# SIMULATING THE OPERATION OF A LOGISTICS SYSTEM

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## SUMMARY

This paper deals with the flow of replacement units through a supply system. It simulates, utilizing Monte Carlo techniques, the logistics flow of these replacement units through the various echelons of support. The operating echelon generates demands on the supply system. These demands cause a flow of requisitions and failed units up through the system. Subsequently, a return of good replacement units comes back to the operational level. The logistics model generates the turn around or reaction time for each replacement unit taking into account all of the delays occurring at each level of the supply system.

## INTRODUCTION

### Background

The complex weapons systems of today place requirements on a supporting supply system far beyond those of past weapons systems. Since quick response and cost are major requirements today, it has become imp .tant to optimize the supply system in order to reduce both time and cost. This paper will illustrate a method of simulating the support system in question, thereby determining the characteristics of this system beforehand and uncovering possible problem areas. By making modifications to the support system and rerunning the simulation, the overall performance can be continually improved. This computer iteration process will be performed before the weapon system is fielded. Although simulation is not an exact tool, it can give tremendous insight into a problem and aid in the decision-making processes. By predicting the characteristics of a support system in advance, changes can be made at a cost far less than what it would take once the system is deployed. Certainly, one would not expect a perfect support system to be based on simulation alone. However, the changes required through operating experience should be fewer than those required without simulation.

### Purpose and Scope

It is the purpose of this report to develop a logistics flow model which will accurately describe the interactions between the various echelons of support. Although it will not consider the flow or maintenance at the operating echelon, the operating echelon will generate demands for replacement units. These demands will be reflected back into the support system and replacement units will be received at the operating echelon. The program will determine the turnaround time for each replacement unit and generate a running commentary of all events that have occurred over the simulated time period. All other delay times at the various stages and levels of the system will be recorded.

### Method of Attack

A model of a typical support system will be constructed. The model developed will be general so that it can handle several different logistics systems simply by changing the model inputs. The model will describe the behavior of a logistic system from the moment a requisition is made until the replacement part is received. It will consider repair of failed units, availability of the appropriate maintenance personnel and test equipment, and the operating and maintenance doctrine of the system.

## GENERAL DESCRIPTION

### Logistics Simulation Model

The Logistics Simulation Model, which simulates the logistics flow through the third, fourth, and fifth echelons of support (DSU, GSU, and Depot) is a Monte Carlo type computer program. It can accommodate up to nine echelons. The Logistics Simulation Program is a general computer program with the flexibility of simulating any support system. It was designed to run either as a part of the total Raytheon Life Cycle Simulation or independently.

When run as a part of the life cycle model, it takes the demands from the Life Cycle Simulation Program and generates the spare replenishment or turnaround time. When run independently, it must have a demand rate input for each type of replacement unit (Battery Replacement Unit or BRU) and will calculate the turnaround time. Additional outputs are a commentary type printout including the number of outstanding requisitions for each Battery Replacement Unit.

Up to nine levels of maintenance support points can be handled. A supply map must be specified for the support system simulated. A typical supply map (Figure 1) shows the supply and maintenance routes required by the BRU's. Additional inputs include:

1) delivery time for each route,
2) the number and type of personnel at each support unit,

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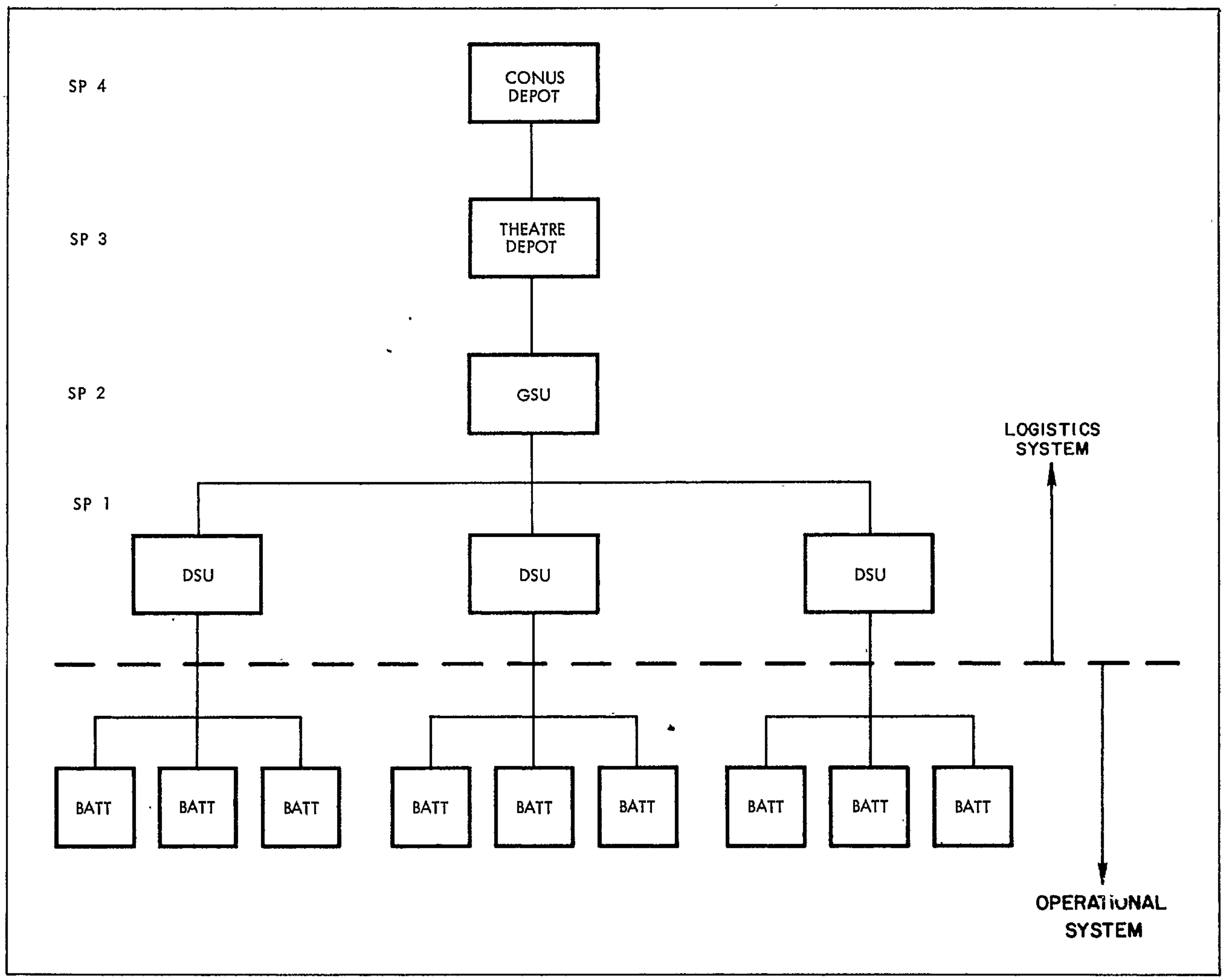


