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ABSTRACT

The reliability and maintainability (R&M) model described in this report represents an important portion of a larger effort called the Digital Avionics Information System (DAIS) Life Cycle Cost (LCC) Study. The R&M model is the first of three models that comprise a modeling system for use in LCC analysis of avionics systems. The total system will provide the Air Force with an enhanced in-house capability to incorporate LCC considerations early in the system acquisition process. As part of the overall modeling system, the R&M model provides estimates of failure rates, maintenance manpower requirements, support equipment requirements, and spares requirements which are used to generate estimates of system support costs. When operated in a stand-alone mode, the R&M model can be utilized to analyze the impact of various avionics design configurations on system support requirements. This report describes the R&M model in detail. The technical approach is discussed in general and then specific terms. Particular attention is given to the analysis that led to the model specification and to the model's functional description in terms of input, output, and process. A specific example calculation is given to illustrate how the model can be utilized to conduct an R&M study. (Author)

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AIR FORCE

HUMAN RESOURCES

DIGITAL AVIONICS INFORMATION SYSTEM (DAIS): RELIABILITY AND MAINTAINABILITY MODEL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The reliability and maintainability (R&M) model described in this report represents an important portion of a larger effort called the Digital Avionics Information System (DAIS) Life Cycle Cost (LCC) Study. The R&M model is the first of three models that comprise a modeling system for use in LCC analysis of avionics systems. The total system will provide the Air Force with an enhanced in-house capability to incorporate LCC considerations early in the system acquisition process. As part of the overall modeling system, the R&M model provides estimates of failure rates, maintenance manpower requirements, support equipment requirements, and spares requirements which are used to generate estimates of system support costs. When operated in a stand-alone mode, the R&M model can be utilized to analyze the impact of various avionics design configurations on system support requirements.

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This report describes the R&M model in detail. The technical approach is discussed in general and then specific terms. Particular attention is given to the analysis that led to the model specification and to the model's functional description in terms of input, output, and process. A specific example calculation is given to illustrate how the model can be utilized to conduct an R&M study.

SUMMARY

This report describes a Reliability and Maintainability (R&M) Model developed to facilitate the performance of design vs. cost trade-offs within the systems acquisition process. It can provide timely visibility to relationships between system design and support requirements and a means of using them to avoid unnecessarily high system operation and maintenance cost. Stand-alone operation permits the user to assess potential impacts of design reliability factors on system support factors and operational availability. However, the R&M Model was also designed to function as part of a modeling system which includes a training requirements analysis model and a system cost model. Joint operation provides the capability of translating the design impact assessments into estimates of the consequent cost of system operation and maintenance and, ultimately, that of performing design vs. cost trade-offs.

The R&M Model operates in conjunction with a computerized data bank containing historical reliability and maintenance data gathered from operational systems. This data is made relevant to new systems by factoring the historical data on the basis of system/subsystem comparability analyses. Inputs to the R&M model include: the frequency of maintenance actions by subsystem and line replaceable unit (LRU) for both aircraft and support equipment (SE); and data concerning the task events within each maintenance action such as type, probability of occurrence, time to complete, manpower type and skill requirements, and SE requirements. The model uses these inputs to compute the manhour resources, SE, and spares consumed, by task event, to satisfy the maintenance requirements of each subsystem and its LRUs for both flightline and shop actions. Outputs are displayed in matrix format.

Capable of extremely rapid operation, the R&M Model affords the user a powerful tool for answering a multitude of "what if" questions concerning the implications of system design on support requirements. Its speed facilitates iterative application and should promote trade-off analyses early in the design process when cost avoidance actions are most effective. This operational speed stems from the fact that, unlike simulation models sometimes used in this type of analysis, the R&M model does not attempt to account for peak loads, saturations, queues, or other nonlinear constraints that exist in the actual maintenance environment. Rather, it is an average value model which uses estimates of maintenance task and equipment R&M factor values to compute the average expected values for resource

requirements. Additionally, a figure of-merit concept is employed to aggregate the detailed data outputs and generate structured data products which allow comparisons to be made and high resource consumers to be identified on either an LRU, subsystem, or system basis. An example of such a figure of merit is maintenance manhours per 1000 flight hours.

Apart from its ability to facilitate sensitivity and trade-off analyses, the R&M Model can aid the user in determining the most acceptable means of avoiding undesirable potential impacts which it has identified. By comparing alternative cause and result situations, trade-off analyses can be employed in a more investigative manner. This entails an iterative model application to determine the differential effects on projected support resource requirements obtainable by changing combinations of R&M parameters. An example of such a trade-off might be the cost to achieve an increased subsystem reliability versus that to obtain a reduced flightline troubleshooting time. The user can determine the various combinations of reliability improvement and reduced flightline troubleshooting time to achieve a specified reduction in support resource requirements for that subsystem. These values would be inputted to training and cost portions of the modeling system to assist in evaluating alternatives on a total cost of ownership basis.

The initial application of the R&M Model is directed at the determination of the potential impacts of the Digital Avionics Information System (DAIS) on system support personnel requirements and life cycle cost. Results will be contained in a later technical report within the series of which this is a member. The model is, however, applicable in the development of almost any new system as well as the evaluation of existing systems.

PREFACE

This two volume report describes the DAIS Reliability and Maintainability Model. This volume describes the model and its development. Volume II is a user's guide to its operation and potential use. The report is one of a series of technical reports, models, and data banks produced under contract no. F33615-75-C-5218, "DAIS Life Cycle Costing Study." This study, in conjunction with present Air Force capabilities, is to provide the means to assess the life cycle cost impact of the operational implementation of the Digital Avionics Information System (DAIS).

This research effort was directed by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio and is documented under Work Unit 20510001, "DAIS Life Cycle Costing Study." It was performed under Air Force Avionics Laboratory program element 63243F, "Digital Avionics Information System", Project 2051. Project 2051, "Impact of the DAIS on Life Cycle Costs", is jointly sponsored by the Air Force Human Resources Laboratory, Air Force Avionics Laboratory, and the Air Force Logistics Command. Contract funds were provided by the Air Force Avionics Laboratory. The DAIS Program Manager is Lt. Col. Robert A. Dessert. The Air Force Human Resources Laboratory Project Scientist is Mr. H. Anthony Baran. The Air Force Logistics Command Project Officer is Captain Ronald Hahn. The latter two are DAIS Deputy Directors. The Contractor Program Manager is Mr. John Goclowski.

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1. INTRODUCTION

The work described in this report is part of a larger effort called the Digital Avionics Information System (DAIS) Life Cycle Cost (LCC) Study. Life cycle costs are comprised of acquisition and ownership (operation and support) costs. Generally, an investment can be made in terms of acquisition costs to reduce subsequent ownership costs. For example, acquisition costs increase as a function of system reliability improvements while support costs decrease. The goal of life cycle costing is to find the system which meets operational requirements at minimum LCC. To accomplish this objective, LCC considerations must be introduced early enough to impact the design of hardware, software, and their support systems to avoid unnecessary cost.

The fundamental objective of the overall study is to provide a means for incorporating LCC considerations, during all stages of the system acquisition process, into the following tradeoff areas: system design, system operation and maintenance, and planning for manpower utilization and training. The reliability and maintainability (R&M) model described in this report represents the first of three models that comprise a LCC impact modeling system. In concerted operation, all three will be under the control of an "executive program" which will integrate their capabilities and manipulate associated data banks. Singly, each will be capable of performing separate analyses in a "stand-alone" mode. The objectives of this report are to describe the work conducted to develop the R&M model and to describe the model's potential uses in the stand-alone mode. Operation under executive program control will be described in a forthcoming technical report covering the operation and capabilities of the complete set of LCC analysis products of the DAIS LCC study.

The R&M model described in this report was designed with two primary objectives in mind. First, the computerized modeling system and associated data banks resulting from the overall study must be capable of generating LCC estimates for certain DAIS-related avionics configurations. Since system support costs comprise a significant portion of LCC, estimates of failure rates, maintenance manpower requirements in terms of numbers and skill levels, support equipment (SE) and spares are required. Alternative means for generating these estimates were considered. The most promising was the AFHRL

Maintenance Manpower Modeling System (MMMS) which is a very effective simulation model for providing detailed estimates of expected manpower and parts requirements and utilization rates. Its main drawback is that it requires significant computational time, detailed design input data, and the running of several lengthy computer programs.

Since numerous trade-off studies are conducted during the acquisition of new avionics systems, many iterations of the entire simulation model would be needed. Consequently, a primary requirement placed on the design of the R&M model was rapid computational ability utilizing the kind of data that are available during the early phases of system acquisition. This objective was accomplished by designing an average value model that determines maintenance resources required per 1000 flight hours. The R&M model, unlike a simulation model, does not account for peak loads, saturations, queues, or other nonlinear constraints that exist in the actual maintenance environment. For this reason, the operation of the model is termed as being unconstrained. Details of the design are given in the following sections. It should be noted, however, that provision is made to incorporate the MMMS simulation during the final trade-off process when more precise estimates are required and more detailed design data are available. To this end, the input and output data associated with the R&M model are MMMS-compatible.

The second major consideration in establishing requirements for the R&M model was the need to influence early design decisions, based upon support cost considerations. Designers need information concerning support cost implications early enough so that trade-off studies will reflect cost considerations as well as operational requirements. Since life cycle support costs are almost linear functions of reliability and maintainability parameters, potentially beneficial options can often be identified directly in terms of these parameters. When used in the stand-alone mode, the R&M model provides a means for analyzing the R&M impact of various avionics design configurations on system support requirements. In general, this is a complex task. A representative avionics suite consists of more than 30 subsystems and has in excess of 100 line replaceable units (LRUs). Comparisons between competing inventoried equipments, modified versions of equipments, and equipments in various stages of development are required. The R&M model employs a figure of merit (FOM) concept to aggregate the detailed data and then to: (1) make comparisons of resources required on a total system, subsystem, or LRU basis; and (2) identify "high drivers" or problem areas in terms of resource requirements.

Typical examples of FOMs utilized in the R&M model are maintenance manhours per 1000 flight hours (measures maintenance resource requirements) and service availability (measures the impact of maintenance on operational readiness). Using FOMs of this type, the R&M model assists the user in making comparisons between competing design configurations. Since high drivers are identified within a given configuration, the information is useful in influencing the designer's selection process. In some cases it could be employed as a guide in modifying designs to reduce future resource requirements.

In addition, the R&M model can be used to conduct sensitivity and trade-off analyses. When high driver items in terms of resource requirements are identified, combinations of R&M parameters can be changed to determine the sensitivities of the FOMs to those changes. Alternatives for achieving a reduction in support resources requirements can then be identified. An example of such a trade-off might be the cost to achieve an increased subsystem reliability versus that to obtain a reduced flight line troubleshooting time. The user can determine the various combinations of reliability improvement and reduced flight line troubleshooting time to achieve a specified reduction in support resource requirements for that subsystem. These values would later be fed into the training and cost model portion of the overall system to assist in evaluating alternatives on a total cost of ownership basis. Thus, the model provides not only the capability to identify potential problem areas in weapon system design, but also to investigate means for corrective action.

In the remaining sections of this report the R&M model will be discussed first in general and then specific terms. An example is also provided and discussed in detail to illustrate the model's potential use.

II. GENERAL TECHNICAL APPROACH

The driving requirements placed upon the R&M model development were in terms of desired outputs and computational speed. Since the model is to be used in the various trade-offs associated with avionics acquisition, rapid computational capability was mandatory. Model outputs can be described in terms of two categories: (1) estimates of the R&M parameters required to determine support costs and (2) information useful to the system designer in identifying areas of high support resource consumption. In general terms, the first category consists of failure rates for the individual subsystems and LRUs, maintenance manpower requirements in terms of numbers and skill levels, support equipment utilization, and spares requirements. The second category consists of a set of FOMs that can focus a designer's attention on support requirement implications of a design which have a potential to precipitate future problems.

The technical approach to these objectives consisted of the following steps or considerations.

1. Define a generic model for avionics suites and an equipment hierarchy.
2. Model the operations and maintenance process.
3. Introduce necessary simplifying approximations.
4. Assess data availability during the conceptual phase of avionics acquisition.
5. Assure MMMS compatibility.
6. Develop algorithms for determining the support resources required.
7. Define the figures of merit (FOMs).
8. Provide for sensitivity analyses.

These considerations are presented in general terms in this section and discussed in detail in the following section.

