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AUTHOR	Goclowski, John C.; Baran, H. Anthony
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ABSTRACT

This report gives a managerial overview of the Life Cycle Cost Impact Modeling System (LCCIM), which was designed to provide the Air Force with an in-house capability of assessing the life cycle cost impact of weapon system design alternatives. LCCIM consists of computer programs and the analyses which the user must perform to generate input data. The system is different from existing models of similar purpose because it incorporates a capability to analytically derive, as well as aggregate, data required for the estimation of life cycle cost. This feature provides an improved capability to conduct trade-offs among candidate design, manpower, and logistic alternatives early in the systems acquisition process. LCCIM represents a systematic approach to resource requirements analysis and cost estimation, which functions in terms of the operation and system support processes associated with the system being examined. Also included in this report is a general description of the initial LCCIM application; i.e., an assessment of the potential impact of the Digital Avionics Information System concept of avionics integration. References are included. (Author/LLS)

AIR FORCE

HUMAN RESOURCES

DIGITAL AVIONICS INFORMATION SYSTEM (DAIS): LIFE CYCLE COST IMPACT MODELING SYSTEM (LCCIM) - A MANAGERIAL OVERVIEW

By

John C. Goclowski
Dynamics Research Corporation
Concord Street
Wilmington, Massachusetts 018

[illegible]

LOGISTICS AND TECHNICAL TRAINING DIVISION
Wright-Patterson Air Force Base, [illegible] 433

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LABORATORY

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

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

This report provides an overview of the Life Cycle Cost Impact Modeling System (LCCIM). The LCCIM can be used to assess the impact of weapon system characteristics on system support resource requirements and life cycle cost (LCC). It was developed to enhance present Air Force capability to conduct trade-offs between competing design, manpower, and logistics alternatives early in the weapon systems acquisition process.

This report also contains a general description of the initial application of the LCCIM: an analysis of the potential impacts of the Digital Avionics Information System (DAIS) concept of avionics integration on LCC and system support personnel requirements. References are provided for other related reports which: describe that application, document the development of LCCIM components, and provide user's guide information and computer program listings.

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The basic application of the LCCIM modeling system involves four steps: (1) perform a Functional Analysis to identify existent operational equipment which can functionally satisfy system requirements and establish a reference list of comparable equipment in the DoD inventory for which data is available: (2) perform a Maintenance analysis to determine how reference values for resource utilization parameters should be modified to reflect design, manpower, and logistics concept changes; (3) exercise the Training Requirements Analysis Model (TRAMOD) component of the LCCIM to determine a baseline training program based on skill and knowledge requirements; and (4) exercise the Reliability and Maintainability and Cost Model (RMCM) component of the LCCIM to aggregate resource utilization and then compute total life cycle cost estimates for use in the comparison of trade-off alternatives.

The LCCIM is a powerful tool for determining system support resource requirements as well as computing LCC trade-off analyses. It is user-interactive and extremely versatile: operable on input data at varying levels of detail during all phases of the weapon system acquisition process. Responsiveness to both general and detailed queries encourages more trade-off analyses to be conducted early in the design process, where cost avoidance information can be most effectively acted upon. LCCIM data processing takes into account the interaction between support requirements and cost parameters. Its outputs provide increased visibility concerning both individual and collective impacts, thus affording information concerning the "why" as well as the "what" of trade-off analysis results. In addition, the LCCIM is operable at the system, subsystem, and line-replaceable-unit (LRU) level of equipment indenture. As such, it is useful in the evaluation of discrete impacts and in the identification of "high drivers" of system support resource requirements.

SUMMARY

Th[illegible] report [illegible] managerial overview of the Life Cycle Cost Impact [illegible]eling System [illegible] a set of models and techniques for analyzing impact [illegible] system characteristics on system support resource requirements and [illegible] cost (LCC). The LCCIM is different from earlier models [illegible] purpose because it incorporates a capability to [illegible], as well as aggregate, data required for the estimation of LCC. This feature provides an improved capability to conduct tra[illegible] among candidate [illegible] manpower, and logistics alternatives [illegible] in the systems acquisition process. The LCCIM represents a systematic approach to [illegible] requirements analysis and cost estimation which [illegible] in [illegible] operation and system support processes associated with the system [illegible] examined. This is a decided improvement over techniques which [illegible] in terms of parametric relationships.

The basic application of the LCCIM involves four steps: [illegible] performance [illegible] Functional Analysis to identify existent operational equipment which [illegible] functionally satisfy the operational requirements of the new system [illegible] to select from that equipment those which, together, [illegible] compare to the new system and for which design, operation, and maintenance data is available (thus defining a reference system [illegible] for analysis of the new system); (2) the performance of a Maintenance Analysis to determine how reference system data values must be modified to reflect design, manpower, and logistics concept changes associated with the new system; (3) the exercise of the Training Requirements Analysis Model (TRAMOD) component of the LCCIM to define a baseline training program on the basis of skill and knowledge requirements associated with the new system; and (4) the exercise of the Reliability, Maintainability and Cost Model (RMCM) component of the LCCIM to assess [illegible] and aggregate resource utilization associated with the new system and then to develop life cycle cost estimates for use in the comparison of trade-off alternatives.

The LCCIM provides a powerful means of conducting system support resource requirement and life cycle cost trade-off analysis at the system, subsystem, and line-replaceable-unit (LRU) levels. It is user-interactive [illegible] extremely versatile; operable on input data at varying levels of detail during all phases of the weapon systems acquisition process. Its responsiveness to both general and detailed query and its user-interactive capabilities encourage more trade-off analyses to be conducted early in [illegible] design process, where cost avoidance information can be most effectively acted upon. LCCIM data processing takes into account the interaction between support requirements and cost parameters. Its outputs provide increased visibility concerning the "why" as well as the "what" of trade-off analysis results.

In addition to overview of the LCCIM and its application methodology, this report provides a general description of the initial LCCIM application: an assessment of the potential impact of the Digital Avionics Information System (DAIS) concept of avionics integration. Referenced reports provide

detailed information concerning the specifics of applying the modeling system, its development, and the computer programs which are a par of it.

PREFACE

This is the final report of the "DAIS Life Cycle Costing Study" which was conducted under contract no. F33615-75-C-5218. Products of this study (models, data banks, computer programs, and reports) were developed to improve the Air Force capability to assess the life cycle cost impact of the operational implementation of new systems or concepts such as the Digital Avionics Information System (DAIS). They also constitute a significant contribution to improving the consideration of system support resource requirements and LCC within the weapon systems acquisition process.