Figure 1 - Typical Supply Map of a Logistic System Showing Four Support Points

3) the maintenance equipment type and number of each at each support point,
4) initial inventory of BRU's and components at each support point, and,
5) the maintenance equipment and personnel types required to repair each BRU.

Each support unit can differ from another in its inventory, crew complement, and maintenance equipment. The functions of each support unit, for purposes of the simulation, are to process requests for BRU's and components, repair a BRU, and maintain a desired inventory level by making requisitions from other support units.

Monte Carlo procedures are used to determine 1) supply processing times, 2) failed component within a BRU, 3) BRU repair times, 4) maintenance equipment downtimes, 5) BRU delivery times, and 6) requisition delivery times.

## Logistics Flow Process

The logistics flow process, illustrated in Figure 2, is initiated by the first demand for a BRU from the battery. This causes a requisition and repair order to be generated and sent to the next higher support point. When received, the requisitions are processed by searching inventory and delivering the item if the support point has it in stock. If the unit is not in stock, a requisition is generated and sent to the next higher supplier of this support point. When repair orders are received at a support point, a determination is made if the necessary crew and maintenance equipment are available. If they are, the repair is performed; otherwise, the BRU is put in a queue either until it can be repaired or until a predetermined holding time is exceeded.

Repairs of a BRU can be interrupted or delayed by failures in the maintenance equipment or unavailability of maintenance equipment or maintenance crew. Each of these cases is considered