A generic model for avionics suites was constructed based upon the functional requirements for a representative close air support (CAS) mission. It was determined that the following functional groups of equipment were required: navigation, communications, counter-measures, air-to-ground attack, control and display, and flight control. The process of its constructed is fully described in AFHRL-TR-76-59, Mid-1980s Digital Avionics Information System Conceptual Design Configuration. An equipment hierarchy was then established to describe a generic avionics suite. The levels in the hierarchy consist of system, functional group, operational function, subsystem, and LRU. Following this, a coding system was assigned so that each element in the generic avionics suite could be rapidly identified and indexed. Figure 1 illustrates the technique by showing a portion of the equipment hierarchy. For example, the highest indenture denoting system level (avionics) is coded in the first space of the code designation (A). The functional group (e.g., communications) is coded in the second space (AC). The operational function (e.g., HF radio) is coded in the third space (AC1), and so on. Thus the equipment hierarchy of any avionics suite, or system, can be described on a common basis which allows it to be modeled.

The next step was to model the operational and maintenance (O&M) process. The approach taken in the development of the previously described MMMS was to simulate the detailed O&M process as shown in Figure 2. Due to the requirement for computational speed, the R&M model was developed based upon a simplified representation of that process as shown in Figure 3. It should be noted that the operational scenario and the maintenance environment are modeled separately. Basically, the operational scenario is modeled as creating a demand upon the maintenance system as a function of the number of sorties flown (or of flying hours) and the failure rates of the individual equipments in the avionics suite. The R&M model computes the demand placed on the maintenance system on an LRU-basis and then aggregates to determine the total demand. Therefore, the R&M model treats the operational scenario in terms of the mean flying hours between maintenance actions of individual LRUs. This mean value of demand on the maintenance system is sufficient for assessing support resources during the conceptual phase of the acquisition process and is, in all probability, the best figure which can be generated on the basis of data available during that time period.

Given that a demand is placed upon the maintenance system, the maintenance process must restore the equipment to operational readiness. This is accomplished by minor on-aircraft repair or by replacement with an operationally-ready LRU. However, since total support resources must be estimated, the R&M model must also provide estimates of the resources required for the repair of the LRUs in the shop.

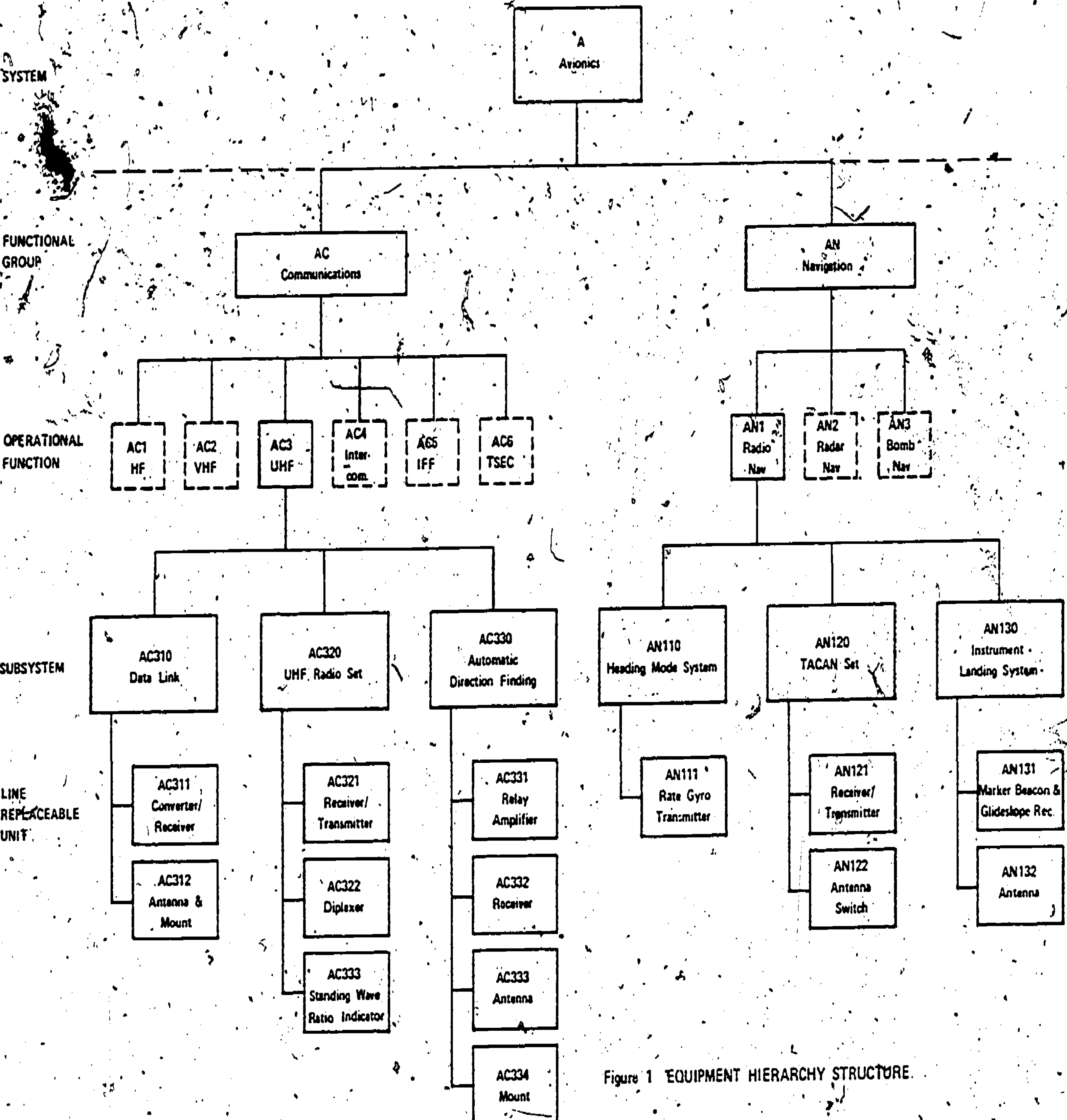

Figure 1 EQUIPMENT HIERARCHY STRUCTURE.

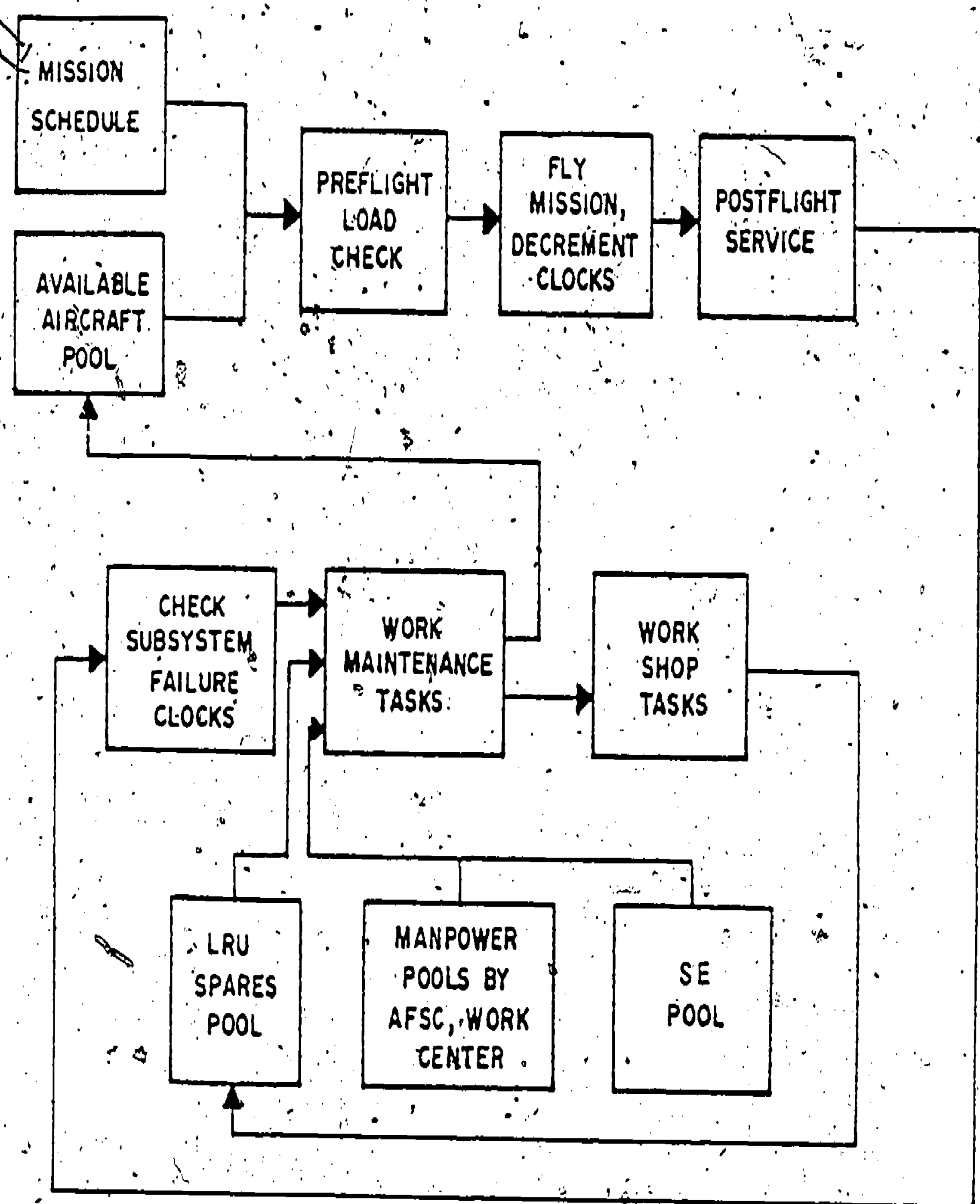

Figure 2 MMMS OPERATIONS AND MAINTENANCE PROCESS

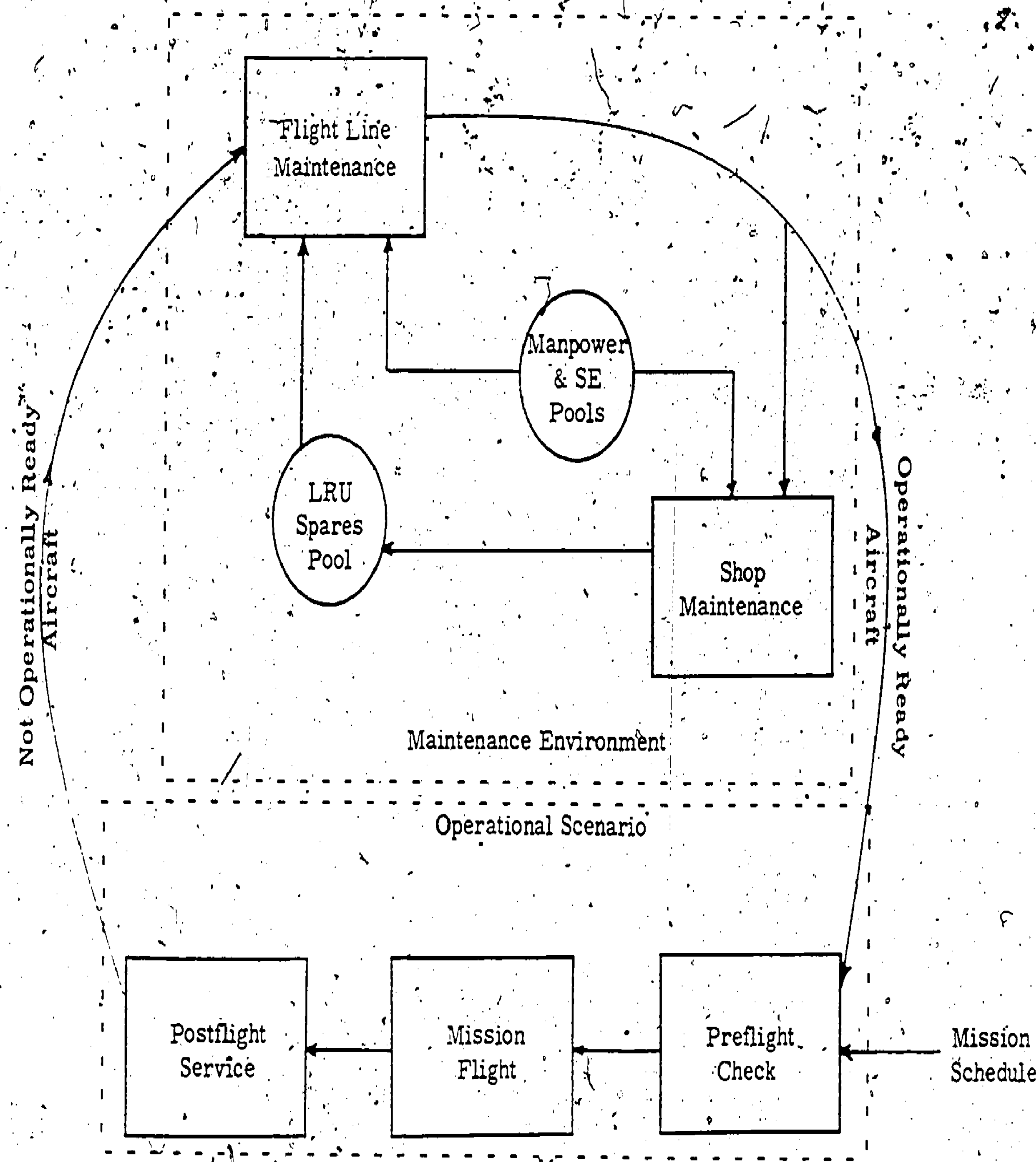

Figure 3 R&M OPERATIONS AND MAINTENANCE PROCESS

The basic approach was to determine all possible maintenance outcomes or events that could result from a specific equipment failure. Each maintenance event places a demand on the maintenance system. The average resources demanded by each maintenance event are determined on an LRU-basis. Finally, the probability of each specific maintenance event occurring (per sortie or per 1000 flying hours) is introduced. Total support resources per LRU are determined by multiplying appropriate probabilities by the support resources associated with each maintenance event. Required support resources are then computed by LRU, subsystem, functional group, and total system by summing across the appropriate levels in the equipment hierarchy. Specific algorithms for making the computations are given in the next section.