The research effort was directed by the Logistics and Technical Training 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 Air Force Logistics Command. Contract funds were provided by the Air Force Avionics Laboratory, Mr. Terrance A. Brim is the DAIS program manager; Mr. H. Anthony Baran, the Air Force Human Resources Laboratory project scientist: Captain Ronald Hahn, the Air Force Logistics Command project officer; and, Mr. John Goclowski, the contractor program manager. Mr. Baran and Captain Hahn are also DAIS deputy directors.

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I. INTRODUCTION

1.1 BACKGROUND

The Department of Defense (DoD) must be able to operate effectively within the constraints of a reduced budget, rising costs, and numerous difficulties associated with a volunteer force. In an attempt to ensure that weapon systems satisfy needs at an affordable cost, the Armed Services are being directed to refine the process by means of which they acquire new weapon systems to improve the cost effectiveness of resource expenditures, particularly in terms of the life cycle cost consequences of system ownership. One of the ways in which the Air Force responded to the series of DoD directives which address this issue was to develop new and more powerful analytic techniques and procedures for use in:

- evaluating the cost-effectiveness of manpower/logistics alternatives
- integrating explicit manpower, personnel, and training assessments into the early phases of system acquisition and modification programs; and,
- conducting requirements, costing, and trade-off analyses during all phases of system development.

This report describes a major technical development included in that response: the Life Cycle Cost Impact Modeling System (LCCIM).

The LCCIM is an effective means of analyzing the resource requirements to be expected as a consequence of implementing a candidate weapon system design, projecting the resource utilization for the proposed life cycle of the weapon system, and identifying and quantifying life cycle impacts in terms of cost and system support effectiveness. This capability allows the user to analyze the potential consequences of policy and system design decisions as they are being made, throughout the systems acquisition process. A primary purpose of LCCIM development was to provide guidance and support to that process in a way which would promote both a fuller and earlier consideration of system support and life cycle cost requirements as design criteria. The overall objective of its development was the provision of a quick response capability to predict the relative costs of alternative weapon system designs and operating/management philosophies, based on a realistic and consistent set of assumptions and operable on data which would be available even in the early stages of design development. The objective was not to produce absolute estimates of life cycle cost, in the sense that LCCIM outputs would account for all actual expenditures to be expected to occur as a result of system ownership. Such costs are dependent on the combined impact of too many variables to be accurately predictable at the points in system development for which the LCCIM is tailored for use. (Examples of such variables are specific operational scenarios, inflation rates, modifications likely to be made over the course of the system's life cycle, and changes in operation and support policy likely to occur within that timeframe.)

The design, development, and acquistion of a major weapon system (depicted in Figure 1.1) is usually long in duration and can take from 10 to 15 years for completion. In addition, the Weapon Systems Acquisition Process (WSAP) is basically "open loop" in that the explicit consideration of manpower and logistics elements does not begin until the overall system design is specified. In-depth examinations of these important elements usually do not occur until the detailed-level design phase; after most system-level design decisions have already been made or are finalized to a point whereat changes would be extremely costly in terms of budget and schedule, or would necessitate post-production modification.

Since manpower and other logistics elements are the major contributors to life cycle cost (LCC), it is beneficial for planners of these elements to participate more fully with the system designers early in the design development process. The LCCIM provides a comprehensive impact analysis capability and a systematic procedure for applying it in the early identification and evaluation of the system support requirements generated by a specific design and support plan. Such a capability, depicted as an analytical modeling system in Figure 1.1, allows the performance of earlier and more comprehensive analyses to forecast the manpower, logistics, and cost effectiveness impacts of alternative designs. It not only facilitates the performance of trade-offs between competing alternatives, but also provides for the establishment of sounder criteria for early decision making. Forecasted impacts could be used to guide decisions regarding both system design and the operating/support policy. By allowing its user to identify, quantify, and accommodate for specific system support drivers of LCC, the LCCIM can be used to close the "open loop" of the current WSAP in a series of iterative analyses performed as the system design is developed.

The LCCIM methodology includes analytic techniques for establishing baseline manpower, logistics, and cost data at earlier points in the WSAP than are now possible. Such techniques, supported by the modeling components of the LCCIM, are capable of systematically analyzing and clearly identifying life cycle impacts and could play a major beneficial role in the WSAP (see Figure 1.2). They would be especially beneficial in the performance of the many trade-off studies of manpower and logistics alternatives conducted throughout its course.

