) the critical skill level is level two, in which a high discharge rate occurs. This level also constitutes independent workers. A small change in the retentivity rate of this level would have manifold benefits. For example, suppose the leaving rate l_2 in the example above was changed from .45 to .30 and p_2 from .05 to .10 per year. Then the new requirements would be:

N_4	= 14
N_3	= 48
N_2	= 106
N_1'	= 80
N_0''	= 41
Total	289

as opposed to the T.O. of 194 and the requirement of 451 previously determined for steady-state maintenance of the personnel structure. The resultant saving of 162 man years per year could be invested to secure the retentivity requirements. In addition, significant savings would be realized through better trained personnel.

Personnel requirements for a system are time dependent: that is, systems phase into and out of active service. These phase-overs generally take place over a period of years and thus it is important to know the number and type of personnel and when they will be required. In the model developed above, personnel requirements are based on demand per year.

2.1.3 Remarks

a. Any personnel system for which

$$P_{i,j-1} \neq D_{ij}+R_{ij}+T_{ij}$$

is an unbalanced system. That is,

1. If $P_{i,j-1} \geq D_{ij}+R_{ij}+T_{ij}+P_{ij}$ then the designation (ij) will not remain stable due to decrease in personnel.

2. If $P_{i,j-1} \geq D_{ij}+R_{ij}+T_{ij}+P_{ij}$, designation (ij) will not remain stable due to increase in personnel.

b. The yearly rates P_{ij}, D_{ij}, etc. may not represent steady state. In order to achieve stable yearly rates a mix of enlistment and discharge dates is required, viz., avoid a significant portion of a given skill supply being given discharge at essentially the same time.

c. Since typically, weapon systems possess a limited existence; the personnel skill distribution may be such that it does not produce enough skilled personnel to meet its own requirements based on an assigned skill distribution; alternatives are:

1. Transfer in from other systems phasing-out or having an excess of skill capability.

2. Over manning at lower skill levels.

3. Adjust rates of promotions and discharges through policy changes or personnel selection.

d. Each weapon system may be explicitly charged for personnel undergoing training to fill existing and anticipated needs, e.g., personnel in training not assigned to a system whose purpose is to replace a potential dischargee.

3. THE PERSONNEL-SKILL PHASEOVER

From the preceding analysis, the number of personnel and associated skill level, can be established for a new system. Assuming that neither experienced or partially experienced personnel were available or scheduled to become available, the number of personnel and skill levels for steady state operation would lead to accurate estimates.

However, personnel becoming available from systems phasing out of active inventory must be mated with existing requirements, since this changes the requirements for either enlistees and nonproductive training. Figure 4 shows the general flow of personnel in inventory.

The effect of system phaseover manifests itself through the release of already trained personnel into the available manpower pool. These personnel may already possess required skills needed in other active or anticipated systems or the skills may require updating (retraining).

Using the technique developed in the preceding section, immediate and future personnel requirements are established for systems in inventory and those anticipated to be phased into inventory. What is now required is a method of mating these requirements with personnel systems phasing out and enlistee requirements.

3.1 Statement of Personnel System Objective

In planning personnel-systems phaseovers, one of several objectives may be desired:

a. A typical objective might be to minimize total training required in terms of time.

b. Scheduling training and transfers during a protracted phaseover with objectives as in (1) above.

c. Scheduling training and transfers subject to limitations on training capacity during any particular period.

The objective established for this program is to minimize the total training time in achieving qualified personnel as in a and b above.

3.2 Model 1 Development

The parameters of the personnel system phaseover model are as follows:

A_k = Availability of personnel having designation k. Here k is used to describe both skill field i and skill level j.

D_l = Demand for personnel of designation l.

N_{kl} = The number of personnel scheduled for training to convert from designation k to l.

T_{kl} = Training duration required to convert from designation k to l.