Next, it was recognized that the detailed R&M information could be combined and expressed in terms that could be useful to system designers during the early phases of system acquisition. The fundamental concept was to define a measure of support resource requirement, evaluate this measure for each element of the total system, and then rank each element in the system in terms of the measure. The ranking would identify the relative impact of each element in the system on subsequent support requirements. This information would be useful to focus the designer's attention on potential problem areas so that corrective action could be taken to avoid future costs.

The measures selected are called figures of merit (FOMs). Specifically, they are (1) mean time to repair (MTTR) per 1000 flight hours, (2) maintenance manhours (MMH) per 1000 flight hours, and (3) flight line service availability*. The first two FOMs can be utilized to measure the impact on maintenance resource requirements while the third measures the maintenance impact on operational readiness.

*Flight line service availability is defined as the product of the inherent subsystem availabilities (A_j) within the system. The values for the inherent subsystem availabilities are calculated using the equation:

$$A_j = \frac{MFHBMA_j}{MFHBMA_j + MTTR_{F_j}}$$

where: MFHBMA is the mean flight hours between maintenance actions,
MTTR$_F$ is the mean time to complete each maintenance action on the flightline
j is the jth subsystem.

An example of the use of the FOMs computed in the R&M model is given in Table 1. Three different conceptual design configurations for avionics suites capable of meeting CAS mission requirements are evaluated.* The current non-DAIS configuration is representative of the present day CAS avionics suite. The current DAIS suite is representative of the DAIS concept of avionics integration applied in avionics of the present time frame. The mid-1980s DAIS configuration is representative of a DAIS concept application achievable in the 1985 time frame.

On the basis of MMH per 1000 flying hours, it is seen that the mid-1980s configuration offers the potential of a 47 percent reduction when compared with the present day non-DAIS configuration.** On the base of flight line service availability, it is seen that a potential 83 percent improvement is possible when a comparison is made between these same two representative configurations. Specific areas where improvements occur, or deficiencies exist, can be investigated by exercising the R&M model to generate a matrix of FOMs. The concept is illustrated in Figure 4. Basically, the R&M output can be viewed as having quantified the particular FOM for each equipment in the hierarchy by maintenance events. Totals are also provided by LRU and subsystem. Therefore, specific rankings can be obtained at the desired level of detail.

The purpose of this section was to discuss the general technical approach to the development of the R&M model. An indication of the potential use of the model was also given. Each step in the technical approach is discussed in further detail in the next section.

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*Three conceptual design configurations of a generic avionics suite were generated within the DAIS LCC Study: A Current Non-DAIS, a Current DAIS and a Mid-1980s DAIS suite. See Reference 2.

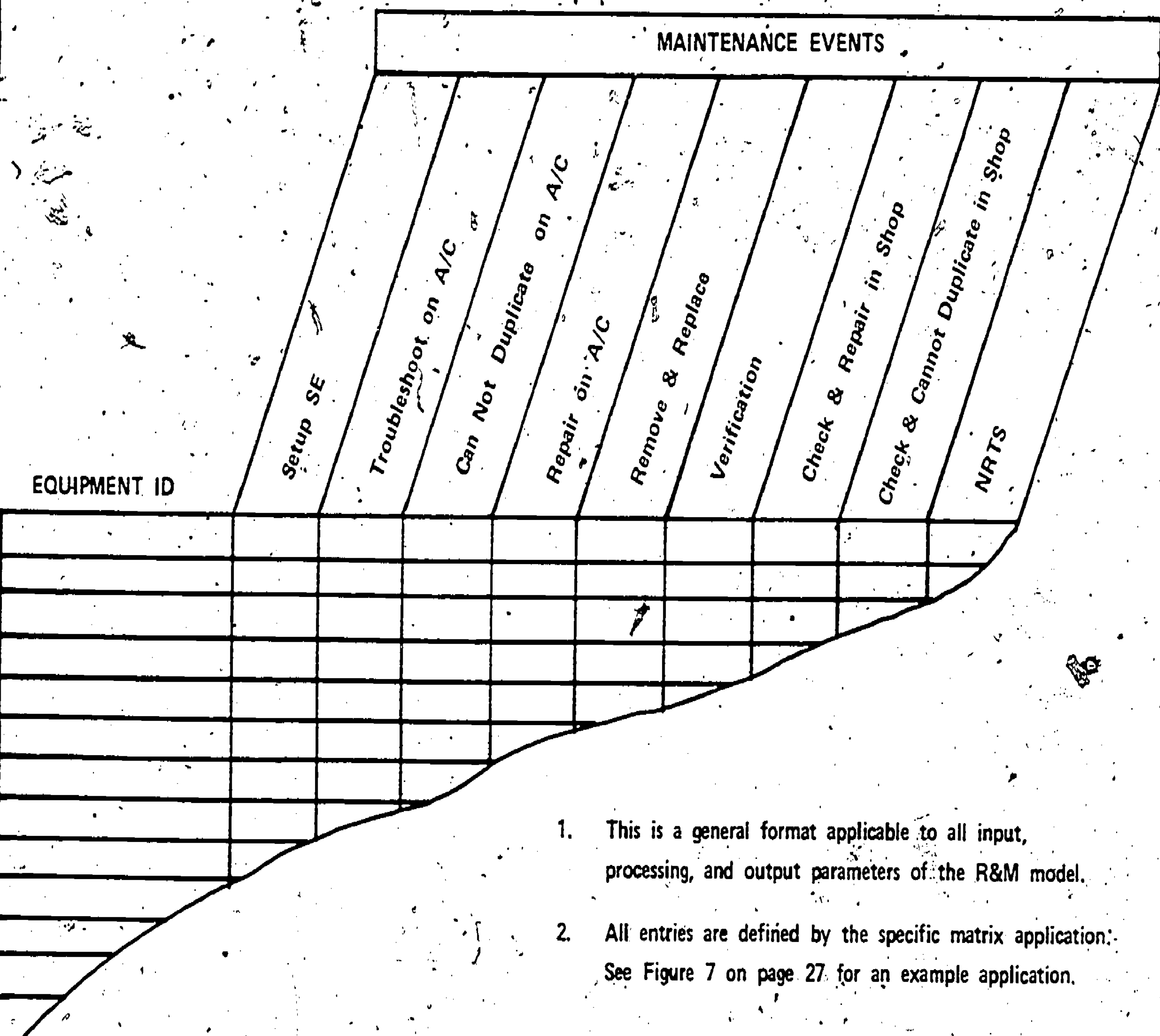
**The R&M model input data used for examples in this report are analyzed in detail in two previous reports; See Reference 1 and 3. These reports define and examine representative conceptual design configurations for DAIS and non-DAIS avionics suites.

	Current Non-DAIS	Current DAIS	Mid 1980s DAIS
MMH/1000 FH. Value % Improvement	6400 -	5000 22%	3400 47%
Flight Line Service Availability: Value % Improvement	.18 -	.26 44%	.33 83%

Table 1 COMPARISON BETWEEN AVIONICS CONFIGURATIONS

Figure 4

ILLUSTRATION OF STANDARDIZED DATA MATRIX USED IN R&M MODEL



1. This is a general format applicable to all input, processing, and output parameters of the R&M model.

2. All entries are defined by the specific matrix application. See Figure 7 on page 27 for an example application.

III. DETAILED TECHNICAL APPROACH

The design and development of the R&M model was discussed in general terms in the preceding section. The purpose of this section is to (1) discuss the analyses that led to the model specification and (2) describe the model in terms of functional capabilities and input and output characteristics.

ANALYSIS

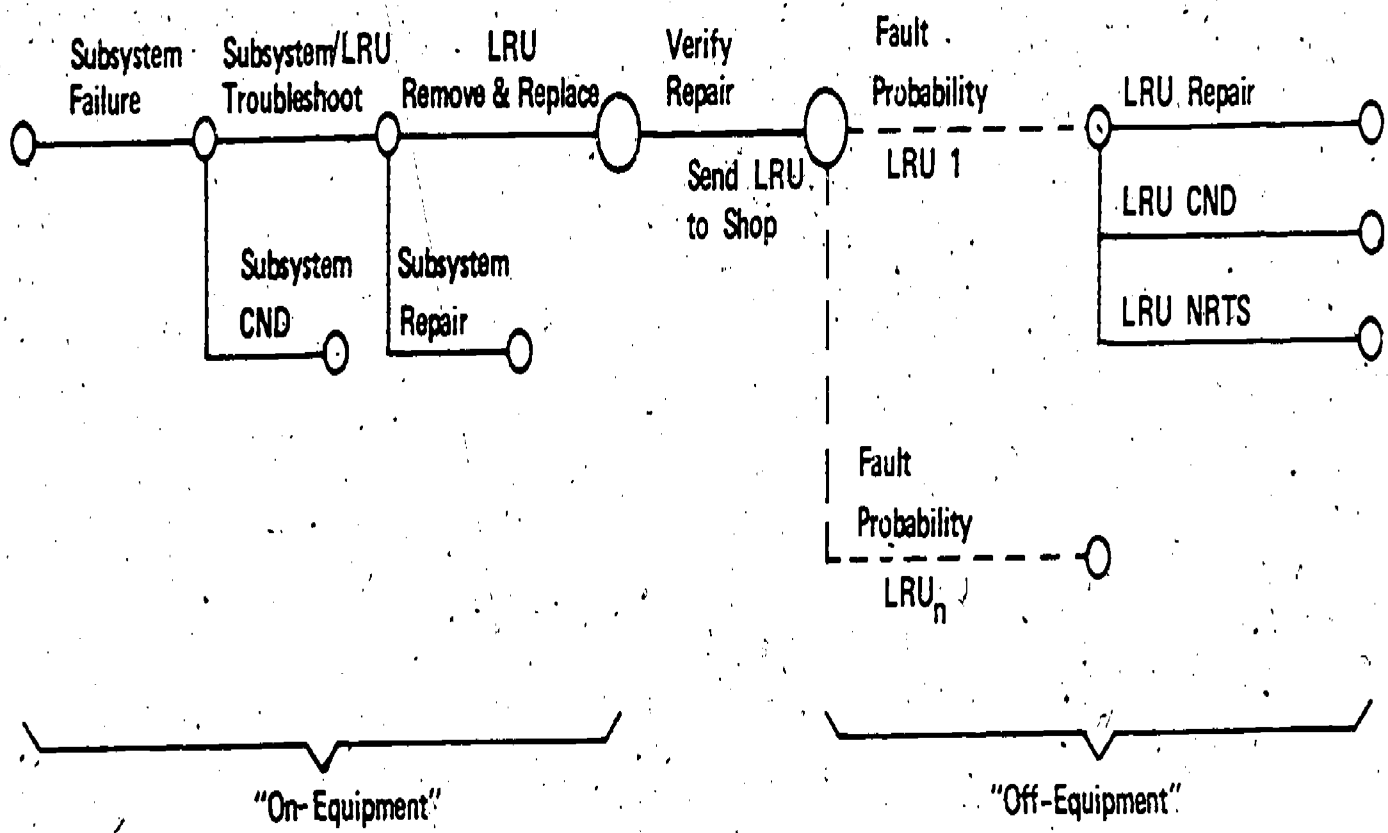
The primary analysis effort was directed toward modeling the maintenance system in terms of resources required to restore a system to operational readiness. An event tree was established to define the possible maintenance events that could result when a particular subsystem or LRU has indicated a malfunction and requires a maintenance action. As we have defined it, then, a maintenance action is a series of maintenance events that occur when a system malfunctions. An example of the basic maintenance event tree is given in Figure 5. It should be noted that this maintenance event tree is directly compatible with the maintenance task network associated with the MMMS. However, different terminology has been adopted to avoid any confusion with the Extended -11 format of the MMMS input data. The maintenance event tree takes on an entirely different role in the R&M model.