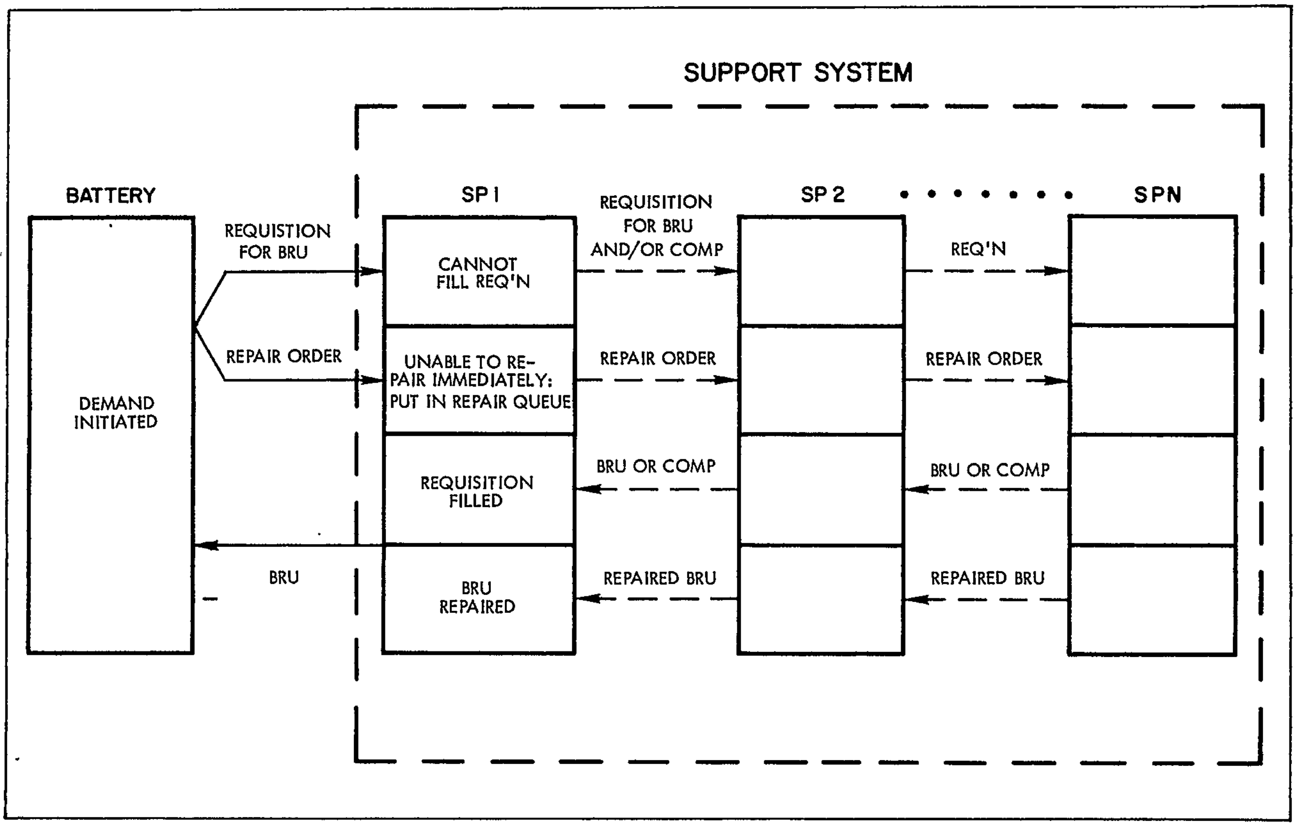


Figure 2 - Simplified Diagram of the Logistics Flow Process

and the necessary adjustments are made to BRU repair times. Similarly, an "off-duty" work shift will further delay the completion time of the BRU repair with the exception of a high priority repair order for which the technician remains or is replaced until the BRU has been repaired. In addition to this, if a BRU in a queue exceeds its holding time, it is sent to the next higher support point for repair.

When a repaired BRU has been or arrives at a support point, a check is made to see if a requisition for this particular BRU is outstanding. If so, the requisition is filled; otherwise, the BRU is put into inventory.

When the BRU for the original requisition arrives at the battery, the process is complete and turnaround time is computed. Other demands are processed as they arise and demand starts a chain of further events.

## Program Operation

The program operation is based on the processing of eight basic events. These are:

1) BRU Demand (TF)
2) Maintenance Equipment Failure (TEF)
3) Maintenance Equipment Repaired (TEU)
4) Completion of a BRU Repair (TC)
5) Holding Time Exceeded (TH)
6) Arrival at a Support Unit of an Item or Requisition (TA)
7) Crew Shift Change (TSH)
8) Arrival of BRU at Battery (TAB)

In simplified form, the basic program consists of an executive routine (Figure 3) and several subroutines (Figure 4). After the variables are initialized and the tables are created, the program searches for a minimum time. When this time is found, the program transfers to the routine which processes this event.

For example, assume that a BRU demand is the first event which occurs. The executive routine will find TF a minimum time and transfer to the TF routine at entry 100 to process the event. In this case, a requisition and repair order are generated and the time of arrival at the support point is determined. The time to the next demand is generated and the program returns to the executive routine at entry 10 to search for the next minimum time.

If the next minimum time is a maintenance equipment failure, the program transfers to the TEF routine at entry 200. This routine generates the time the maintenance equipment is repaired and also determines if the failed equipment is in use. If it is not, the maintenance equipment inventory is decreased. Otherwise, the downtime is added to the repair time of the BRU under repair. The program again returns to the