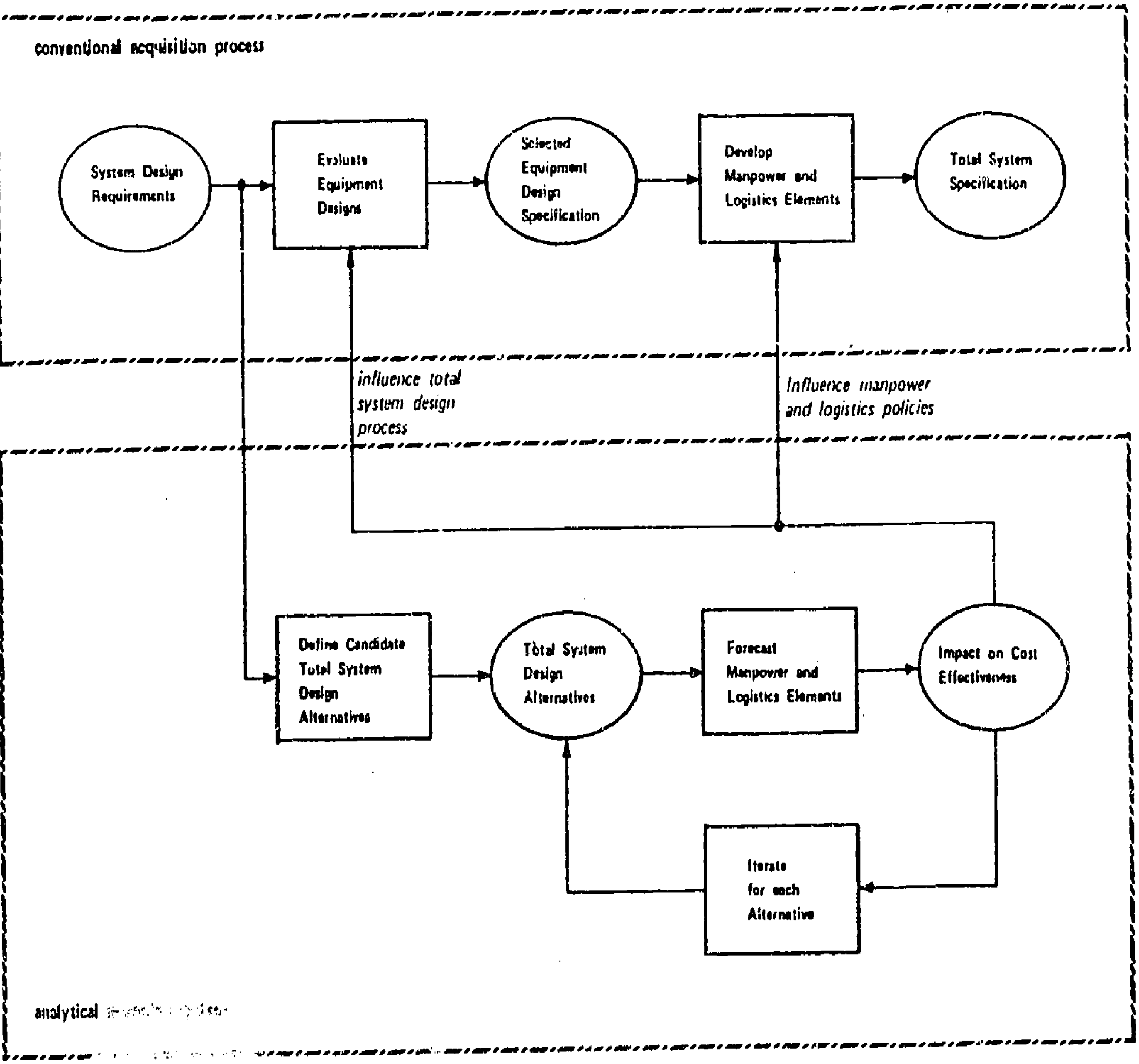

Figure 1.1 Augmentation of Acquisition System

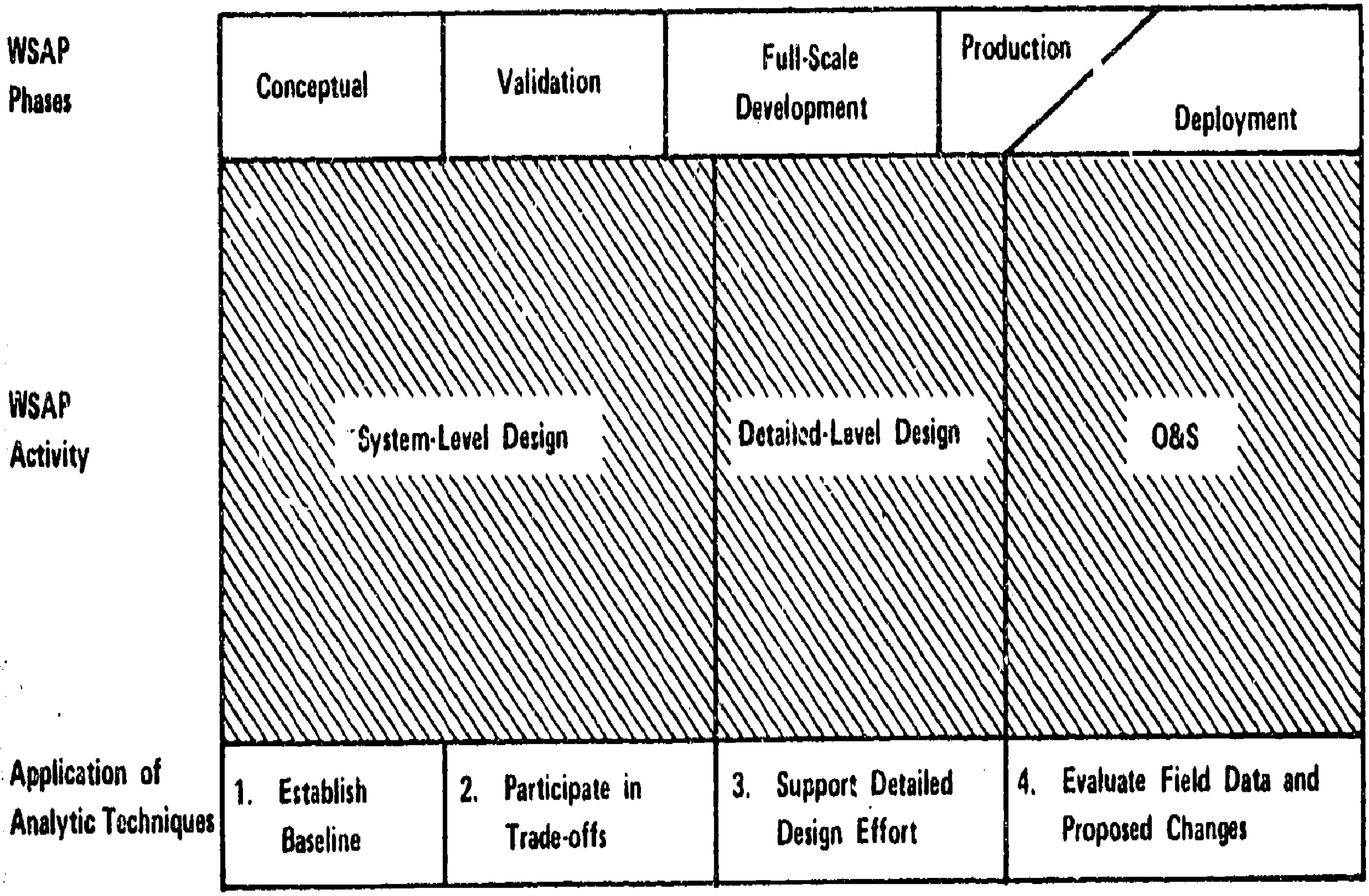

Figure 1.2 – Analytic Techniques and WSAP Relationship

As the weapon system design effort becomes more detailed during the Validation and Full Scale Development Phases, the LCCIM also would be valuable in supporting design/support planning optimization activities. Its utility would continue throughout the Production Phase and could also be significant in supporting the Operation and Support (O&S) activities of the Deployment Phase in the evaluation of candidate system modifications. Besides providing an analytic capability needed in the front end of the weapon system acquisition program, the LCCIM incorporates a data base concept which can serve as a nucleus in establishing a "single thread" data system linking all phases of the acquisition process. It would be "single thread" in that all acquisition, logistics, and support costs from conception to production and beyond would be maintained in a single continually updated data base.

The following section summarizes the development and operation of the LCCIM.

1.2 APPROACH

A literature search was conducted to determine the availability of LCC models which provide sufficient visibility into manpower and other logistics areas to allow for the ready identification of the "real" cost drivers. The search confirmed that hundreds of LCC models exist. Almost without exception, they apply cost factors to given resource utilization estimates, calculate the expected values of cost elements, and then aggregate the cost elements to determine total LCC. However, because they do not incorporate a comprehensive method for estimating the input values of resource utilization, outputs of these LCC models lack consistency and traceability. Lacking viable estimating techniques, users of these models must wait until detailed design activities are sufficiently completed to generate valid input data values. Furthermore, since these models are inadequate for use in direct conjunction with system level design activities, their application occurs after the basic system design is completed and lends little insight into the possibilities available for designing to effect cost avoidance.