The maintenance process has been modeled in terms of "on-equipment" and "off-equipment" events. On-equipment pertains to organizational level maintenance on the entire subsystem while off-equipment refers to intermediate level maintenance on particular LRUs. The maintenance process is initiated by a discrepancy report or indication on the part of the aircrew or maintenance personnel that a malfunction exists. Whether this proves to be an actual failure or is a human (or equipment) error which will later result in a "cannot duplicate" (CND) is important. However, since both result in a demand for maintenance resources, the subsystem failure frequency (maintenance action rate) is based on all discrepancy reports which trigger subsequent maintenance events on the flight line. The possibe flight line maintenance events are:

a) Set up flightline SE
b) Troubleshooting
c) Troubleshooting, cannot duplicate discrepancy

Figure 5

MAINTENANCE EVENT TREE



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d) Remove and replace
e) Minor repair
f) Verify replacement correcting discrepancy
g) Verify minor repair correcting discrepancy.

The model treats the above as generic maintenance events consisting of one or more maintenance functions (i.e., adjust, align, calibrate, troubleshoot, inspect, operate, remove/install, repair, service, etc.). However, the support resources associated with each maintenance function are aggregated at the event level. Although not fine-grained, results are sufficient for the purpose of assessing support requirements in the early stages of the systems acquisition process and approach the practical limits of analysis using the less-than-detailed data that are available during that time period.

The initial maintenance event is to set up the necessary test equipment and power sources at the flight line and exercise the subsystem that has a discrepancy. If, in fact, a failure has occurred, a troubleshooting event will take place in order to locate the cause of the malfunction. In some instances, the apparent failure cannot be duplicated and the maintenance activity will terminate as a CND disposition.

The flight line troubleshooting event, carried to its conclusion, isolates the malfunction to a hardware entity (normally a line replaceable unit). Depending on the nature of the malfunction it may be necessary to remove the malfunctioning LRU(s) and send it to the field shop for repair. If this is done, the aircraft is put back into service by replacing the unit(s) removed with a functioning LRU(s) from spares stock. Alternatively, it may be possible to effect the needed repair on the aircraft. In either case, a verification event is required to provide assurance that the procedure used has, in fact, corrected the problem.

Two sets of parallel events have been noted above for the "on-equipment" maintenance. The checkout of the subsystem may, in the first case, result in a troubleshooting event in order to locate a malfunction detected by the test equipment and flight line technician. On the other hand, if no malfunction is detected, a CND is recorded as the outcome. Similarly, the repair of the malfunction may be accomplished through a flight line remove and replace (and subsequent shop activity on the removed LRUs) or by an on-aircraft repair event. In each case, the parallel events are mutually exclusive. In terms of the utilization of maintenance resources, it is necessary that the probabilities of these parallel events be determined. Furthermore, since the events are mutually exclusive, the sum of the probabilities of each pair of parallel events will equal unity.

The right side of Figure 5 shows the event flow for "off-equipment" or shop maintenance. While "on-equipment" maintenance is concerned basically with the subsystem repair, shop maintenance deals with individual LRUs removed from the aircraft. Determining the resources demanded at this maintenance level also requires a measure of failure frequency. This is indicated by the LRU fault probability given in maintenance actions per flighthour. The number (n) of parallel branches in this part of the maintenance event tree is equal to the number of different LRUs, within the parent subsystem, that generate a significant number of maintenance actions. Each branch indicates the entry of that LRU into the shop maintenance activity in terms of its failure rate per flight hour. The possible maintenance events that can be conducted will then be:

a) LRU bench check and repair
b) LRU bench check OK (shop CND)
c) LRU not repairable this station (NRTS).

It may be noted that shop events, as defined, are somewhat broader in scope in terms of possible maintenance functions than flight line events. The LRU bench check and repair encompasses a troubleshooting activity which detects a malfunction in that LRU and subsequent part replacement, calibration, adjustment, or whatever additional functions are necessary to bring the LRU to full operating status. The shop CND result which sometimes occurs is due to the fact that fault location at the flight line is imperfect and leads to the wrong LRU being sent to the shop. Sometimes the flight line procedures can only isolate the malfunction to a group of LRUs so that all have to be sent on to the shop. Such a circumstance would result in the reporting of a bench check and repair on the LRU that had actually failed, with CNDs for the remaining units of the group.

The NRTS disposition is used to describe the maintenance event which results in shipping a unit to another maintenance echelon where greater capability exists for certain types of testing and/or repairs. Usually this is a depot where more sophisticated test equipment and higher skill levels have been pooled. The units shipped may be either LRUs or shop replaceable units (SRUs). If the shop has no capability to maintain a specific LRU, it will be NRTS'd to depot. In other instances, repairs can be effected by removing and replacing malfunctioning SRUs which, in turn, cannot be serviced at that location. The SRUs will then be NRTS'd to the appropriate depot.

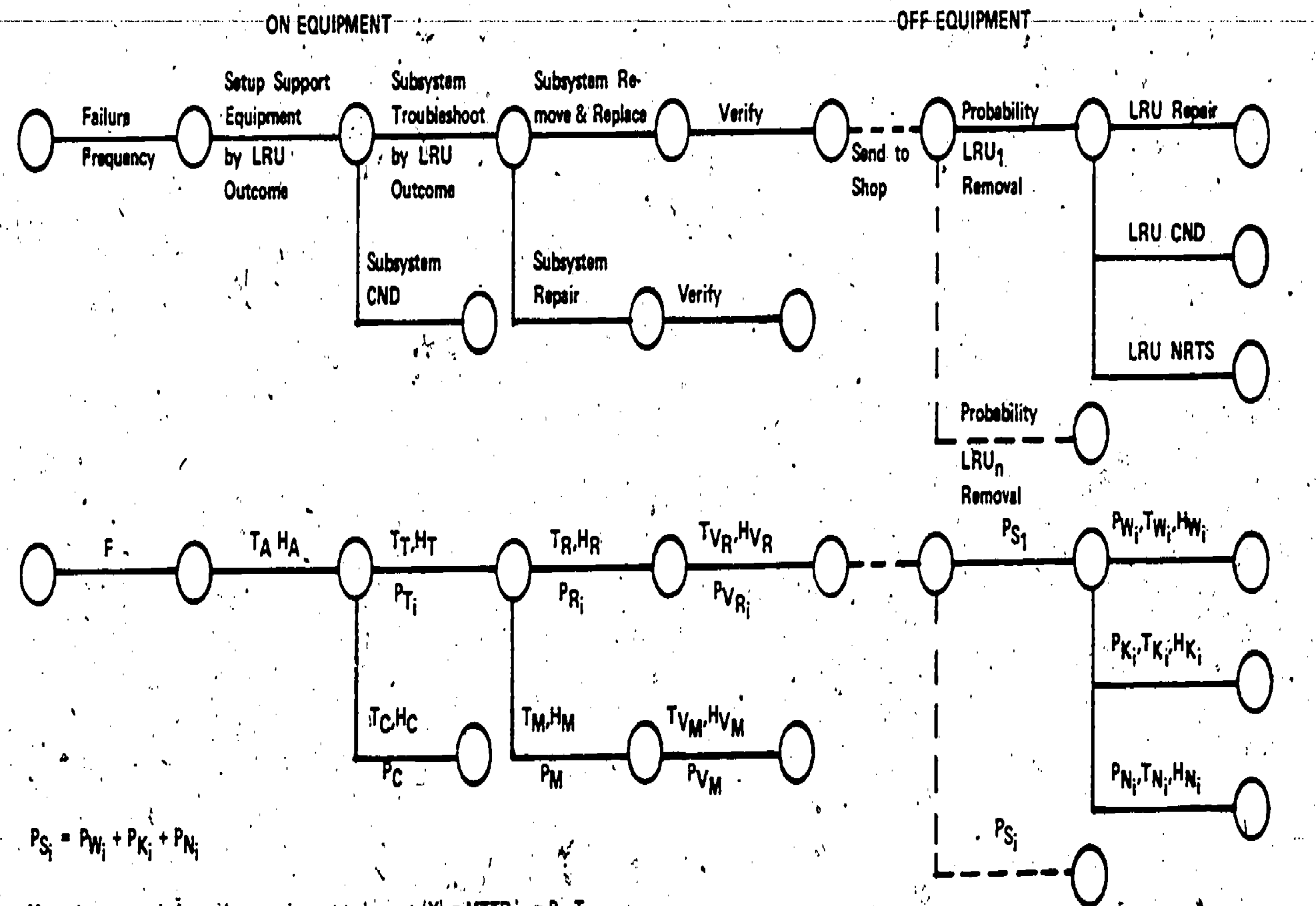
The maintenance event tree, as described above, serves to identify the possible maintenance outcomes associated with a subsystem or LRU discrepancy or failure. Total demand on the maintenance system can be computed, on the average for the unconstrained condition, by multiplying the support resources required per event by the average frequency of event occurrence and then summing across all maintenance events associated with the equipment hierarchy. Support resources required per event must be provided as inputs to the R&M model. They are defined in terms of crew size, skill categories, skill levels, support equipment, and average time required to complete the tasks associated with the event. Event frequency is defined simply as the per flighthour probability of that event occurring.

Conceptually, the R&M model can be defined in terms of (1) the maintenance event tree with appropriate probabilities and support resources quantified, and (2) the algorithms required to make the specific computations. A conceptual representation of the R&M model is given in Figure 6. The top half of the figure shows the basic maintenance event tree. The middle portion provides the parametric definition of the support resources required per event, and the bottom portion provides the algorithms utilized for aggregating the computed values for these events. Table 2 gives the specific definition for each of the parameters. The algorithms utilized to provide the specific computations are given in Appendix C.

It should be noted that a separate representation (Figure 6) is required for each subsystem in the generic avionics suite multiplied by the number of LRUs per subsystem for some of the events. Therefore, the design of the R&M model required structure additional to that obtainable from the basic maintenance event tree to make it computationally efficient. It is this structured representation, the principal result of the R&M model development effort, that is the subject of the following subsection.

FUNCTIONAL DESCRIPTION

The R&M model can be described functionally in terms of input, output, and process. The basic input data consists of the R&M parameters listed in Table 2 quantified for each element in the equipment hierarchy (e.g., Figure 1). These parameters were evaluated for three representative CAS avionics configurations as described in references 1 and 3.



$P_{S_i} = P_{W_i} + P_{K_i} + P_{N_i}$

Mean time to repair for each on equipment task event (X) = $MTTR_{X_i} = P_{X_i} T_{X_i}$

Mean time to repair in the shop = $MTTR_S = \sum_{i=1}^{n} (P_{W_i} T_{W_i} + P_{K_i} T_{K_i} + P_{N_i} T_{N_i})$

MTTR Total = $\sum_{x_i} MTTR_{X_i} + MTTR_S$

Maintenance manhours for each on equipment task event (X) = $MMH_{X_i} = H_{X_i}$(MTTF[illegible]

Maintenance manhours in the shop = MMH_S

$= \sum_{i=1}^{n} (H_{W_i} MTTR_{W_i} + H_{K_i} MTTR_{K_i} + H_{N_i} MTTR_{N_i})$

MMH Total = $\sum_{x_i} MMH_{X_i} + MMH_S$

MTTR or MMH per flight hour is obtained by dividing by the failure frequency (MFHBMA).