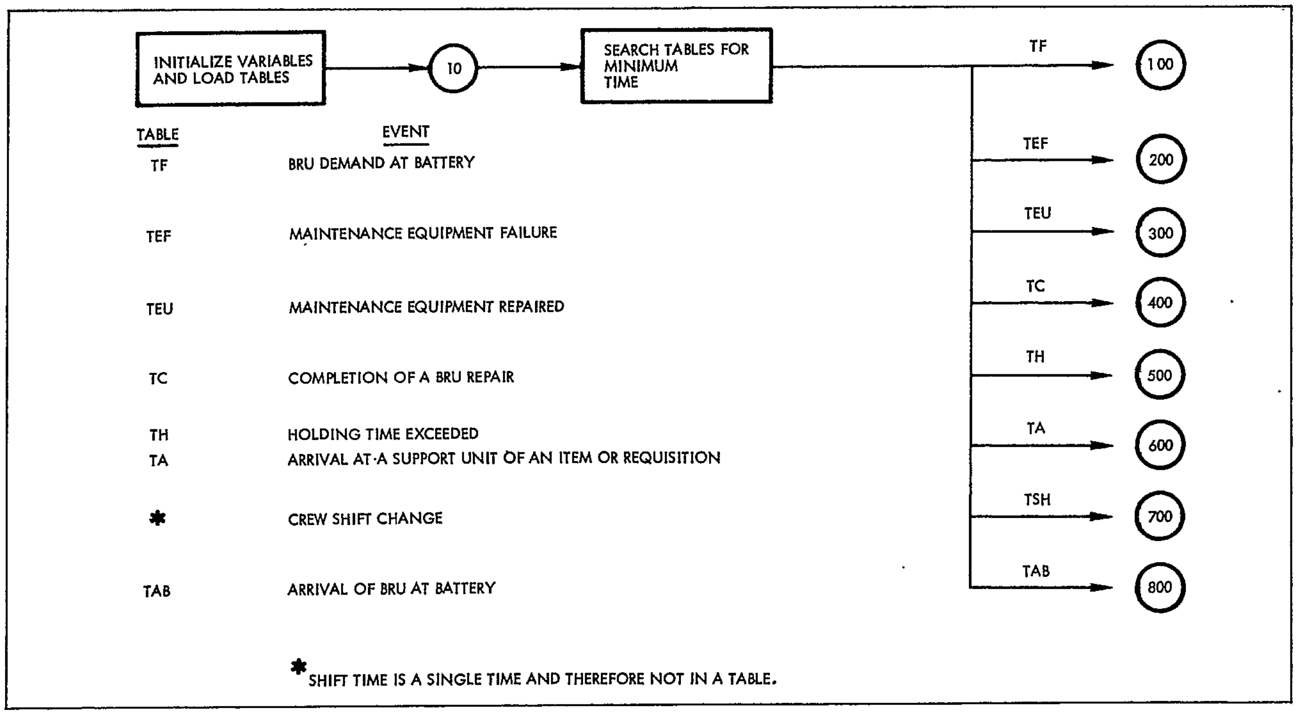


Figure 3 - Simplified Executive Routine of Logistics Flow Program

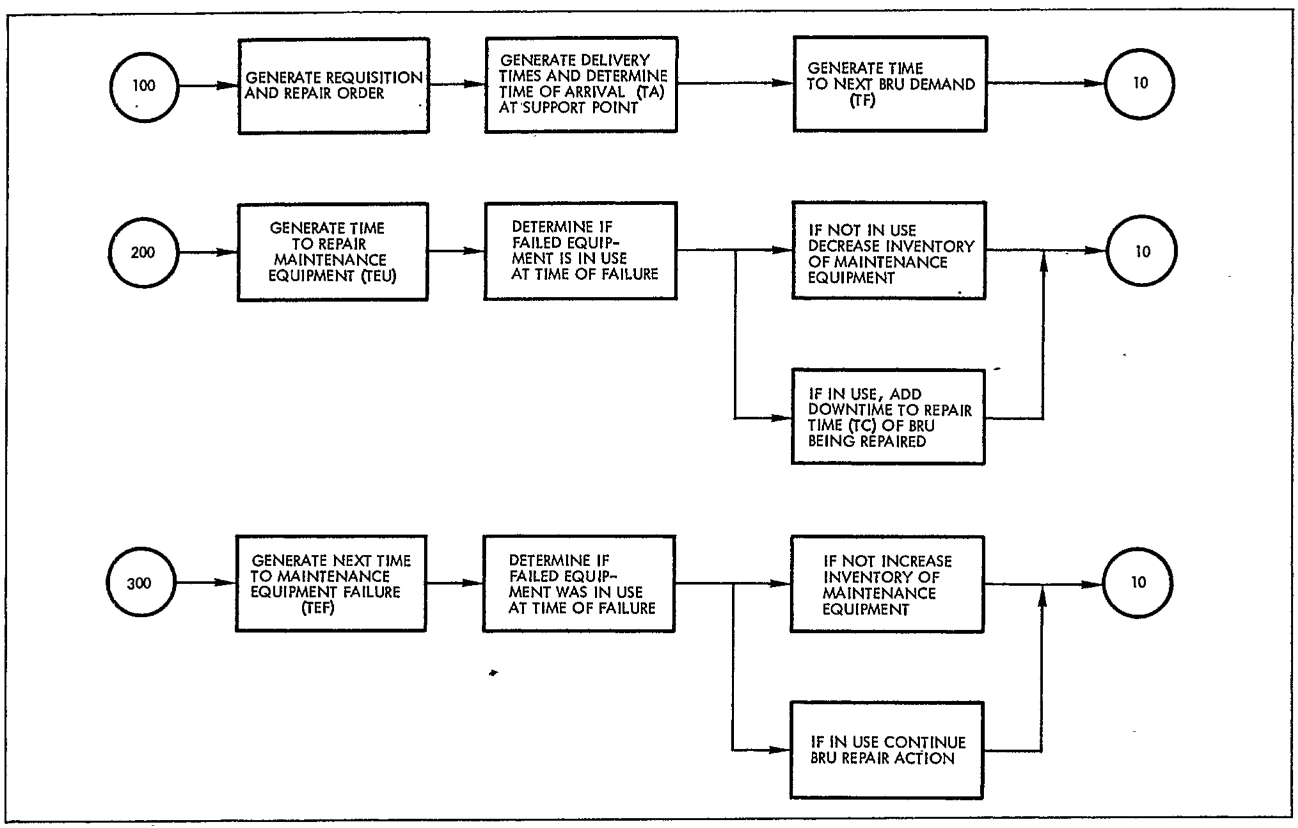


Figure 4 - Simplified Routines of Logistics Flow Program

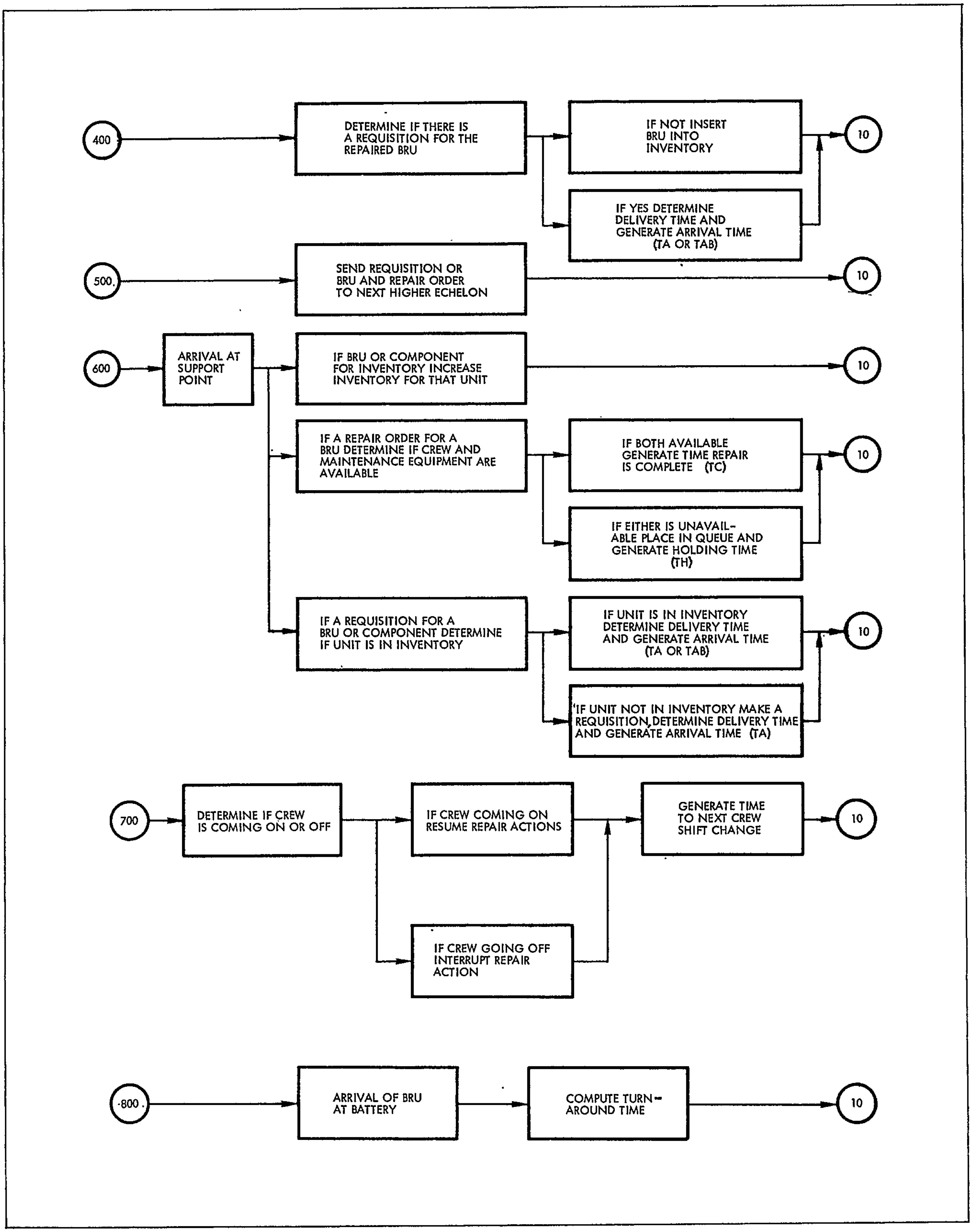


Figure 4 - (Continued)

executive routine. In a like manner, each of the eight possible events are processed when their times are minimum.

During the simulation, a taped account is kept of all events which occur. These are processed by the output edit program to produce an output commentary.

Data Input Requirements

The specific inputs required can be supplied on seven different data sheets. These have been developed for the collection of inputs required in the logistics flow simulation. These data sheets are illustrated in Figure 5.

Input data for the Logistics Flow Simulation Model is provided from several of the support engineering disciplines. These included reliability, maintenance, engineering, maintainability, provisioning, and personnel/training. Table 1 illustrates the disciplines required for each of the seven input data sheets. The input sheets are defined in the following manner:

BRU Inventory (Sheet 1) - Definition of BRU inventory at each supply point is on input data sheet 1. Each BRU number is specified by a 4-digit identifier; its demand rate is given per 1,000 hours and the mean and standard deviation of procurement time in 0.1 hour. For each supply point, the initial inventory level and supplier are listed.

Component Inventory (Sheet 2) - Definition of component inventory at each supply point is on input data sheet 2. Each component number is specified by a 5-digit identifier; its failure rate is given per 1,000 hours and the lot size specified. For each supply point, the initial inventory level and supplier are listed.

BRU Data (Sheet 3) - Definition of BRU data is on input data sheet 3. For each BRU, the test equipment ID number required for maintenance is listed. Also specified is the total number of components making up the BRU (maximum of 999); and each component in the BRU is listed by its 5-digit identifying number.

BRU Repair Data (Sheet 4) - Definition of BRU repair data is on input data sheet 4. For each BRU, the mean and standard deviation of repair time in 0.1 hour is given per mode of failure. The specialty, number of men, and skill level are also specified for each BRU per mode of failure.

Test Equipment Inventory (Sheet 5) - Definition of test equipment inventory of each supply point is on input data sheet 5. Each piece of test equipment