A systematic approach was taken in developing the LCCIM modeling system. It proceeded as follows: (1) the objective function of the modeling system was stated at the highest level, (2) relationships between its input and output variables were defined, and (3) interactions between all its major variables were identified. The highest level objective function of the modeling system (depicted in Figure 1.3) is the use of LCCIM to make cost and effectiveness impact estimates a basis for selecting alternatives in system design to control manpower and logistics characteristics. The goal of that function is to minimize LCC subject to specifiable constraints such as equipment availability, equipment performance requirements, and the selected operational and logistic scenarios. The iterative application of this objective function (closing the loop in Figure 1.3) can effect the convergence of weapon system design, operation, and support planning activities to yield the most cost effective set of total system parameter values.

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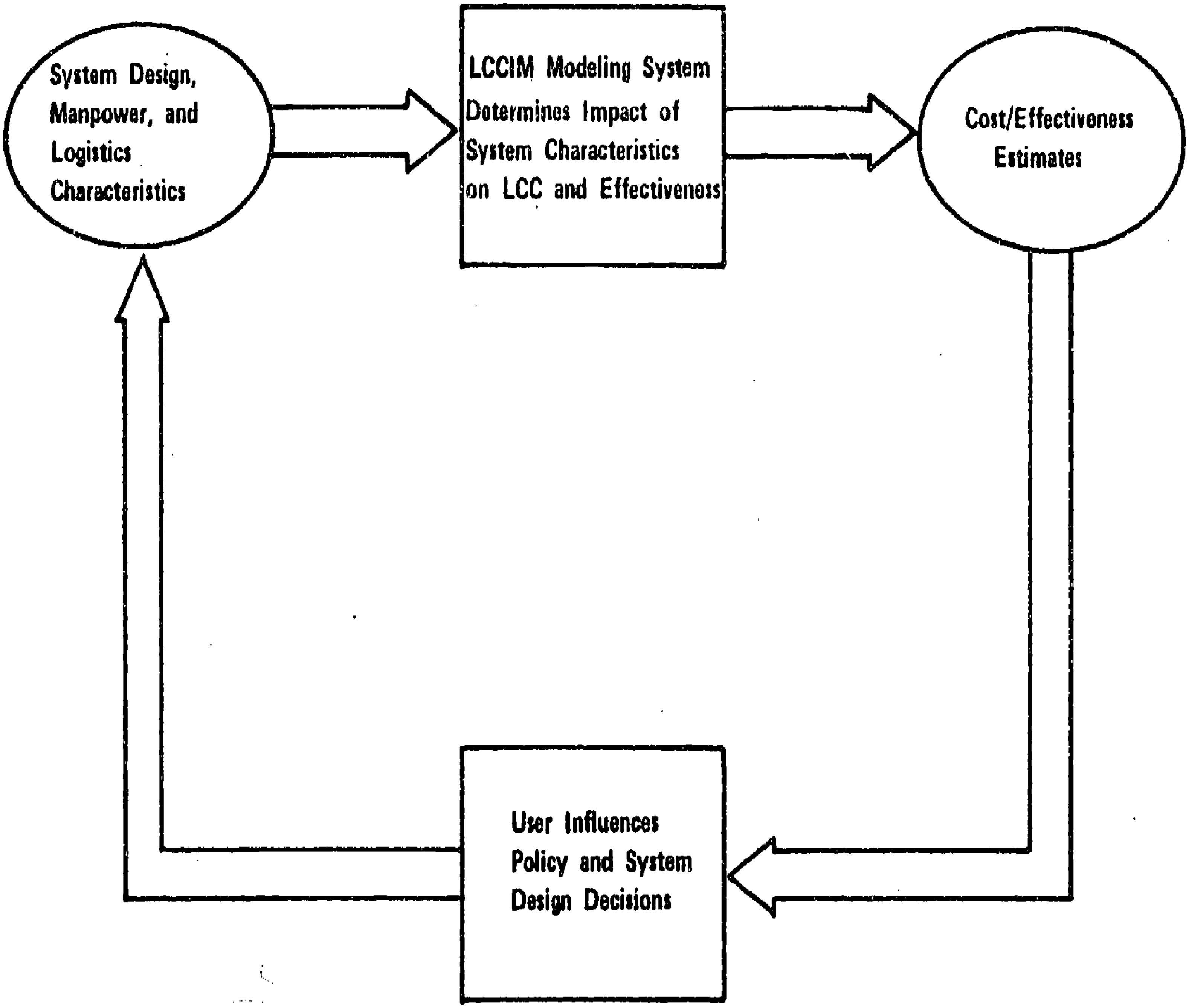

Figure 1.3 – User Interaction with LCCIM Modeling System

The components of the LCCIM modeling system are shown in Figure 1.4. Two of the five analyses are performed entirely by the user. The other three are accomplished with the aid of computerized models. The Reliability, Maintainability and Cost Model (RMCM) [8]* combines the Reliability and Maintainability (R&M) Model [1,2] with a cost model developed for that purpose. The LCCIM modeling system also includes a training model which is provided in a separate computer program called the Training Requirements Analysis Model (TRAMOD) [3,4]. While user interaction in the Functional and Maintenance Analysis is recognized as a necessity, the RMCM and TRAMOD models perform all the functions of these analyses that can be computerized. In addition to providing these computer programs, the LCCIM modeling system includes the procedures for generating inputs and interpreting outputs.

The analyses performed and models exercised in the LCCIM modeling system are depicted, in sequence, in Figure 1.5. The Functional Analysis of the Mission Element Need Statement (MENS) identifies a baseline set of equipment which can functionally satisfy the system mission requirements by employing a combination of existing and new technologies. Comparable equipment currently existing in the DoD inventory is selected as the reference for the baseline set of equipment. Operational and logistic scenarios to be used in the other analyses are also defined at this time to complete a set of given conditions for exercising the RMCM.

Networks are used in the Maintenance Analysis to depict the sequence of maintenance events necessary to maintain the weapon system, along with average values for the probability of occurrence and the resource utilization associated with each event. Resource utilization parameters include skill category, skill level, crew size, event duration, and support equipment required for each event. To generate baseline values for parameters in the maintenance networks, actual field data on the reference equipment is collected and modified to reflect the effect of known design differences in the proposed weapon system. In addition to accounting for design differences, network parameters are also modified to reflect anticipated changes in maintenance, manpower, training, and technical documentation concepts anticipated to result from the new design or be implemented with it.

The R&M Model aggregates resource (manhours, support equipment) utilization by line replaceable unit (LRU), subsytem, and system for use as input to the Cost Model. It also identifies drivers of high resource consumption and measures effectiveness in terms of equipment availability. Using existing courses as references. skill, and knowledge requirements for each maintenance event are simultaneously evaluated throughout the Training Model for the purpose of generating a baseline training program.