Figure 6 CONCEPTUAL REPRESENTATION OF R&M MODEL

Table 2 TERMS USED IN R&M MODEL

Symbol	Description
P_C	Probability that a given malfunction will result in a CND at the flightline.
P_{K_i}	The probability that the malfunction isolated to the i^{th} LRU will result in a shop CND outcome.
$P_M, P_{V_{M_i}}$	Probability that a given troubleshoot operation will result in an on-aircraft repair and the repair is verified for the subsystem.
P_{N_i}	The probability that the malfunction isolated to the i^{th} LRU will result in a NRTS outcome.
$P_{R_i}, P_{V_{R_i}}$	Probability that a given troubleshoot operation will result in a removal of an LRU and the repair verified.
P_T	Probability that a given malfunction will result in a troubleshoot operation.
P_{W_i}	The probability that the malfunction isolated to the i^{th} LRU will result in a shop repair outcome
P_{S_i}	Probability that the i^{th} LRU of the subsystem will require shop maintenance.
F	Subsystem failure cycle in mean flight hours between maintenance actions (MFHBMA)
H_A	Number of human resources (maintenance technicians) required to set up support equipment.
H_C	Number of human resources required to determine that a CND condition exists.
H_{K_i}	Number of human resources required to determine that a shop CND condition exists with respect to the i^{th} LRU of a given subsystem.
H_M	Number of human resources required to repair the subsystem on the aircraft.
H_{N_i}	Number of human resources required to determine that a NRTS action exists with respect to the i^{th} LRU of a given subsystem.
H_R	Number of human resources required to remove and replace LRUs from the aircraft on the flightline.

Table 2 (continued)

Symbol	Description
H_T	Number of human resources required for subsystem troubleshooting
H_{V_M}	Number of human resources required to verify subsystem operation following an on-equipment repair
H_{V_R}	Number of human resources required to verify subsystem operation following a remove and replace operation
H_{W_i}	Number of human resources required to perform bench check and repair of the i^{th} LRU of a given subsystem
T_A	Average time required to set up support equipment
T_C	Average time required to determine that a CND condition exists
T_{K_i}	Average time required to determine that a shop CND condition exists with respect to the i^{th} LRU
T_M	Average time required to repair the subsystem on the aircraft
T_{N_i}	Average time required to determine that a not repairable this station (NRTS) or a condemnation condition exists with respect to the i^{th} LRU
T_R	Average time required to remove and replace one or more of the LRUs of the subsystem from the aircraft
T_T	Average time required to troubleshoot the subsystem
T_{V_M}	Average time required to verify subsystem operation following an on-equipment repair
T_{V_R}	Average time required to verify subsystem operation following a removal and replacement
T_{W_i}	Average time required to repair the i^{th} LRU in the shop

The fundamental computations made by the R&M model fall into two categories. First, FOMs are computed to identify high drivers of support resource requirements. The second set of computations consists of intermediate products that lead to resource requirements assessed in terms of number and skill level of maintenance personnel required, required repair times, and support equipment requirements. These parameters can then be evaluated by LRU, subsystem, and/or total system. The intermediate products and FOMs are summarized in Table 3.

The concept of a file is utilized throughout this discussion to describe different groupings of data. The terms input and output are standard, while intermediate implies results of computations within the model that can be output if an appropriate option is specified by the user. The matrix shown in Figure 7 illustrates the basic structure of the model and the interrelationships among the equipment, the maintenance events, and the results or outcomes resulting from a particular maintenance action. The elements listed illustrate the probability matrix of each maintenance event occurring given that that event will culminate in the outcome shown in parentheses. Similar matrices are used for the maintenance event times, human resource utilization, and SE used.

In the left-hand column, the equipment is described by the specific code assigned in the hierarchy (see Figure 1 for an example). Maintenance events are those possible consequences of an equipment failure, as described previously, and are summarized below with the code assigned to them in the R&M model.

Code	Maintenance Event
AGE F/L	= set up support equipment on the flight line
TS F/L	= troubleshooting on the flight line
R&R	= remove and replace a line replaceable unit
VR&R	= verification that R&R action corrected the discrepancy
CND A/C	= troubleshooting on the aircraft, cannot duplicate the discrepancy
M A/C	= minor maintenance on aircraft
VM A/C	= verification that the maintenance performed corrected the discrepancy
SHOP	= bench check, test, and repair of units removed to the shop.

Table 3

INTERMEDIATE PRODUCTS AND FIGURES OF MERIT FILES

Matrix-Formatted Files:

Option No.	File Content
1.	Mean time to repair (MTTR) by task event per subsystem and its associated LRUs
2.	MTTR by task event per subsystem and LRU as % of total MTTR for that subsystem
3.	Maintenance man hours (MMH) by task event per subsystem and its associated LRUs
4.	MMH by task event per subsystem and LRU as % of total MMH for that subsystem
5.	MMH per 1000 flight hours by task event per subsystem and its associated LRUs
6.	MTTR per 1000 flight hours by task event per subsystem and its associated LRUs (defined as maintenance index)

Listing File:

- Subsystem inherent flightline availability values for each subsystem ranked by order of magnitude

Equipment	AGE F/L	TS F/L	R&R	VR&R	CND A/C	M A/C	VM A/C	SHOP	OUTCOMES
	MAINTENANCE EVENTS								
LRUs	$P_{A_i}(w)$	$P_{T_i}(w)$	$P_{R_i}(w)$	$P_{VR_i}(w)$	–	–	–	P_{W_i}	W
	$P_{A_i}(K)$	$P_{T_i}(K)$	$P_{R_i}(K)$	$P_{VR_i}(K)$	–	–	–	P_{K_i}	K
	$P_{A_i}(N)$	$P_{T_i}(N)$	$P_{R_i}(N)$	$P_{VR_i}(N)$	–	–	–	P_{N_i}	N
	•								•
	$P_{A_i}(w)$	$P_{T_i}(w)$	$P_{R_i}(w)$	$P_{VR_i}(w)$	–	–	–	P_{W_i}	W
	$P_{A_i}(K)$	$P_{T_i}(K)$	$P_{R_i}(K)$	$P_{VR_i}(K)$	–	–	–	P_{K_i}	K
	$P_{A_i}(N)$	$P_{T_i}(N)$	$P_{R_i}(N)$	$P_{VR_i}(N)$	–	–	–	P_{N_i}	N
SUBSYSTEM	$P_A(C)$	–	–	–	$P_C(C)$	–	–		CND
	$P_A(M)$	$P_T(M)$	–	–	–	$P_M(M)$	$P_{V_M}(M)$		M

Figure 7 EXAMPLE APPLICATION OF R&M MODEL DATA MATRIX

The rows give the possible outcomes of each subsystem's maintenance action (MA), including whether it culminated in an on-equipment repair or required removal to the shop for test and repair. For the case of the removals, the LRU that required removal and replacement is identified along with its eventual shop disposition. The off-equipment outcome probabilities for LRUs are:

P_W = bench test and repair
P_K = bench test and find serviceable (no repair required)
P_N = not repairable this station (NRTS), which is a return to depot for repair.

The on-equipment outcome probabilities for the subsystem are:

P_M = minor maintenance on aircraft
P_{CND} = cannot duplicate the discrepancy.

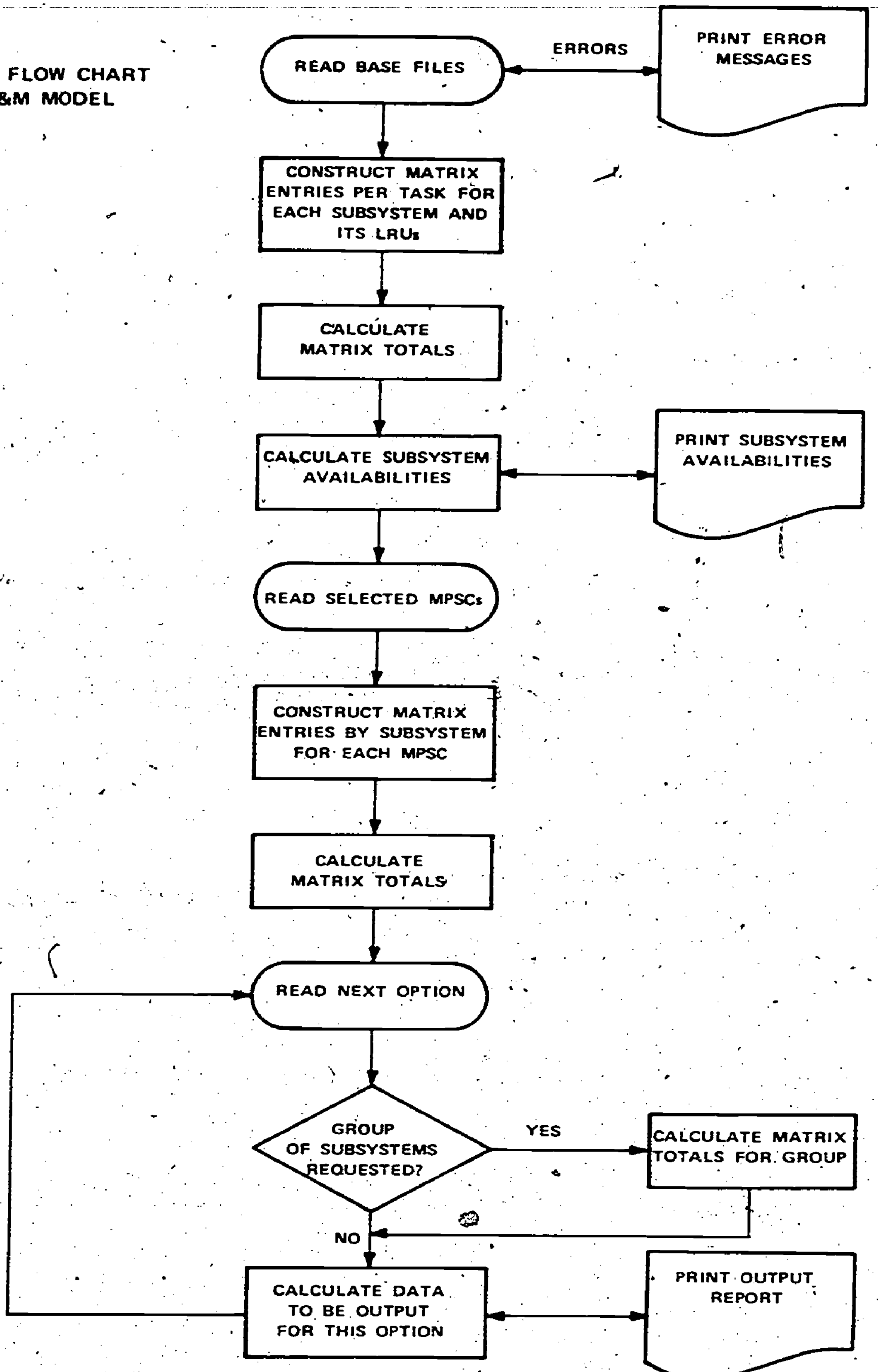
The model computes the average resources required per maintenance event for each possible outcome by subsystem and LRU. This information can be output directly in addition to being utilized in subsequent computations.

Resources consumed on the flight line are normally computed on a subsystem basis. Therefore, the apportionment of the resources on an LRU-basis requires the assumption that flight line maintenance events culminating in a removal are distributed in the same ratio as the shop outcome probabilities. The apportionment of the resources required for each event was accomplished by first assigning the outcome probability (W, K, and N by LRU; CND and M for the subsystem) to each appropriate element of the R&M model matrix. This probability value matrix was then overlaid with the respective input matrix of the average resources required to accomplish each of these events. The R&M model is programmed to compute the resources consumed per maintenance event by combining the respective terms from each matrix.

Although the details associated with the specific computations are complex, the computational problem is conceptually straightforward. The summary flow chart shown in Figure 8 outlines the R&M model's process. Each piece of equipment is related in the base file to its specific maintenance events in terms of average resources and time required per event along with its probability of occurrence. The model reads the base file data and constructs FOM and intermediate

Figure 8

SUMMARY FLOW CHART OF THE R&M MODEL



product matrix entries for each subsystem and its LRUs, as well as a list of subsystem availabilities. Next, it computes the MMH/1000 FH required by subsystem and LRU for each selected manpower specialty code (MPSC). MPSCs are used in the base file to denote skill type and level of each technician required per maintenance event. A count of these MPSCs are used in the algorithm that compute maintenance manhour output matrices. The model also prints, in accordance with several output product options, the matrix information summed across selected groups of subsystems. This completes the functional description of the R&M model. The specific algorithms utilized in the model are summarized in Appendix C. An example illustrating the model's potential use is given in the following section.

IV. EXAMPLE CALCULATIONS

The basic features and functional characteristics of the R&M model have been described in the preceding sections. Specific computations for a complete avionics suite are quite complex because a typical suite is comprised of more than 30 subsystems and in excess of 100 LRUs. However, the fundamental computational process can be illustrated by examining a specific LRU. The following is an example of the calculations performed by the R&M model for LRU AC321, a UHF receiver-transmitter.

To place this example in proper perspective it is helpful to re-examine the equipment hierarchy given in Figure 1. It is noted that LRU AC321 is associated with the subsystem AC320, UHF radio set. Furthermore, this receiver-transmitter (AC321) is part of the UHF (AC3) operational function and is a member of the communications (AC) functional group. Hopefully, it is clear that the portion of the input data set given in Tables 4 and 5 for LRU AC321 and subsystem AC320 represents only a small portion of the total input data set for the entire avionics suite. Nevertheless, these tables contain the data describing the salient information required for all subsequent calculations associated with this example. Other LRUs and subsystems will have similar input data sets.