P_{kl} = Attrition rate in training. An adjustment to N_{kl} to compensate for (1) discharge, (2) retirement,

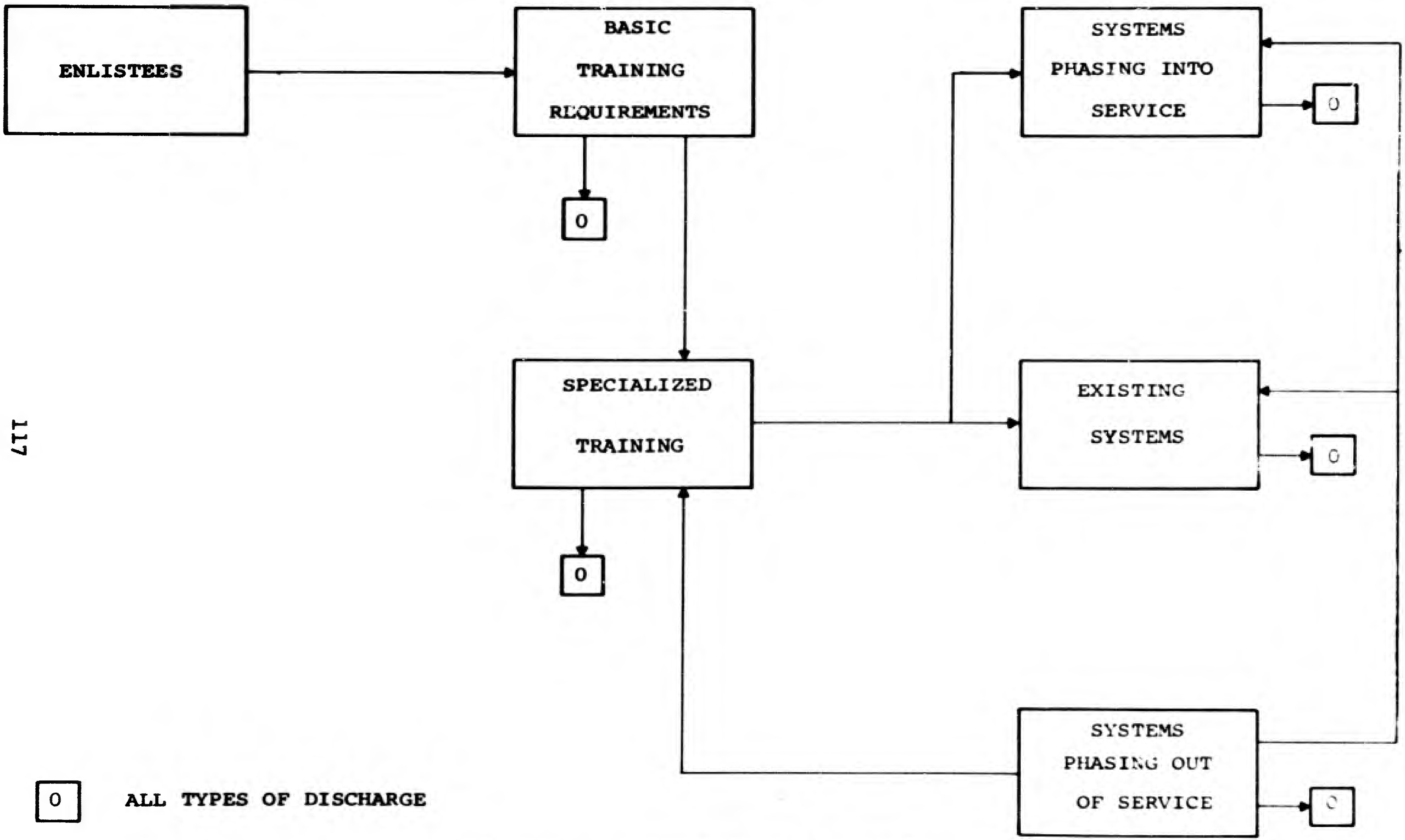

FIGURE 4. PERSONNEL FLOW SYSTEM

(3) transfers and recalls, and (4) probability of successful conversions. Items (1) and (2) can be controlled by selection.

The model may now be formulated as:

Objective function = Minimize $\sum_{k}\sum_{l} T_{kl}N_{kl}$; (VI-12)
it is desired to minimize the total training time of personnel to meet manning skill requirements.

Subject to the constraints:

a. $\sum_{l} N_{kl} \leq A_k$: (VI-13)

Personnel scheduled for training must be equal to or less than the personnel available.

b. $\sum P_{kl}N_{kl} \leq D_l$: (VI-14)

Adjusted attrition rate must be equal to or less than the demand.

c. $T_{kl} \leq T_{max}$: (VI-15)

Training duration must be equal to or less than the maximum time allowed for training.