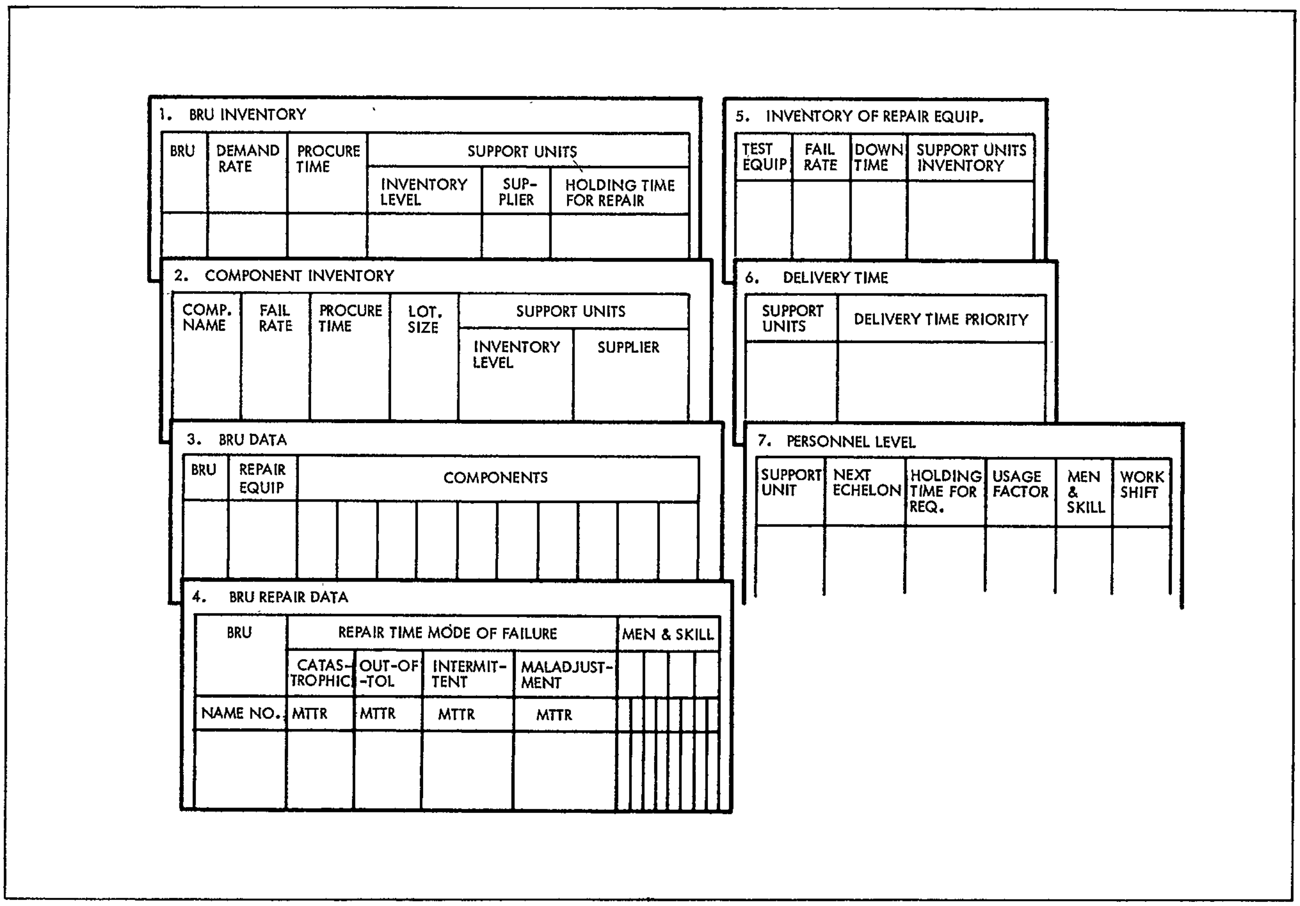


Figure 5 - Logistic Simulation Input Data Sheets

TABLE 1

INPUT DATA SHEETS SUPPORT DISCIPLINE REQUIREMENTS (LOGISTICS)

| Sheet No. | Description | Support Disciplines Required |
|---|---|---|
| 1 | BRU Inventory | Provisioning, Reliability |
| 2 | Component Inventory | Provisioning, Reliability |
| 3 | BRU Data | Reliability, Maintenance |
| 4 | BRU Repair Data | Maintainability, Personnel/Training |
| 5 | Inventory of Repair Equipment | Maintenance, Reliability, Maintainability |
| 6 | Delivery Time | Provisioning |
| 7 | Personnel Level | Personnel/Training, Provisioning |

is specified by a 4-digit ID number, its failure rate per 1,000 hours, and the mean and standard deviation of downtime in 0.1 hour. For each supply point, the inventory level is listed.

Delivery Time (Sheet 6) - Definition of delivery time between supply points is on input data sheet 6. The mean and standard deviation of delivery time in 0.1 day is given for both heavy and light BRU's for normal, intermediate, and high priority. In addition, the mean and standard deviation of delivery time in 0.1 day is listed for a requisition.

Personnel Inventory (Sheet 7) - Definition of personnel inventory at each supply point is on input data sheet 7. For each supply point, the usage factor and the number of men per skill level of each specialty are listed. In addition, the next higher echelon and the requisition holding time in days are given for the supply point.

## Computer Program

The Logistics Simulation Program consists of a main program (representing the Battery), 62 subroutines, and an Edit Program which converts the output into "readable" results. These are all FORTRAN IV programs.

The main program has several control functions:

1) to read and convert data,
2) to process all events that occur during the simulation,
3) to call the subprograms which generate various times of failure, completion, arrival, etc., and which create the internal tables used,
4) to initilize various parameters used in the simulation,
5) to keep track of time and duration of each pass through the system.

Figures 6 through 8 show the tables which contain information connected with the events to be processed. General Tables 1 through 9 (Figure 6) contain the basic data for each support point, i.e., the current status of inventory of men, equipment, etc., at any given time. Table 10 contains BRU failure time and therefore is searched for a minimum time. Tables 1 through 9 are not event tables.

Support Point Tables 1 through 5 (Figure 7) contain events to be processed. These tables are searched for a minimum time during each pass through the simulation. There are five such tables for each support point simulated.

Battery Tables 1 and 2 (Figure 8) show the status of requisitions in relation to the Battery. Table 1 contains information concerning BRU arrivals at the Battery indicating filled requisitions. Table 2 indicates which BRU's are still outstanding. Table 1 is an event table and therefore is searched for a minimum time along with the support tables. Table 2 is for information only along with General Tables 1 through 9.