The sequence of computations performed by the R&M model was given in the execution flow chart of Figure 8. The basic input data are read and, after a format check, the MTTR and MMH matrices are constructed for each subsystem and LRU. For example, the R&M model computes the bench check and repair MTTR for each LRU by multiplying task event time by probability of occurrence; e.g., using data from Table 4, 5.0 x .6790 = 3.3950 as shown within the circle in Figure 9. Similarly, the remainder of the output values in Figure 9 are calculated for the other shop and flight line maintenance events.

The output given in Figure 9 is the MTTR matrix for the LRUs that comprise subsystem AC320. The parameters indicated across the top are the flight line and shop maintenance events. A brief discussion of the specific entries will help to describe the process. The MTTR entry for the AGE F/L task, column 1, for LRU AC321 is calculated using flight line input data from Table 5 for the task time needed to set up support equipment. This value multiplied by the probability of occurrence of a bench check and repair action outcome for LRU AC321 from Table 5 yields

.2 x .6790 = .13580

Table 4 INPUT DATA FOR LRU AC321 RECEIVER-TRANSMITTER

Shop Maintenance Event	Task Event Time (hrs)	Occurrence Probability	Number of Technicians
Bench Check and Repair (W)	5.0	.6790	2
Bench Check and CND (K)	1.4	.0295	1
Bench Check and NRTS (N)	1.3	.0295	1

Table 5 INPUT DATA FOR SUBSYSTEM AC320 UHF RADIO SET

Flight Line Maintenance Event	Task Event Time (hrs)	Occurrence Probability	Number of Technicians
Set Up Support Equipment (AGE)	.2	1.0000	2
Troubleshooting (TS)	.2	.8700	1
Cannot Duplicate (CND)	.8	.1300	2
Remove and Replace (R&R)	1.4	.7569	1
On Aircraft (A/C) Maintenance (M)	1.1	.1131	1
R&R Verification (VR&R)	.5	.7569	1
On A/C Maintenance Verification (VM)	.5	.1131	2

MTTR BY TASK PER LRU

SUBSYSTEM- AC320 (63A00) UHF RADIO SET MFHBMA= 62.9

	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
LRU- AC321 (63AA0) RECEIVER/TRANSMITTER (UHF)									
W	0.13580	0.13580	0.95060	0.33950				3.39500	4.95670
K	0.00590	0.00590	0.04130	0.01475				0.04130	0.10915
N	0.00590	0.00590	0.04130	0.01475				0.03835	0.10620
SUB	0.14760	0.14760	1.03320	0.36900				3.47465	5.17205
LRU- AC322 (63AE0) DIPLEXER									
W	0.00158	0.00158	0.01106	0.00395				0.00632	0.02449
K	0.	0.	0.	0.				0.	0.
N	0.00018	0.00018	0.00126	0.00045				0.00090	0.00297
SUB	0.00176	0.00176	0.01232	0.00440				0.00722	0.02746
LRU- AC323 (63AL0) STANDING WAVE RATIO INDICATOR									
W	0.00104	0.00104	0.00728	0.00260				0.03068	0.04264
K	0.	0.	0.	0.				0.	0.
N	0.00104	0.00104	0.00728	0.00260				0.00364	0.01560
SUB	0.00208	0.00208	0.01456	0.00520				0.03432	0.05824
CND	0.02600				0.10400				0.13000
M	0.02262	0.02262				0.12441	0.05655		0.22620
TOT/TSK	0.20006	0.17406	1.06008	0.37860	0.10400	0.12441	0.05655	3.51619	5.61395

High Shop MTTR
W = Bench Check & Repairs

Figure 9 SAMPLE OF MTTR VALUES MATRIX

All other LRU outcomes are calculated in the same manner. LRU subtotals are provided as shown in Figure 9.

Task event series which culminate in actions exclusive to the subsystems are the cannot duplicate (CND) and subsystem repair (M) task outcomes (two bottom rows of Figure 9). To arrive at the subsystem results shown in Figure 9, the probability of occurrence of the two task events (Table 5) are multiplied by the respective task event times which lead to these two outcomes. In the case of the cannot duplicate outcomes, only the set up support equipment and cannot duplicate task events occur. The MTTR values shown for these two task events are thus obtained from the calculations.

AGE F/L = .1300 x .2 = .026
CND A/C = .1300 x .8 = .104

Similarly, the MTTR of the four tasks which occur as a result of a subsystem repair on-aircraft (A/C) maintenance outcome, are calculated as the product of the probability of occurrence of that maintenance event (.1131) times each of the four task event times which occur in conjunction with the subsystem repair; thus

AGE F/L = .1131 x .2 = .02262
TS F/L = .1131 x .2 = .02262
M A/C = .1131 x 1.1 = .12441
VM A/C = .1131 x .5 = .05655.

Totals are provided for outcomes and tasks by the sum of rows and columns, respectively, as shown in Figure 9.

A useful measure of the relative time spent on the various maintenance tasks is determined by computing the MTTR for each task as a percentage of the total MTTR associated with a given LRU. The total MTTR of the subsystem is first computed and stored in the subsystem MTTR matrix. Then MTTR as a percentage of total is computed. For example, the output shown in Figure 10 is the MTTR as a percentage of total for LRU AC321. It is obtained by dividing every entry in Figure 9 by the total MTTR of the subsystem (5.61395) and multiplying by 100; thus

$$\frac{3.39500}{5.61395} \times 100 = 60.474\%$$

MTTR AS % OF TOTAL

SUBSYSTEM- AC320 (63A00) UHF RADIO SET MFHBMA= 62.[illegible]

	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
LRU- AC321 (63AA0) RECEIVER/TRANSMITTER (UHF)									
W	2.419	2.419	16.933	6.047				60.474	88.293
K	0.105	0.105	0.736	0.263				0.736	1.944
N	0.105	0.105	0.736	0.263				0.683	1.892
SUB	2.629	2.629	18.404	6.573				61.893	92.129
LRU- AC322 (63AE0) DIPLEXER									
W	0.028	0.028	0.197	0.070				0.113	0.436
K	0.	0.	0.	0.				0.	0.
N	0.003	0.003	0.022	0.008				0.016	0.053
SUB	0.031	0.031	0.219	0.078				0.129	0.489
LRU- AC323 (63AL0) STANDING WAVE RATIO INDICATOR									
W	0.019	0.019	0.130	0.046				0.546	0.760
K	0.	0.	0.	0.				0.	0.
N	0.019	0.019	0.130	0.046				0.065	0.278
SUB	0.037	0.037	0.259	0.093				0.611	1.037
CND	0.463				1.853				2.316
M	0.403	0.403				2.216	1.007		4.029
TOT/TSK	3.564	3.100	18.883	6.744	1.853	2.216	1.007	62.633	100.000

$R_X T_X$ Bench Check & Repair MTTR is 60% of the sub-system total.

Figure 10 SAMPLE MATRIX OF TASK MTTR AS % OF TOTAL SUBSYSTEM MTTR

The corresponding circled entry in Figure 10 shows that the bench check and repair task for LRU AC321 consumes over 60 percent of the MTTR for subsystem AC320, and thus serves to focus attention to the bench check and repair task as a potential high consumer of maintenance resources.

Next, the MMH matrix is computed by multiplying the task MTTR by the number of technicians required for the task. For the bench check and repair task event for LRU AC321, two technicians are required as shown in Table 5. The MMH is, therefore

$$2 \times 3.3950 = 6.790$$

This value is circled in Figure 11. The remainder of the MMH matrix for each LRU in the subsystem AC320 is also shown here.

Total MMH per subsystem is computed by summing across the individual LRUs that make up the particular subsystem. In this case, both flightline and shop MMHs are summed for LRUs AC321, AC322, and AC323 to give 9.43742 as shown at the bottom right-hand column of Figure 11.

Total MMH for each task and subsystem is computed in the same fashion. The matrix totals can be output for selected subsystems. Figure 12 shows an example output for the several subsystems in the communications and navigation groups. In this example, the UHF radio set (AC320) accounts for 9.437 MMH and represents the largest value for those subsystems shown in Figure 12.

While the output matrix in Figure 12 allows one to readily key in on the high drivers in terms of MMH, it is useful to compare the requirements of all the individual LRUs. A simple yet valid measure for making these comparisons is MMH per LRU per event as a percentage of total MMH required for the subsystem. In this example the bench check and repair task requires the largest percentage as shown in Figure 13. Specifically,

$$\frac{6.79000}{9.43742} \times 100 = 71.948\%$$

This is circled in the output report shown in Figure 13.

MMH BY TASK PER LRU

SUBSYSTEM- AC320 (63A00) UHF RADIO SET MFHBMA= 62.9

	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
LRU- AC321 (63AA0) RECEIVER/TRANSMITTER (UHF)									
W	0.27160	0.13580	0.95060	0.33950				6.79000	8.48750
K	0.01180	0.00590	0.04130	0.01475				0.04130	0.11505
N	0.01180	0.00590	0.04130	0.01475				0.03835	0.11210
SUB	0.29520	0.14760	1.03320	0.36900				6.86965	8.71465
LRU- AC322 (63AE0) DIPLEXER									
W	0.00316	0.00158	0.01106	0.00395				0.00632	0.02607
K	0.	0.	0.	0.				0.	0.
N	0.00036	0.00018	0.00126	0.00045				0.00090	0.00315
SUB	0.00352	0.00176	0.01232	0.00440				0.00722	0.02922
LRU- AC323 (63AL0) STANDING WAVE RATIO INDICATOR									
W	0.00208	0.00104	0.00728	0.00260				0.03068	0.04368
K	0.	0.	0.	0.				0.	0.
N	0.00208	0.00104	0.00728	0.00260				0.00364	0.01664
SUB	0.00416	0.00208	0.01456	0.00520				0.03432	0.06032
CND	0.05200				0.20800				0.26000
M	0.04524	0.02262				0.24882	0.05655		0.37323
TOT/TSK	0.40012	0.17406	1.06008	0.37860	0.20800	0.24882	0.05655	6.91119	9.43742

Figure 11 SAMPLE OF MMH VALUES MATRIX

MMH FOR ALL SUBSYSTEMS

SUBSYS	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
AC310	0.400	0.440	0.792	0.106	0.240	0.915	0.070	1.494	4.457
AC320	0.400	0.174	1.060	0.379	0.208	0.249	0.057	6.911	9.437
AC330	0.400	0.930	0.279	0.279	0.140	0.781	0.651	1.063	4.524
AN110	0.400	0.860	0.942	0.565	0.448	0.650	0.209	0.502	4.576
AN120	0.400	0.480	0.826	0.413	0.144	0.215	0.027	4.901	7.405
AN130	0.400	0.184	0.662	0.530	0.432	0.515	0.103	1.295	4.121
TOTAL	2.400	3.068	4.561	2.272	1.612	3.325	1.117	16.166	34.520

UHF Radio

High MMH Consumed per Maintenance Action

Figure 12 SAMPLE MATRIX OF MMH TOTALS BY TASK FOR SELECTED SUBSYSTEMS

MMH AS % OF TOTAL

SUBSYSTEM- AC320 (63A00) UHF RADIO SET MFHBMA= 62.9

	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
LRU- AC321 (63AA0) RECEIVER/TRANSMITTER (UHF)									
W	2.878	1.439	10.073	3.597				71.948	89.935
K	0.125	0.063	0.438	0.156				0.438	1.219
N	0.125	0.063	0.438	0.156				0.406	1.188
SUB	3.128	1.564	10.948	3.910				72.792	92.341
LRU- AC322 (63AE0) DIPLEXER									
W	0.033	0.017	0.117	0.042				0.067	0.276
K	0.	0.	0.	0.				0.	0.
N	0.004	0.002	0.013	0.005				0.010	0.033
SUB	0.037	0.019	0.131	0.047				0.077	0.310
LRU- AC323 (63AL0) STANDING WAVE RATIO INDICATOR									
W	0.022	0.011	0.077	0.028				0.325	0.463
K	0.	0.	0.	0.				0.	0.
N	0.022	0.011	0.077	0.028				0.039	0.176
SUB	0.044	0.022	0.154	0.055				0.364	0.639
CND	0.551				2.204				2.755
M	0.479	0.240				2.637	0.599		3.955
TOT/TSK	4.240	1.844	11.233	4.012	2.204	2.637	0.599	73.232	100.000

Bench check & repair MMH is 72% of subsystem total.