Finally, detailed cost factors are applied in the Cost Model to the resources used in performing tasks on the equipment and to the training programs which continuously replenish the complement of personnel

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*Numbers enclosed in brackets indicate references. A list of references is provided at the end of this volume.

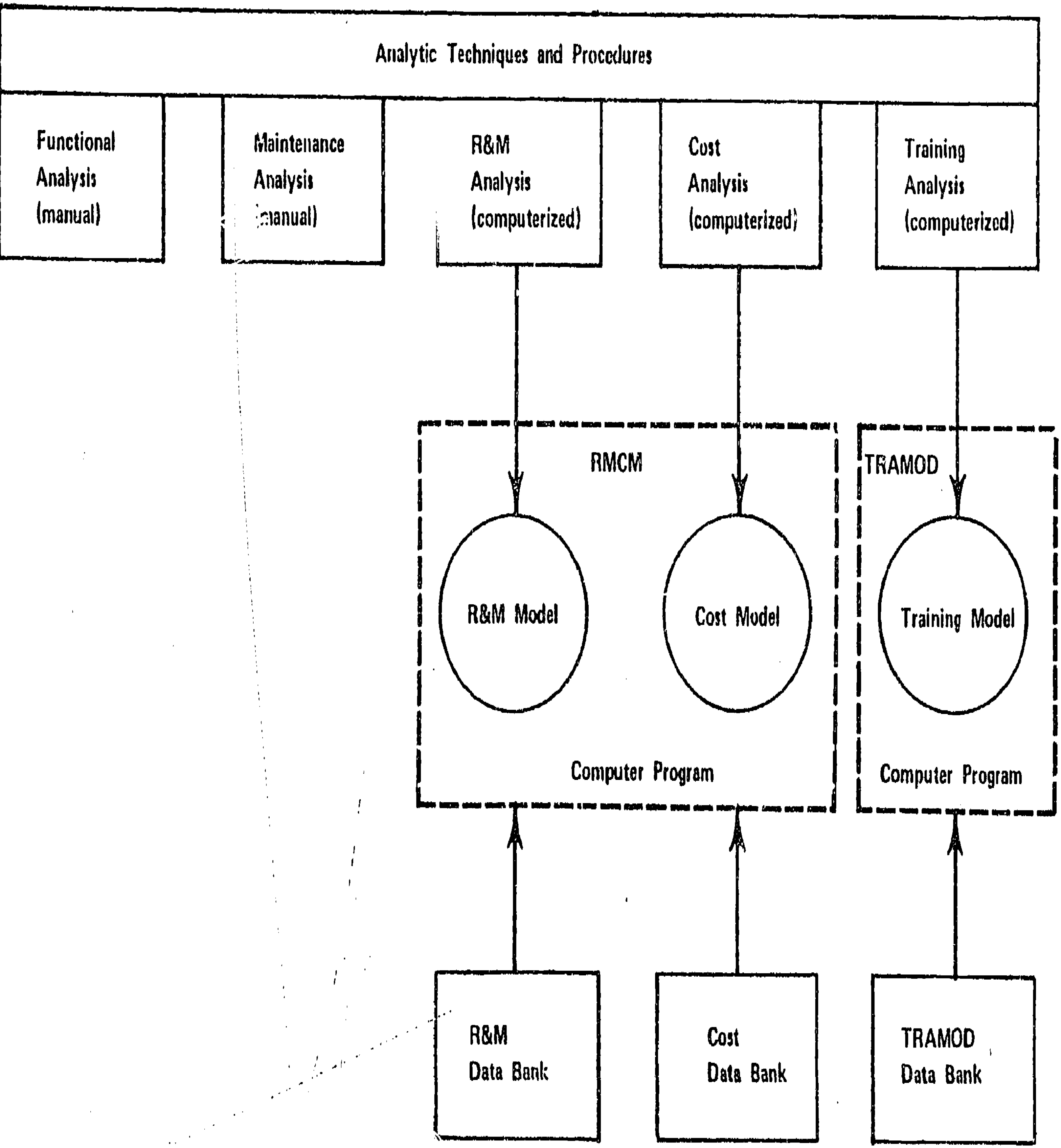


Figure 1.4 LCCIM MODELING SYSTEM

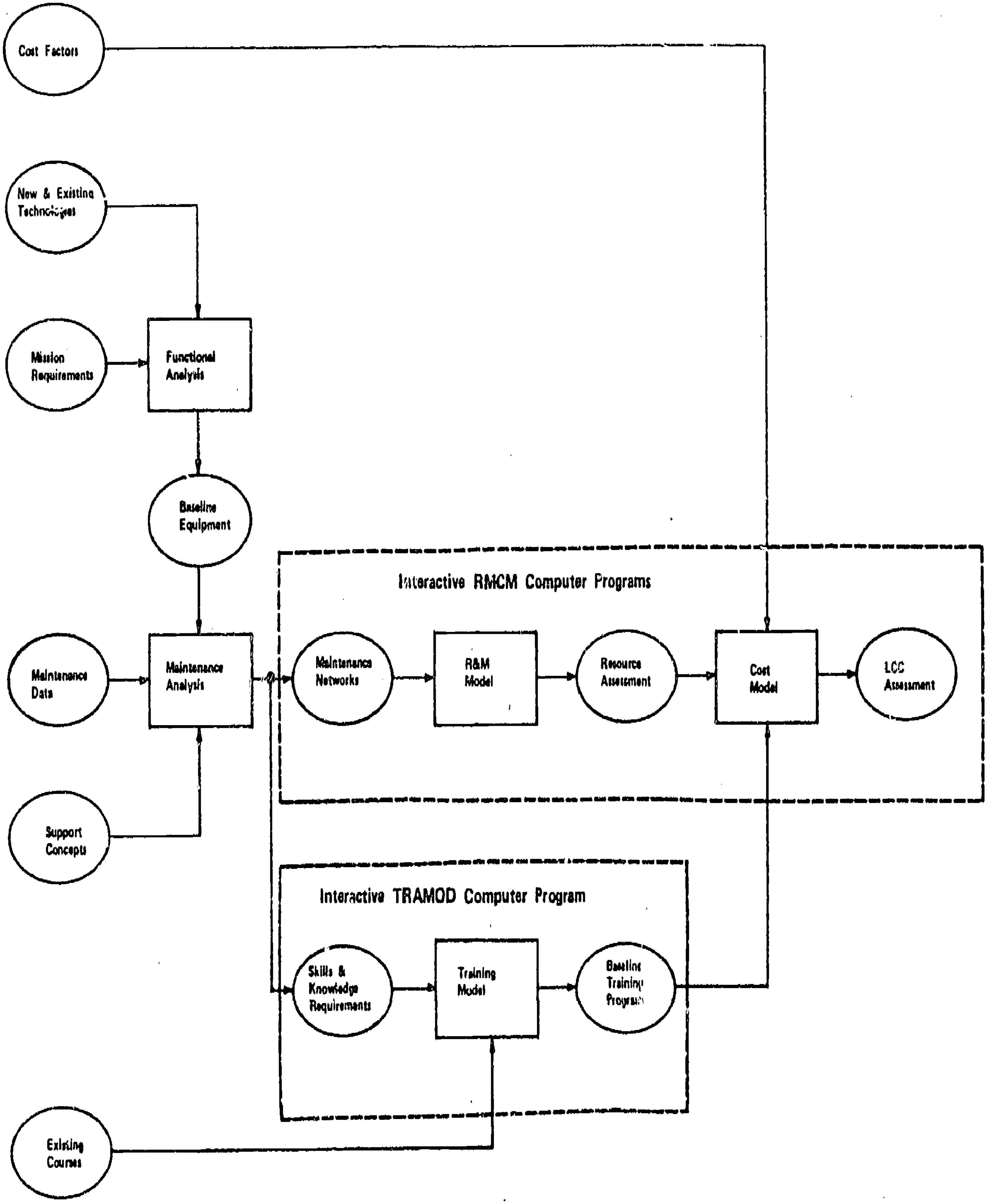


Figure 1.5 – LCCIM Modeling System Process

assigned to the weapon system. More general factors are then applied to other cost elements to produce a total life cycle cost estimate. The user can iteratively apply the LCCIM process in trade-off studies, sensitivity studies, or for results based on updates of the data base with either more refined design data on actual test data. The interactive design of the RMCM computer program allows the user to obtain instantaneous results on the computer terminal. However, some iterations may involve additional maintenance or training analysis to redefine resource requirements to be used in subsequent exercising of the RMCM computer program. There are also iterations that involve some additional functional analysis to redefine input parameter values in order to examine the effects of modifying the logistics concept in such areas as support equipment, level of repair, or central integrated test capability. The modeling system provides a broad spectrum of both analytical products and back-up data which can be presented in aggregate on detailed formats at user option. The kinds of information it affords and the flexibility of its application, operation, and outputs allow the user to support the weapon system acquisition process (WSAP) by providing more complete information for decision making.

II. APPLICATION

After describing, in the previous section, the general appro used in employing the LCCIM Modeling System, this section ad its application to the Digital Avionics Information System (DAI model/user interface can be best illustrated by describing a spe application. This will be accomplished by first describing hardw software design characteristics of DAIS. Then, the application o LCCIM Modeling System to DAIS will be described in the sequence in which the models were used and the analyses were applied.

STEP 1 Perform Functional Analysis
STEP 2 Perform Maintenance Analysis
STEP 3 Exercise TRAMOD Computer Program
STEP 4 Exercise RMCM Computer Program

2.1 DAIS CHARACTERISTICS

The designer of military avionics systems has been confronted with an extremely difficult task in recent years. Rapid advances in technology have placed an increasing premium on both capability and flexibility. Simultaneously, cost pressures from increased system complexity, higher maintenance expense, and general economic inflation have forced the designer to address the LCC of avionics systems. Historically, information processing design requirements have been established autonomously for each subsystem. Human resources and training requirements were often considered after the fact. The result was a proliferation of nonstandard avionics equipment, and a design process that fails to satisfy mission needs at an affordable cost.

The Digital Avionics Information System (DAIS) concept offers a potential solution to the proliferation of nonstandard aircraft avionics equipment. The DAIS concept is capable of producing significant reductions in avionics operation and support cost because it includes: (1) an ability to modify software to meet new requirements; (2) the potential for improved reliability through the planned use of redundancy at subsystem, equipment, and component levels; (3) the opportunity for adding new sensors and capabilities to the system without rewiring the aircraft; and (4) an effective means for using modular or common equipment design on different types of aircraft.