At the start of the simulation, all tables of events are empty except for Time of BRU Failure (General Table 10), and Time of Equipment Failure (Support Point Table 4) at each Support Point. The main program then calls a routine which searches these tables for a minimum time. If the chosen time is less than the time for the next shift change, the event associated with this time is processed by a subprogram or series of subprograms called by the main program. If the time for shift change is smaller than the minimum chosen, necessary adjustments are made to tables and the minimum of the tables is processed.

The second and succeeding times through the simulation of the tables at each supply point in addition to the above mentioned are searched. After an event has been processed, the main program searches for new events. This succession of events is continued for one pass, until the time reaches a specified limit (input data). At this time, if another pass through the program is specified (again input data), the main program does some initialization and the whole simulation is restarted. * If the required number of passes has been made, the simulation is ended.

During the simulation an output tape is constantly recording information concerning each event. At a later time, this output tape is edited to produce a running commentary of the simulation.

*Each pass will be unique since the random number generator is not re-initialized each time.

TABLE I

(2 cols.)

DEMAND RATE PER BRU

| BRU | DEMAND RATE |
|---|---|
| | |
| | |
| | |

TABLE 2

(40 cols)

BRU INVENTORY

| BRU | DEMAND RATE | SUPPLY TIME | | DESIRED LEVEL | CURRENT LEVEL | SUPPLIER | MAX HOLD TIME |
|---|---|---|---|---|---|---|---|
| | | MEAN | SIGMA | | | | |
| | | | | 9 GROUPS OF DATA LIKE THIS 1 PER S.P. | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

TABLE 3

(2 cols)

FAILURE RATE PER COMP.

| COMP. NO | FAILURE RATE |
|---|---|
| | |
| | |

Figure 6 - Logistics Simulation Description of Tables

TABLE 4

(30 COLS.)

COMPONENT INVENTORY

| | | | S.P. 1 | | | S.P. 2 | | | • • • • • | S.P. 9 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COMP. NO | FAILURE DATE | LOT SIZE | DESIRED LEVEL | CURR LEVEL | SUPPLIER | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
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TABLE 5

(VARIABLE NO. OF COLS.)

COMPONENTS PER BRU AND REQUIRED EQUIPMENT FOR BRU REPAIRS

| BRU | TEST EQUIP. | NO. OF COMP. | COMP NO. | COMP NO. | COMP NO. | | | | | | | • • • UP TO A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | MAX OF 999 COMPONENTS |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

TABLE 6

(18 COLS.)

DATA FOR BRU REPAIRS

| BRU | CATASTROPHIC | | INTERMITTENT | | OUT OF TOLERANCE | | MALADJUSTMENT | | SPECIAL-TY | CATASTROPHIC | | INTERMITTENT | | OUT OF TOLERANCE | | MALADJUSTMENT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | | MEN | LEVEL | MEN | LEVEL | MEN | LEVEL | MEN | LEVEL |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | |

Figure 6 (Continued)

TABLE 7
(22 COLS.)
INVENTORY OF MAINTENANCE EQUIP.

| TEST EQUIP. | | DOWN TIME | | S.P. 1 | | S.P. 2 | | S.P. 3 | | S.P. 4 | | S.P. 5 | | S.P. 6 | | S.P. 7 | | S.P. 8 | | S.P. 9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ID NO. | FAILURE RATE | MEAN | SIGMA | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV | DESI LEV | CURR LEV |
| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
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TABLE 8
(16 COLS.)
DELIVERY TIME

| SUPPLY POINTS | | NORMAL | | | | RED | | | | BLUE | | | | PAPER REQUISITION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HEAVY | | LIGHT | | HEAVY | | LIGHT | | HEAVY | | LIGHT | | | |
| FROM | TO | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA | MEAN | SIGMA |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

TABLE 9
(VARIABLE NO. OF COLS.)
INVENTORY OF PERSONNEL

| SUPPLY POINT | NEXT ECHELON | HOLDING TIME | USAGE FACTOR | NO. OF GROUPS PER SPECIALTY | SPECIALTY | MEN | | SKILL LEVEL |
|---|---|---|---|---|---|---|---|---|
| | | | | | | DESIRED | CURRENT | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

WILL HAVE AS MANY GROUPS OF DATA AS ARE SPECIALTIES PER S.P.

Figure 6 (Continued)

TABLE 10
(6 COLS)
TIME OF FAILURE PER BRU

| TIME OF FAILURE | BRU NO. | SUPPLIER | RE-QUISITION NUMBER | OUT-STANDING REQ P/BRU | DEMAND RATE |
|---|---|---|---|---|---|
| TF | BRU | SUPPLIER | REQN | TR | DRATE |
| | | | | | |
| | | | | | |
| | | | | | |

Figure 6 (Continued)

TABLE 1
(7 COLS)
TABLE OF ARRIVALS (TA)

| TIME OF ARRIVAL TA | S.P WHERE ITEM CAME FROM S.P | RE-QUISITION REQN | UNIT NUMBER UNITN | REASON R | PRIORITY P | MODE OF FAILURE FM |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

TABLE 2
(14 COLS)
HOLDING TIME (TH)

| HOLDING TIME | TIME REQ. WAS SENT OR BRU STARTED WAITING | REQ NUMBER | ITEM NUMBER | REASON BEING HELD | PRIORITY | ORIGINAL S.P | REQ. NO OF ORIGINAL S.P. | REF NO OR PRIORITY OF ORIGINAL S.P | SPECIALTY | LEVEL | NO OF MEN | MODE OF FAILURE | FAILED COMP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TH | TE? | REQN | UNITN | RH? | P | X | Y | [illegible] | SPEC? | RLEV? | RMEN? | FM | FCOMP |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

Figure 7 - Support Point Tables

TABLE 1

(5 COLS.)