Figure 13 SAMPLE MATRIX OF TASK MMH AS % OF TOTAL SUBSYSTEM MMH

Up to this point, maintenance resources have been compared on the basis of resources required per event. Next, the frequency of event occurrence is considered by introducing the failure frequency in terms of mean flight hours between maintenance actions (MFHBMA). The MMH per 1000 flying hours can then be computed and subsystems and LRUs can be compared on the basis of their combined reliability and maintainability characteristics. Since the MFHBMA for subsystem AC320 was 62.9, the MMH per 1,000 flight hours for LRU AC321 becomes

$$\frac{6.790}{\frac{62.9}{1000}} = 107.949$$

This is shown in the output report in Figure 14. Calculations for all output formats for the remaining shop tasks, bench check, and cannot duplicate (K), and bench check and not repairable this station (N) are arrived at similarly. It is noted that the value associated with the shop effort for LRU AC321 is by far the highest driver.

The following summarizes how the sample calculations displayed in Figures 9 through 14 can be utilized to conduct a typical R&M study. Figure 12 shows the MMH consumed per maintenance action by maintenance task event for six subsystems chosen from a particular avionics design configuration. The specific equipment can be identified by referral to Appendix A through the ID code. ID code AC320 is the UHF radio set.

This radio is the high driver of this sample set since it consumes more than twice the MMH of the other two UHF subsystems (AC310 and AC330) in Figure 12. Figures 9 and 10 provide, respectively, the MTTR by task per LRU and the MTTR as percent of total for this UHF radio set.

These figures make possible an analysis of what the individual LRUs contribute to the maintenance requirement generation. In particular, Figure 9 shows that LRU ID code AC321, the receiver-transmitter unit, consumes over five hours of the MTTR of that subsystem for each maintenance action. The shop bench check and repair uses 3.4 of those hours. Figure 10, which presents time-to-repair in percentages, shows that the receiver-transmitter consumes approximately 92 percent of the MTTR for the subsystem and its shop bench check and repair time requires 60 percent of the subsystem total.

MMH PER 1000 FH HR

SUBSYSTEM- AC320 (63A00) UHF RADIO SET MFHBMA= 62.9

	AGE F/L	TS F/L	R+R	VR+R	CND A/C	M A/C	VM A/C	SHOP	TOT/OUT
LRU- AC321 (63AA0) RECEIVER/TRANSMITTER (UHF)									
W	4.318	2.159	15.113	5.397				107.949	134.936
K	0.188	0.094	0.657	0.234				0.657	1.829
N	0.188	0.094	0.657	0.234				0.610	1.782
SUB	4.693	2.347	16.426	5.866				109.215	138.548
LRU- AC322 (63AE0) DIPLEXER									
W	0.050	0.025	0.176	0.063				0.100	0.414
K	0.	0.	0.	0.				0.	0.
N	0.006	0.003	0.020	0.007				0.014	0.050
SUB	0.056	0.028	0.196	0.070				0.115	0.465
LRU- AC323 (63AL0) STANDING WAVE RATIO INDICATOR									
W	0.033	0.017	0.116	0.041				0.488	0.694
K	0.	0.	0.	0.				0.	0.
N	0.033	0.017	0.116	0.041				0.058	0.265
SUB	0.066	0.033	0.231	0.083				0.546	0.959
CND	0.827				3.307				4.134
M	0.719	0.360				3.956	0.899		5.934
TOT/TSK	6.361	2.767	16.853	6.019	3.307	3.956	0.899	109.876	150.038

High

Figure 14. SAMPLE MATRIX OF MMH PER 1000 FLIGHT HOURS BY TASK EVENT

An indicator of the rate at which resources are consumed is obtained by combining these MMH required per maintenance action with the rate at which these unscheduled maintenance actions occur. Figure 14 displays this output as MMH per 1000 flight hours based on an MFHBMA of 62.9 hours. Figure 13 displays these MMH per 1000 flight hour values as percentage of total. The bench check and repair time of the receiver-transmitter unit consumes over 72 percent of the total subsystem MMH.

Now it is possible to conduct a sensitivity analysis to seek possible means for improvement. A sensitivity analysis of the two dominant parameters causing the high MMH per 1000 flight hour was conducted (i.e., MFHBMA and shop MTTR of the receiver-transmitter LRU). First, the MFHBMA of the subsystem was postulated to be improved by 20 percent, i.e., from 62.9 to 75.5 hours, and the effect on the dependent variable MMH/1000 FH was noted. The change resulted in a MMH/1000 FH decrease from 149 to 124, an improvement of 17 percent. Then, the shop MTTR value for the receiver-transmitter LRU was computed that would result in the same 17 percent improvement in MMH/1000 FH. In this case, the shop MTTR would have had to be reduced from a value of 3.47 to 2.89 hours, a 17 percent improvement. Therefore, it requires a 17 percent improvement in the shop MTTR of this particular LRU to attain the same effect as would an overall 20 percent reliability improvement (decrease in MFHBMA) for the entire radio. This kind of tradeoff visibility which the exercise of the R&M model provides should be a valuable aid in system design and planning activities.

For the purpose of illustration and to further define the sensitivities, an additional 20 percent postulated reliability improvement was input. The dependent variable value was computed and the subsequent MTTR improvement alternative was calculated, as described previously. These values, along with those from the first model run, are recorded in Table 6 and plotted comparatively in Figure 15. Results indicated that an additional 12 percent improvement in MMH/1000 FH could be achieved by effecting either a 12 percent improvement in MTTR or a 20 percent improvement in MFHBMA.

Table 6

SENSITIVITY ANALYSIS VALUES*

AC320, UHF Radio Set

Sensitivity Parameter	Dependent** Variable	Sensitivity Parameter
MFHBMA:	MMH/1000 FH:	Shop Maintenance MTTR: LRU AC321
62.9	149	3.47
75.5 (20% increase)	124 (17%)	2.89 (17% decrease)
88.1 (40% increase)	106 (29%)	2.47 (29% decrease)

*This table is to be used in conjunction with Figure 15 to give values for points on the graphs.

**The effect shown on the dependent variable is obtained from varying either of the sensitivity parameters as indicated. (The percent changes in relation to the original values are shown in parenthesis.)

SENSITIVITY ANALYSES

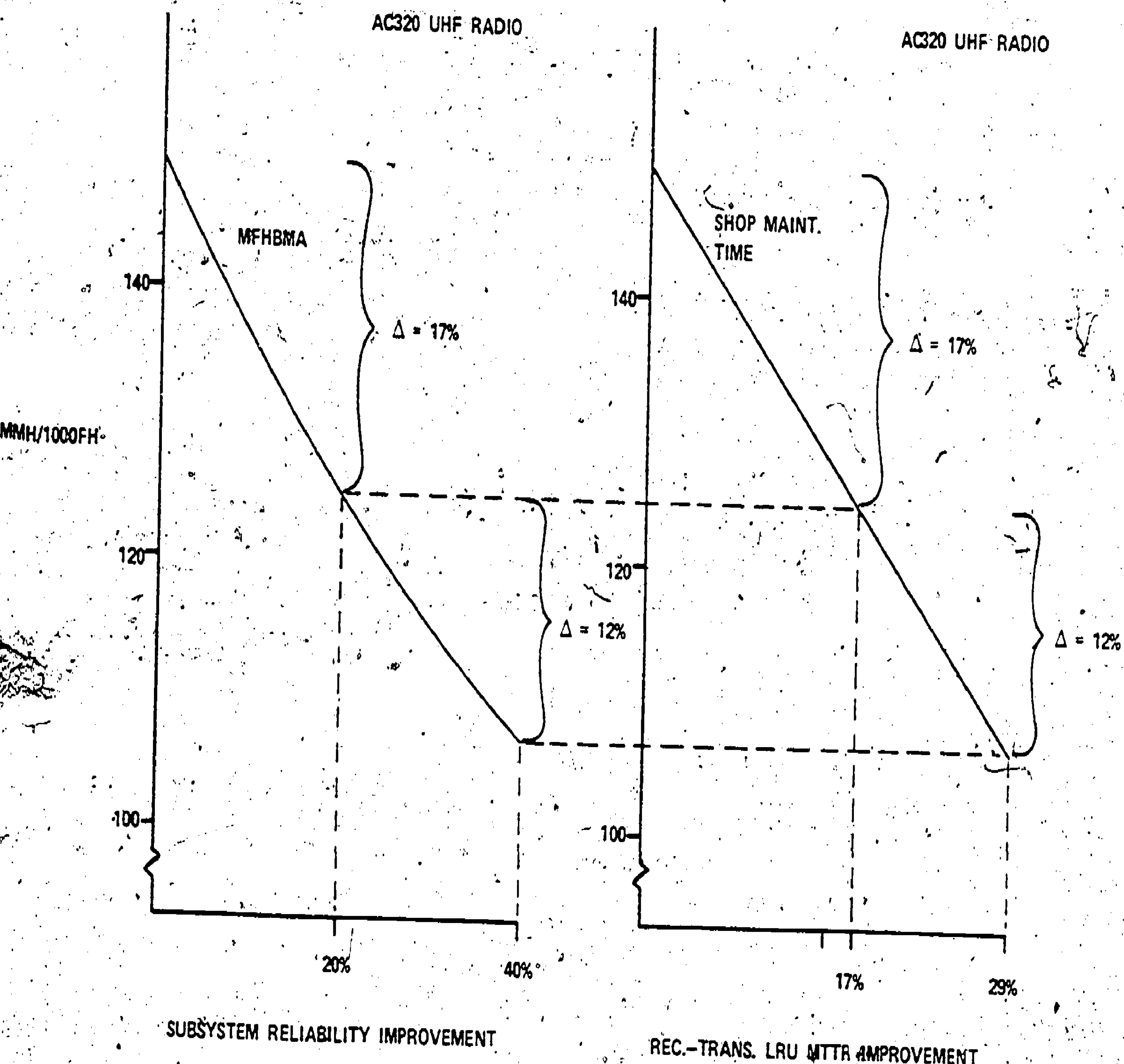


Figure 15

The information regarding these two alternatives provides the basis for a tradeoff analysis. Its generation by the R&M model clearly demonstrates the usefulness of its application in either a one-time only or iterative manner. In actual practice, a cost benefit analysis would be conducted. The cost that results from the 17 percent reduction in MMH/1000 FH should be compared with the investment costs required to attain each of the two alternatives to provide a basis for design or planning action.

The purpose of this section has been to illustrate the specific calculations performed by the R&M model when actual data for LRU AC321, receiver-transmitter, were utilized. Sample output products have been used to explain how the model functions. However, the illustrations used also indicate the potential of the model as an analysis tool. For example, the sample products illustrate how high driver subsystems can be identified in terms of service availability, mean time to repair, and maintenance manhours consumed. The format of the model makes it possible to analyze each LRU by shop outcome including the resources the LRU consumed as a part of the subsystem. Also, the LRUs causing high CND and maintenance on aircraft rates for the flightline subsystem repairs can be evaluated. The units that are high cost drivers or that may be causes of poor operational availability can be thus identified and studied.

The example was then used to discuss the use of the model to conduct a sensitivity analysis. This important application leads to the performance of tradeoff analyses and "what if" evaluations that can be accomplished by examining parameters that would influence the design. These "what if" evaluations include exercising the R&M model to determine the impact of varying equipment characteristics or maintenance considerations such as:

(1) Reliability: probability of maintenance actions and the rate of failures of subsystems and LRUs
(2) Maintainability: average time to accomplish specific tasks and the probability of specific maintenance actions occurring
(3) Central integrated test system (CITS) and built-in-test-equipment (BITE) effectiveness: time to troubleshoot CND events
(4) Level of repair or maintenance concept: proportions of flightline, shop, and depot maintenance events
(5) Design: effect on any of the above parameters due to any new or modified design characteristic.