To capitalize on this potential, the U.S. Air Force (USAF) established, in July 1973, a DAIS Advanced Development Program at the Air Force Avionics Laboratory (AFAL). The objectives of the program are to demonstrate the DAIS concept on a functional basis and to develop: (1) an in-house cadre of skilled personnel who can perform preliminary design tasks and prepare specifications; and, (2) standards and techniques for the four common, or core elements of all avionics systems, namely the multiplex systems, processors, controls and displays, and software.

The basic configuration selected by AFAL for development consists of several identical processors communicating with one another and the other elements of the system on a time-division multiplex line in a so-called federated configuration. Bus Control Interface Units (BCIU) connect the processors to the multiplex lines. Remote terminal units (RTU) connect the sensors to the multiplex bus. The multiplex bus, the BCIUs, and the RTUs constitute this multiplex core element. A group of units such as displays and keyboards constitute the controls and displays core elements. The programs of the software core element are loaded into the individual processors on the on-board storage unit.

The DAIS effort also recognizes that the software element plays a key integrating role with a significant potential impact on life cycle costs. Current Air Force software expenditures exceed computer hardware expenditures and, therefore, have supplied one of the motivations for the development of the DAIS system. DAIS mission software uses a higher order language (JOVIAL) which is expected to have a beneficial cost-effective impact on development and maintenance of the software. A highly modular architecture is used so that minimal reprogramming is required for any mission-to-mission reconfiguration. Furthermore, these software modules can be changed as readily as the hardware using its' plug-in/plug-out design concept.

The basic design concepts established for the DAIS can be applied to any weapons system. However, before the maintenance, logistics, and life cycle costs can be estimated for such a concept, even after a configuration has been proposed, it is necessary to define the platform which will carry it with its mission and support scenario. A close-air-support mission using an avionics suite comparable to the A-7D aircraft was chosen for the DAIS analysis

2.2 MODELS AND ANALYTICAL APPLICATIONS

This section provides a description of the sequence in which the models and analyses were applied.

STEP 1: Perform Functional Analysis

Based on the characteristics of both new and existing technologies, the Functional Analysis of the avionics requirements for a close-air-support (CAS) mission resulted in the development of three conceptual avionics design configurations [5].

- Conventional (NonDAIS) Avionics
- Current DAIS
- Mid-1980s DAIS

Current DAIS serves only as an intermediate configuration in developing a baseline DAIS for the mid-1980s using conventional avionics as a reference.

The conventional avionics suite consists of equipment selected from the present Air Force inventory to serve as reference subsystems. A current DAIS configuration was then developed by physically partitioning the line replaceable units (LRUs) of a subsystem into two categories: core or sensor. Functions performed by some LRUs of a conventional subsystem are taken over by DAIS core elements such as the processor or the integrated controls and displays. Sensor LRUs of the subsystems remain unchanged by incorporation of the DAIS architecture. From this current DAIS configuration, a mid-1980s DAIS configuration was postulated as the baseline system. Advanced technology projections, such as a central integrated test system and consolidated support equipment, were considered in addition to further partitioning of LRU functions that could be accomplished by core elements in the mid-1980s.