The objective function and the first two constraints determine the structure of the linear programming problem; the last constraint, along with other restrictions on permissible conversions, determine the possibilities to be considered.

3.3 Model 2 Development

Extending the model to deal with gradual phase-in of a new system, the phase-in must be divided into time periods and skill supply and demand determined for each period. All possibilities must be considered subject to imposed constraints. The parameters are conveniently described as follows:

A_{ke} = skill k available in period e

D_{lf} = demand for skill to be ready in period f [20]

N_{kelf} = number skill k available in period e to be trained for skill l to be ready in period f.

T_{kl} = training duration required to convert from skill k to skill l.

P_{kl} = attrition rate in training

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[20] In some instances, there can be varying degrees of success in conversion. For example, the degree of success may determine the level attained in the new field. In such instances, more than one D may be associated with a P.

Other parameters remain the same. The objective function and constraints are now as follows:

Minimize:

$$\sum_{k}\sum_{l} T_{kl} \left(\sum_{e}\sum_{f} N_{kelf}\right) \qquad \text{(VI-16)}$$

Subject to constraints:

$$\sum_{e}\sum_{f} N_{kelf} \leq A_{ke}: \qquad \text{(VI-17)}$$

Number of personnel of skill k available in period e, to be trained for skill l to be ready in period f must be equal to or less then the number of personnel scheduled for training to convert from skill k to skill l.

$$\sum_{k}(1-P_{ke})\left(\sum_{e}\sum_{f} N_{kelf}\right) \geq D_{lf} \qquad \text{(VI-18)}$$

The number of personnel of skill k available in period e to be trained by f, adjusted by probability of successful conversion $(1-P_{kl})$ must be equal to or greater than the demand for skill l at period f.

The linear programming problem can be solved by the Simplex method or other methods which might take advantage of the peculiarities of the problem.

The resultant assignment of personnel to systems and training schedules will not, in general, mate exactly with the total number of personnel in Air Force inventory. This will be due to having more personnel than required to meet existing demands. The utilization of these personnel may be directed by Air Force policy. Alternatively, the number of personnel available may not meet existing or anticipated requirements. In this case, the number of new entrees (enlistees) into the personnel system must be increased until the personnel requirements are satisfied. As one alternative to increasing enlistment rate, the recall into service of already training personnel may be evaluated.

3.4 Establishment of Training Schedules

The solution to the linear programming problem above will contain assignments of personnel, either available or becoming available, to either existing or anticipated systems. Training schedules may be established based on the personnel system assignments. Most personnel designated to be assigned to a system at a given time will be available for training at least as long as the training duration before being actually assigned. The quantity of personnel available for a specific type of training at any specific time may be immediately taken from personnel-system assignments and grouped into convenient training classes. Where the training is principally on-the-job, the personnel may be directly assigned to the system.

3.5 Discussion of Model Information Requirements

Determination of the training required can be made as it has been in past retraining programs. Where men remain within their fields, familiarity with the new equipment may be all that is required.

Where there are revolutionary differences between old and new equipments, training in principles may be required as well. For changes of field, training required in the two fields must be compared, and common elements eliminated from the conversion course. Frequently, it will be possible to accelerate courses because students will have greater familiarity with Air Force terminology, practices, and procedures; and will have demonstrated motivation to learn in attaining a previous Air Force Specialty Code (AFSC).

The probability of successful retraining can be estimated on the basis of results of earlier retraining programs where analogous conversions have been made. Where such data is not available, the estimates based on experience in initial training may be substituted.

The probability of successful retraining and conversion of the individual to meet the requirements of a new system will generally depend on both his initial skill and his intended new one. The success of such a program can be measured in terms of probability that a trainee will pass requisite tests, and that he will serve at least y additional years, including re-enlistments. At least one year would appear to be a minimum value for y if there is appreciable training involved. Specific requirements for trainees may vary (DOD or Air Force policy, state of national emergency), but the method will remain unchanged.

3.6 Required Information

Required information relevant to the availability of skills is obtained from the following:

a. Anticipated phaseout of existing systems in the Air Force inventory,

b. Enlistees anticipated,

c. Discharges, and

d. Rate of skill level acquisition.

Required information relevant to the demand for specific skills is obtained from manning analysis applied to each anticipated system entering Air Force inventory and the time-phasing of the entry of the system. Required information relevant to the time required to train a person from skill level j to skill level j' (j < j') is obtained through standard procedures employed by the Air Force in the past.