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Appendix A

DATA BANK CODES & SYMBOLS AND EQUIPMENT IDENTIFICATION NUMBERS

DATA BANK SAMPLE - MID-1980s DAIS AVIONICS

- Major System (Avionics)
- Functional Group
- Operational Function
- Subsystem
- Line Replaceable Unit

FUNCTIONAL GROUP - (A) AIR-GROUND-ATTACK

OPERATIONAL FUNCTION - (1) FIRE CONTROL

ID	WUC	NAME
AA110	74G00	Forward Looking Infrared Detecting Set
AA111	74GA0	Infrared Receiver
AA112	74GB0	Power Supply
AA113	74GC0	Optical Sensor Stabilization Pod
AA120	74H00	Laser Target Identification Set
AA121	74HA0	Laser/Electro-Optics/Gimbals-Pod

FUNCTIONAL GROUP - (C) COMMUNICATIONS

OPERATIONAL FUNCTION - (1) HF

ID	WUC	NAME
AC110	61A00	HF Radio
AC111	61AA0	Receiver/Transmitter
AC112	61AB0	Amplifier Power Supply
AC113	61BA0	Antenna Coupler
AC114	61BC0	Variable Capacitor

OPERATIONAL FUNCTION - (2) VHF

ID	WUC	NAME
AC210	62A00	VHF-FM Communications Set
AC211	62AA0	Receiver/Transmitter
AC212	62AE0	Antenna Coupler

ID	WUC	NAME
OPERATIONAL FUNCTION - (3) UHF		
AC310	63510	Data Link
AC311	63511	Converter/Receiver
AC312	63515	Mount & Antenna
AC320	63A00	UHF Radio Set
AC321	63AA0	Receiver/Transmitter
AC322	63AE0	Diplexer
AC323	63AL0	Standing Wave Ratio Indicator
AC330	63B00	Automatic Directional Finding Group
AC331	63BA0	Relay Amplifier
AC332	63BB0	Antenna
AC333	63BC0	Receiver
AC334	63BF0	Mount
OPERATION FUNCTION - (4) INTERPHONE		
AC410	64A00	Intercom Set
AC411	64AA0	Intercom Set Control
AC412	64AC0	Station Intercom
AC413	64AG0	Audio Relay Assembly
OPERATIONAL FUNCTION - (5) IFF		
AC510	65A00	IFF Transponder Set
AC511	65AA0	Receiver/Transmitter
OPERATIONAL FUNCTION - (6) TSEC		
AC610	69A00	Speech Security System
AC611	69AA0	Coder/Decoder
AC612	69AC0	Relay

ID	WUC	NAME
FUNCTIONAL GROUP - (I) INSTRUMENTS		
OPERATIONAL FUNCTION - (1) FLIGHT		
AI110	51A00	Flight Instruments
AI111	51AA0	Airplane System Instruments
AI112	51AB0	Counting Accelerometer
AI113	51AD0	Approach Attitude Indicating System
AI114	51AE0	Pitot Static System
OPERATIONAL FUNCTION - (2) NAVIGATION		
AI120	51B00	Navigational Instruments
AI121	51BA0	Remote Standby Attitude Indicating System
FUNCTIONAL GROUP - (M) MISCELLANEOUS		
OPERATIONAL FUNCTION - (1) ELECTRONIC COUNTERMEASURES		
AM110	76E00	Radar Homing & Warning System
AM111	76EA0	Signal Processor
AM112	76EB0	Receiver
AM113	76EC0	Amplifier Detector
AM120	76L00	Infrared Tail Warning
AM121	76LA0	Search Track Scanner
OPERATIONAL FUNCTION - (2) PHOTO		
AM210	77A00	Strike Camera System
AM211	77AA0	Strike Camera
AM212	77AB0	Mount
AM213	77AC0	Camera Box
AM214	77AE0	Camera Control, Electrical
FUNCTIONAL GROUP - (N) NAVIGATION		
OPERATIONAL FUNCTION - (1) RADIO NAVIGATION		
AN110	71A00	Heading Mode System
AN111	71AD0	Rate Gyro Transmitter

ID	WUC	NAME
AN120	71B00	Tacan Set
AN121	71BA0	Receiver/Transmitter
AN122	71BD0	Antenna Switch
AN130	71C00	Instrument Landing System
AN131	71CA0	Radio Marker Beacon and Glideslope Receiver
AN132	71CD0	Antenna

OPERATIONAL FUNCTION - (2) RADAR NAVIGATION

ID	WUC	NAME
AN210	72A00	Radar Altimeter Set
AN211	72AA0	Receiver/Transmitter
AN212	72AB0	Antenna Switching Unit (Interference Blanker)
AN213	72AC0	Antenna Receiver
AN220	72B00	Radar Beacon Set
AN221	72BA0	Receiver/Transmitter
AN222	72BD0	Antenna

OPERATIONAL FUNCTION - (3) BOMBING NAVIGATION

ID	WUC	NAME
AN310	73A00	Forward Looking Radar
AN311	73AA0	Antenna/Transmitter
AN312	73AB0	Radar Receiver
AN313	73AC0	Power Supply
AN314	73AJ0	Radar Set Mounts
AN315	73AK0	Blower and Duct Assembly
AN320	73C00	Air Data Computer System
AN321	73CA0	Air Data Computer
AN322	73CH0	Total Temperature Probe
AN330	73F00	Inertial Measurement Set
AN331	73FA0	Inertial Measurement Unit

FUNCTIONAL GROUP - (Z) CORE ELEMENTS

OPERATIONAL FUNCTION - (1) DISPLAYS

ID	WUC	NAME
AZ110	7WA00	DAIS Electronic Display Group
AZ111	7WAA0	Multipurpose Display QPA = 2
AZ112	7WAC0	Horizontal Situation Display

ID	WUC	NAME
AZ120	7WB00	Special Purpose Displays
AZ121	7WBA0	Heads-Up Display
AZ122	7WBB0	Vertical Situation Display
AZ130	7WC00	Display Controls
AZ131	7WCA0	Modular Programmable Display Gen. QPA = 2
AZ132	7WCC0	Display Switch/Memory Unit
AZ140	7WD00	Mass Memory Unit
AZ141	7WDA0	Electronic Unit
AZ142	7WDB0	Magnetic Tape Transport Unit
AZ143	7WDC0	Control Unit

OPERATIONAL FUNCTION - (2) CONTROLS

ID	WUC	NAME
AZ210	7XE00	Multifunctional Controls
AZ211	7XEA0	Integrated Multifunctional Keyboard
AZ212	7XEC0	Multiple Functional Control Panel QPA = 2
AZ220	7XF00	Dedicated Controls
AZ221	7XFA0	Power/Start-up Panel
AZ222	7XFB0	Armament Panel
AZ223	7XFC0	Communications Panel
AZ224	7XFD0	Alpha/Numeric Entry Keyboard (DEK)
AZ225	7XFE0	Master Mode Panel
AZ226	7XFF0	Sensor Controller Panel (SMCP)
AZ227	7XFG0	Sensor Controller Unit (SCU)

OPERATIONAL FUNCTION - (3) PROCESSOR

ID	WUC	NAME
AZ310	7YA00	Processor
AZ311	7YAA0	Computer Processor
AZ312	7YAB0	Maintenance/Control Panel

OPERATIONAL FUNCTION - (4) MULTIPLEX UNITS

ID	WUC	NAME
AZ410	7ZA00	Bus Control Interface Units
AZ411	7ZAD0	Bus Control Interface Units QPA = 4
AZ420	7ZB00	Remote Terminal Units
AZ421	7ZBA0	Remote Terminal Units QPA = 10

Appendix B

ACRONYMS

AFSC	Air Force specialty code
BITE	built-in-test-equipment
CAS	close air support
CITS	central integrated test system
CND	cannot duplicate
DAIS	digital avionics information system
FOM	figure of merit
ID	equipment identification number
LCC	life cycle cost
LCCIM	life cycle cost impact model
LCOM	logistics composite model
LRU	line replaceable unit
MA	maintenance action
MFHBMA	mean flight hours between maintenance actions
MMH	maintenance manhours
MMMS	maintenance manpower modeling system
MPSC	manpower specialty code
MTTR	mean time to repair
NRTS	not repairable this station
O&M	operation and maintenance
R&M	reliability and maintainability
SE	support equipment
SRU	shop replaceable unit
UHF	ultra high frequency
WUC	work unit code

Appendix C

BASIC ALGORITHMS FOR R&M MODEL

1. Probability Algorithms*

Maintenance Task Event Probability Matrix	Inputs
$P_{A_i}(W) = P_{T_i}(W) = P_{R_i}(W) = P_{V_{R_i}}(W)$	$= P_{W_i}$
$P_{A_i}(K) = P_{T_i}(K) = P_{R_i}(K) = P_{V_{R_i}}(K)$	$= P_{K_i}$
$P_{A_i}(N) = P_{T_i}(N) = P_{R_i}(N) = P_{V_{R_i}}(N)$	$= P_{N_i}$
$P_A(C) = P_C(C)$	$= P_{CND}$
$P_A(M) = P_T(M) = P_M(M) = P_{V_M}(M)$	$= P_M$

where:

$P_{X_i}(\ )$ = probability of maintenance event X occurring in the ith LRU given that that action will culminate in the outcome in parenthesis (W, K, N, C, or M). No ith subscript indicates that the event is applicable to the subsystem (i.e., all the LRUs). Each probability in a given row is assigned the value of the input parameter (outcome event probability) for that row. This apportions the probabilities by outcome for that series of maintenance events.

2. MTTR by Maintenance Event for each Subsystem and LRU**

$$MTTR = P_{i,j} \bullet t_j$$

where:

P = probability of a maintenance event occurring whenever a maintenance action (MA) has been initiated

*These probabilities are not programmed as direct outputs but form the [P] matrix for all required computations. Refer to Figure 7 for the format of the array resulting from these probability equations.

**Figure 9 illustrates the matrix format obtained from this equation.

t = average task time required to accomplish each maintenance event in the array (e.g., $t_{A_{i,j}}(W) = t_{A_{i,j}}(K) = t_{A_{i,j}}(N) = T_{A_j}(C) = T_{A_j}(M)$)

i = i^{th} row of the array (each LRU requires three rows, i.e., W, K, nor N outcomes)

j = j^{th} column of the array (maintenance events)

MTTR = mean time to repair

3. MMH by Maintenance Event for each Subsystem and LRU

$$MMH_{i,j} = MTTR_{i,j} \bullet N_j$$

where MMH = maintenance manhours

N = number of technicians assigned to each of the maintenance events (j^{th} column) in the MTTR matrix

4. MMH per 1000 Flight Hours by Maintenance Event for each Subsystem and LRU

$$MMH/1000FH_{i,j} = \frac{1000}{MFHBMA} \bullet MMH_{i,j}$$

where

MFHBMA = mean flight hours between maintenance actions for the subsystem

5. MTTR per 1000 Flight Hours by Maintenance Event for each Subsystem and LRU

$$MTTR/1000FH_{i,j} = \frac{1000}{MFHBMA} \bullet MTTR_{i,j}$$

SUMMATION ALGORITHMS FOR MTTR OR MMH MATRICES

6. MTTR or MMH Total by Outcome for each LRU in each Subsystem

$$\text{MTTR TOT/OUT} \Big|_i = \sum_{i=1}^{m} MTTR_{i,j}$$

where:

j identifies the maintenance task events (columns of the matrix)

m = the various maintenance task event values (MTTR or MMH) in that row

i = the outcomes (W, K, and N for each LRU, and CND and M for the subsystem)

$_i$ = indicates evaluated at the i^{th} outcome

7. MTTR or MMH Subtotal is the Aggregate of the Maintenance Task Event Values for each LRU (columnar sums of the W, K, N values for that LRU)

$$\text{MTTR SUB} = \text{MTTR}_{X_i}(W) + \text{MTTR}_{X_i}(K) + \text{MTTR}_{X_i}(N)$$

where:

X_i is maintenance event X for the i^{th} LRU.

Letter in parenthesis is the shop outcome for that LRU.

8. MTTR or MMH Total per Maintenance Task Event is the Aggregate of the Values for that Subsystem (sums of the columns)

$$\text{MTTR TOT/TSK} = \sum_{i=1}^{n} (\text{MTTR SUB}) + \text{MTTR(C)} + \text{MTTR(M)}$$

where:

n is the LRUs in that subsystem

Letter in parenthesis is the subsystem outcome.

9. MTTR or MMH Total per Subsystem is the Grand Total for all of the Maintenance Task Events (sum of the columnar sums)

$$\text{MTTR TOT} = \Sigma(\text{MTTR TOT/TSK})$$

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10. MTTR as Percent of Total MTTR by Maintenance Event for each Subsystem and LRU

$$\% \, MTTR_{i,j} = \frac{100}{MTTR_{TOT}} \bullet MTTR_{i,j}$$

where:

$MTTR_{TOT}$ = total MTTR for all maintenance events for a subsystem

11. MMH as Percent of Total MMH by Maintenance Action for each Subsystem and LRU

$$\% \, MMH_{i,j} = \frac{100}{MMH_{TOT}} \bullet MMH_{i,j}$$

where:

MMH_{TOT} = total MMH for all maintenance events for a subsystem

12. Subsystem Inherent Flight Line Availability

$$A = \frac{MFHBMA}{MFHBMA + MTTR_F}$$

where:

$MTTR_F$ is the MTTR for flight line maintenance events only.

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