Data on the reference subsystems were collected, recorded, and cross-checked between sources wherever possible. Reliability, maintainability, training, and cost data of existing avionics subsystems that were identical, or at least similar to those chosen as the baseline provided the most accurate inputs. These included subsystems flown in the A-7D, A-7E, F-15, A-10, F-14, and F-1 1 aircraft. Data sources included the Air Force AFM66-1 maintenance data collection (MDC) systems, the Navy 3M MDC system, equipment specifications, occupational survey reports, training plan outlines, and discussions with Air Force and contractor personnel. Other documents describe, in detail, this phase of the process [6]. The historical maintenance data collected for the reference subsystems are included in data banks [14] that provide inputs to the Maintenance Analysis.

A hierarchical structure is used within the data base to designate equipment identified through the functional analysis. The levels in the hieararchy in decreasing order consist of system, functional group, operational function, subsystem, and LRU. A coding system was used so that equipment at any one of these levels can be rapidly located and indexed without ambiguity. Figure 2.1 illustrates this hierarchical structure where, by showing a portion of the equipment as an example, the highest indenture-level denotes system and is coded A (for avionics) in the first space of the code designation. The functional group (such as communications) is coded in the second space (A<u>C</u>), and so on. These identification codes established a common reference for identifying all the equipment data for input into the data base.

STEP 2: Perform Maintenance Analysis

A network representation is used in the Maintenance Analysis to describe the possible maintenance events that result whenever there is an indication that a particular subsystem has malfunctioned and requires a maintenance action. A generalized example of this basic network is shown in Figure 2.2.

Maintenance activity is modeled in terms of on- and off-equipment events. On-equipment pertains to organizational level maintenance performed on the entire subsystem and keeps that particular weapon system off alert.