3.7 <u>Example of Model 2</u>

Consider a situation in which men with three skills, A, B and C will become available at the beginning of time periods 1 and 2. At the beginning of periods 2, 3, and 4, men with skills a and b are required. For each possible retraining alternative, training time and probability of success is assumed. These data are presented in tables 47,48,49, and 50, on the next page. A simplex solution of the linear programming matrix is obtained with results as noted below.

Because the values selected are simple, in this case, there are several equivalent solutions involving meeting a3 with various combinations of A1 and A2. One solution of these is given in table 51.

TABLE 51

OPTIMUM SCHEDULE

(in Number of Men Scheduled)

To \ From	A1	B1	C1	A2	B2	Average Numbers Obtained
a2	20 (16)					16
b2		10 (9)				9
a3	1[21] (0.8)			20 (16)		17[22]
b4		4 (3.6)	2 (1.6)		12 (10.8)	16
Not Used	9		8			
Total Available	30	14	10	20	12	

The upper number of pairs, e.g., 20, represents the number of men assigned from the source represented by the column heading, e.g., A1, to fulfill the demand represented by the row identification, e.g., a2. Entries in parentheses (e.g., 16) represent average number successfully retrained out of the number above it.

[21]Actually 1.125 before rounding downward.
[22]Actually 16.8 before rounding upward.

Input Data for Example of Phaseover Training Scheduling

TABLE 47

AVAILABILITY

(in Number of Men)

Time Period \ Skill	A	B	C
1	30	14	10
2	20	12	

TABLE 48

DEMAND

(in Number of Men)

Time Period \ Skill	a	b
2	16	9
3	17	
4		16

TABLE 49

TRAINING TIME

(in Number of Periods)

Demand \ Avail.	A	B	C
a	1	1	2
b	2	1	1.5

TABLE 50

PROBABILITY OF SUCCESS

(in Fraction of Men Successful)

Demand \ Avail.	A	B	C
a	.8	.9	.7
b	.6	.9	.8

APPENDIX VII

CORRECTION FOR NON-EXPONENTIAL DISTRIBUTION

The analysis of flightline maintenance downtime is based on the assumption that the service time of the entire team is exponentially distributed. This assumption is questionable. In fact, what probably takes place is that each subsystem service time is exponentially distributed along with a fixed scheduled time. In this case the resultant distribution is not exponentially distributed. (This distribution is derived in Appendix 3 of AMRL TDR-64-21.) Using the method cited, it is desired to estimate mean service time for the entire team consisting of n subsystem teams.

If all subsystems have identical exponential distributions the following relation holds.

$$\bar{t} = \frac{n}{\mu} \left\{ \sum_{i=o}^{n-1} \left[\frac{-1}{(i+1)^2} \right]^i \frac{(\mu-1)!}{i!\,(n-1-i)!} \right\} \qquad \text{(VII-1)}$$

where $\bar{t}$ is the mean service time for the entire team to complete preflight inspection and u is the mean service rate of the subsystem team.

For values of n=8, and 2, respectively, $\bar{t}$ becomes

$\bar{t}(n=8) = 2.72(\frac{1}{n})$

$\bar{t}(n=2) = 1.5\ (\frac{1}{n})$

These adjustments apply only to the random demand service time. If these adjustments are made to the random time estimates for preflight and dock maintenance established previously and using also the number of channels established preciously for preflight and dock maintenance, the following estimates of aircraft inoperative are established.

n=8	P	N	C	d	C	d
Preflight	.3	48	10	.344	10	.344
Postflight & Periodic	.05		2	.217	3	.075
Operational Readiness (R)				.439		.681

n=2	P	N	C	d	C	d
Preflight	.2	48	10	.183	10	.183
Postflight & Periodic	.03		2	.052	3	.033
Operational Readiness (R)				.765		.784

The values of n=8 and n=2 represent worst and best cases respectively when using the longest random task time of all subsystem teams. In the former it assumes all subsystems have a random task time equal to that of the longest and in the latter it assumes that subsystems having a random task time less than the longest will not influence the result (two subsystem teams have equal longest task time).

Since the case of n=2 is more representative of the actual service time distribution, the operational readiness based on this case can be approximately achieved. The difference in operational readiness achievable as a function of the number of dock teams probably not worth the investment in an additional dock team.

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