TABLE OF ARRIVALS

| TIME OF ARRIVAL TA | BRU NUMBER BRU | REQ. NUMBER REQN | PRIORITY P | MODE OF FAILURE FM |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

TABLE 2

(3 COLS.)

HOLDING TIME

| TIME OF FAILURE TF | BRU NUMBER BRU | REQ. NUMBER REQN |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

TABLE 3

(10 cols)

TIMES OF COMPLETION OF REPAIRS (TC)

| TIME OF COMPLETION TC | BRU NUMBER BRU | STARTING TIME FOR REPAIR OR WHEN IT IS RESTARTED TI | PRIORITY P | MODE OF FAILURE FM | EQUIP. NUMBER EQPN | SPECIALTY SPEC | LEVEL FLEV | NO. OF MEN FMEN | REPAIR TIME RT |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

TABLE 4

(3 cols)

TIMES OF EQUIP. FAILURES (TEF)

| TIME OF EQP. FAILURE TEF | EQUIP. NUMBER EQPN | DOWN TIME DT |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

TABLE 5

(4 cols)

TIMES OF EQUIP. UP (TEU)

| TIME WHEN EQP. IS UP TEU | TIME AT WHICH EQP. REPAIRS WILL START AGAIN TRI | EQP. NUMBER EQPN | FL = 1 EQP WAS BEING USED WHEN IT FAILED<br>FL = 0 EQP WAS NOT BEING USED<br>FL |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

Figure 8 - Battery Tables

## Output Data

A special Edit Program takes output that was recorded during the simulation, consolidates it, and assembles it into commentary form (Figure 9).

One of the important outputs of the simulation is the total turnaround time of a BRU from the Battery, through the support system, and back to the Battery. This total time is broken down further into turnaround time between Support Points.

Other measures of supportability can be determined from basic simulation outputs. Further work is being done in this area.

## CONCLUSIONS

This report has summarized the process involved in performing a logistics flow simulation. It has described both the input requirements and program operation. To date, the simulation has been performed on test data, and it is possible that program changes will be required when the logistics flow of a complete support system is simulated. However, the feasibility of the system has been demonstrated, and no problems are anticipated.

The limitations of the simulation, as in any simulation, include the estimates and approximations made in developing the model. The closer the model resembles the real life situation, the better the results. Often, compromises must be made in order to keep the model from becoming too complex and unwieldy. Other important items are the accuracy and availability of good input data. Unless the inputs are accurate, the outputs will be meaningless. In the final analysis, useful simulation results can only be obtained if the system model is a good approximation of the actual system and the inputs used are valid.

START OF PASS 1.

| TIME | EVENT | LOCATION | UNIT NO. | COMMENTS |
|---|---|---|---|---|
| 480.0 | CREW SHIFT CHANGE | | | SHIFT ON |
| 587.6 | MAINTENANCE EQUIPMENT FAILURE | S.P. 2 | 1. | |
| 643.2 | COMPLETION OF MAINTENANCE EQUIPMENT REPAIR | S.P. 2 | 1. | |
| 960.0 | CREW SHIFT CHANGE | | | SHIFT OFF |
| 988.0 | BRU SUPPLY ACTION INITIATED | BATTERY | 2346. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1013.0 | BRU SUPPLY ACTION INITIATED | BATTERY | 2321. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1045.9 | BRU SUPPLY ACTION INITIATED | BATTERY | 1234. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1096.4 | BRU SUPPLY ACTION INITIATED | BATTERY | 2321. | REQN NO. 2.--- 2. REQNS OUTSTANDING |
| 1143.1 | BRU SUPPLY ACTION INITIATED | BATTERY | 1234. | REQN NO. 2.--- 2. REQNS OUTSTANDING |
| 1343.7 | BRU SUPPLY ACTION INITIATED | BATTERY | 5017. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1599.7 | BRU SUPPLY ACTION INITIATED | BATTERY | 2346. | REQN NO. 2.--- 2. REQNS OUTSTANDING |
| 1611.7 | BRU SUPPLY ACTION INITIATED | BATTERY | 5017. | REQN NO. 2.--- 2. REQNS OUTSTANDING |
| 1662.5 | MAINTENANCE EQUIPMENT FAILURE | S.P. 2 | 2. | DELAY DETECTION UNTIL CREW IS BACK ON |
| 1840.7 | BRU SUPPLY ACTION INITIATED | BATTERY | 3333. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1888.8 | BRU SUPPLY ACTION INITIATED | BATTERY | 2203. | REQN NO. 1.--- 1. REQNS OUTSTANDING |
| 1920.0 | CREW SHIFT CHANGE | | | SHIFT ON |
| 1920.0 | MAINTENANCE EQUIPMENT FAILURE | S.P. 2 | 2. | |
| 2032.9 | COMPLETION OF MAINTENANCE EQUIPMENT REPAIR | S.P. 2 | 2. | |
| 2148.6 | BRU SUPPLY ACTION INITIATED | BATTERY | 3333. | REQN NO. 2.--- 2. REQNS OUTSTANDING |

Figure 9 - Special Edit Program