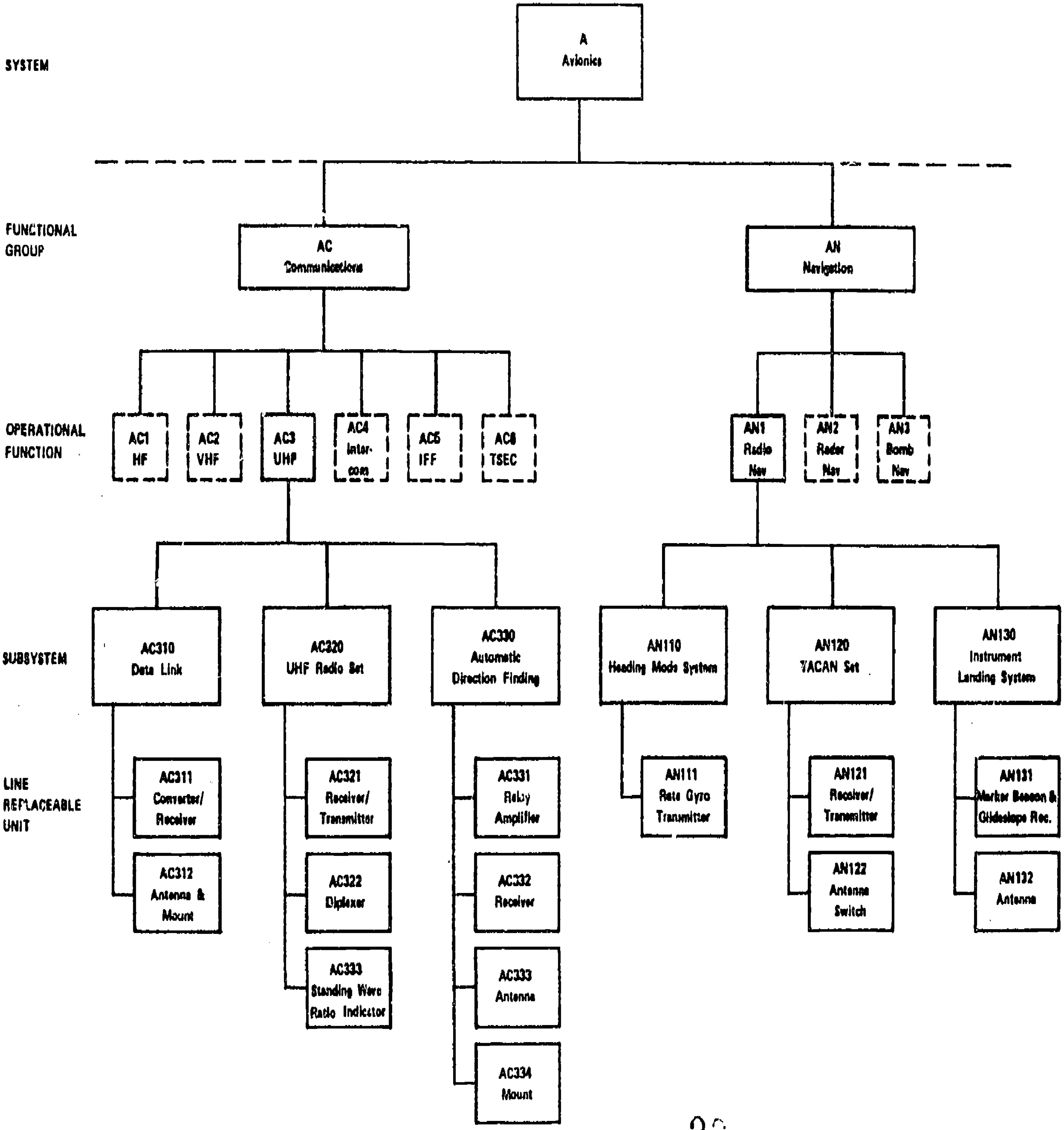


Figure 2.1 – Equipment Hierarchy Structure for the Example Run

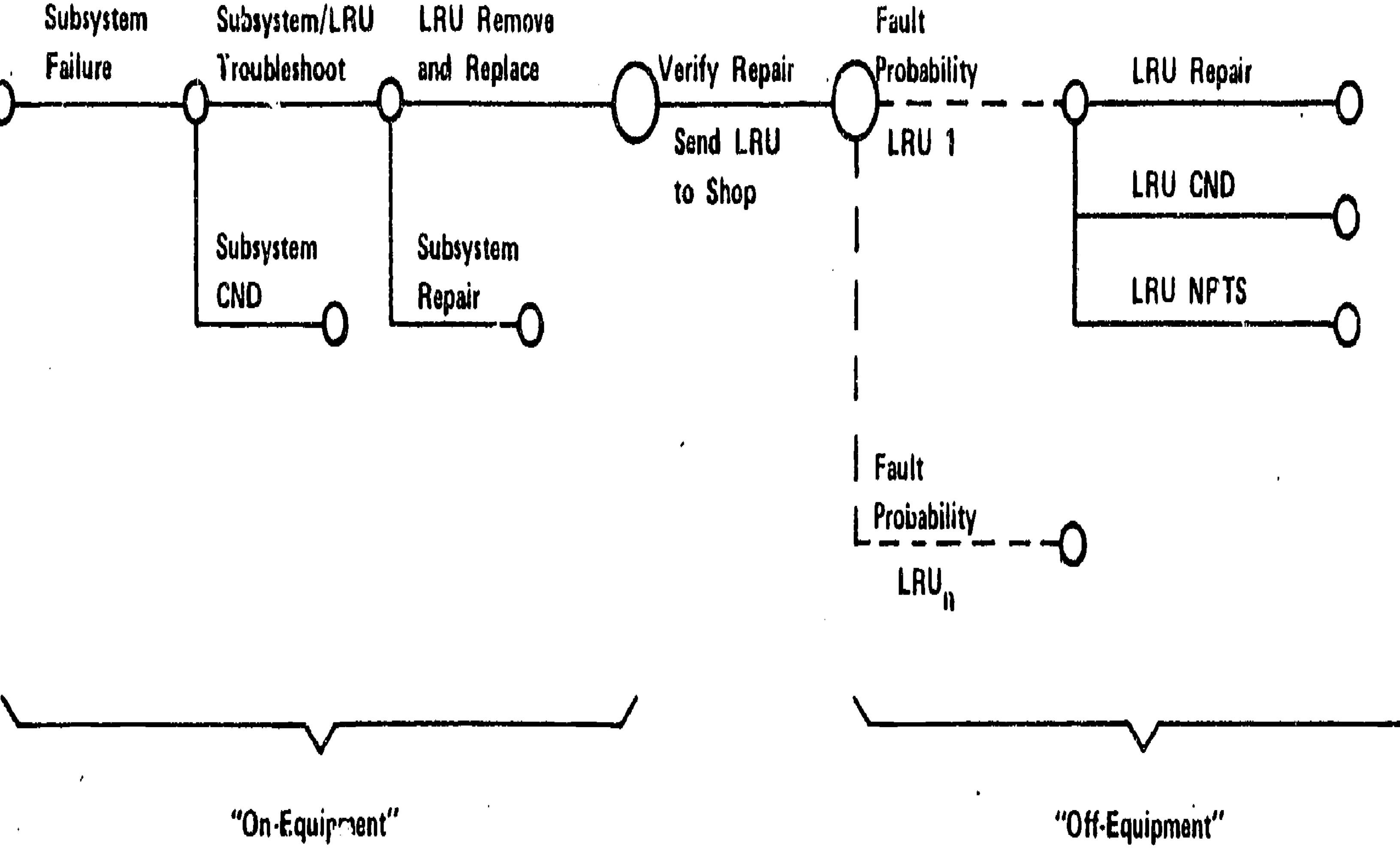


Figure 2.2 – Basic Maintenance Network

Off-equipment refers to intermediate level maintenance on particular LRUs. A maintenance action is initiated by a discrepancy report or indication on the part of the aircrew or maintenance personnel that a malfunction exists. It is important that the network account for all maintenance regardless of whether this malfunction indication is due to an actual failure or a human (or equipment) error, which will later result in a "cannot duplicate discrepancy" (CND), since both result in a demand for maintenance resources. Subsystem failure frequency (maintenance action rate) is based on all discrepancy reports which trigger subsequent maintenance events on the flight line. The possible flight line maintenance events are listed below.

- Set up flight line support equipment (SE)
- Troubleshooting
- Troubleshooting, cannot duplicate discrepancy
- Remove and replace
- Minor repair
- Verify replacement correcting discrepancy
- Verify minor repair correcting discrepancy

The network treats the above as generic maintenance events consisting of one or more maintenance functions (such as adjust, align, calibrate, troubleshoot, inspect, operate, remove/install, repair, and service). Hence, support resources associated with each maintenance function are aggregated at the event level. Although not fine-grained, this representation is: (1) sufficient for the purpose of assessing support requirements in the WSAP, and (2) practical when considering the fact that detailed-level information is not available during that time period.

The initial maintenance event in the network is setting up the necessary test equipment and power sources at the flight line and exercising the subsystem that had a malfunction indication. If a failure had occurred, a troubleshooting event will take place 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. In terms of the utilization of maintenance resources, it is necessary that the probabilities of these alternative events be determined. Furthermore, since the events are mutually exclusive, the sum of the probabilities of this pair of parallel events will equal unity.

Each branch of off-equipment maintenance in the network indicates the probable entry of that LRU into the shop maintenance activity. The possible maintenance events that can be conducted in the shop are:

- LRU bench check and repair
- LRU bench check and find serviceable (shop CND)
- LRU not repairable this station (NRTS)

The LRU bench check and repair encompasses troubleshooting which detects a malfunction in that LRU and the subsequent part replacement, calibration, or adjustment necessary to bring the LRU back to a fully operational status. The shop CND results when the fault isolation at the flight line incorrectly leads to the wrong LRU being sent to the shop. 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).

The maintenance network serves to identify the possible maintenance outcomes associated with a subsystem or LRU malfunction indication. Support resources required per event 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. Average demand on maintenance can be computed 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.

Resource data associated with the networks are stored in the computerized data base in a matrix format. Each maintenance network parameter used in characterizing resource utilization has its own matrix. Information in this matrix format can be readily combined to aggregate resource utilization across equipment, tasks, or skill categories. Examples of these matrices, inputs, and outputs are provided in other available documents [2]. In addition to the matrices that contain data pertinent to the maintenance networks, the data base contains the skill and knowledge data needed for the Training Model and the cost factors to be used in the Cost Model.

The Maintenance Analysis continues by modifying parameter values in the reference networks to reflect the effect of anticipated design, manpower, and training changes for the baseline [7]. This theoretical information, in the form of baseline networks, is then placed in the R&M data bank [15] with any appropriate modifications to the training and cost data banks [13,16].

The generation of baseline data for use in the RMCM would be a difficult task if values were to be forecasted in an absolute sense. Instead, to attain sufficient accuracy, baseline values are estimated on a relative basis by evaluating the impact of any design differences between the reference and baseline subsystem, as shown in both block diagram and equation form in Figure 2.3.

This procedure is used to establish a baseline value for each manpower, logistic, training, or cost parameter in the RMCM. Wherever there are differences in design characteristics between the reference and baseline configurations, the impact on each RMCM parameter is quantified by using evaluation guidelines that provide a logical basis for decisions regarding the generation of baseline data from reference data. The DAIS analysis guidelines are listed below.

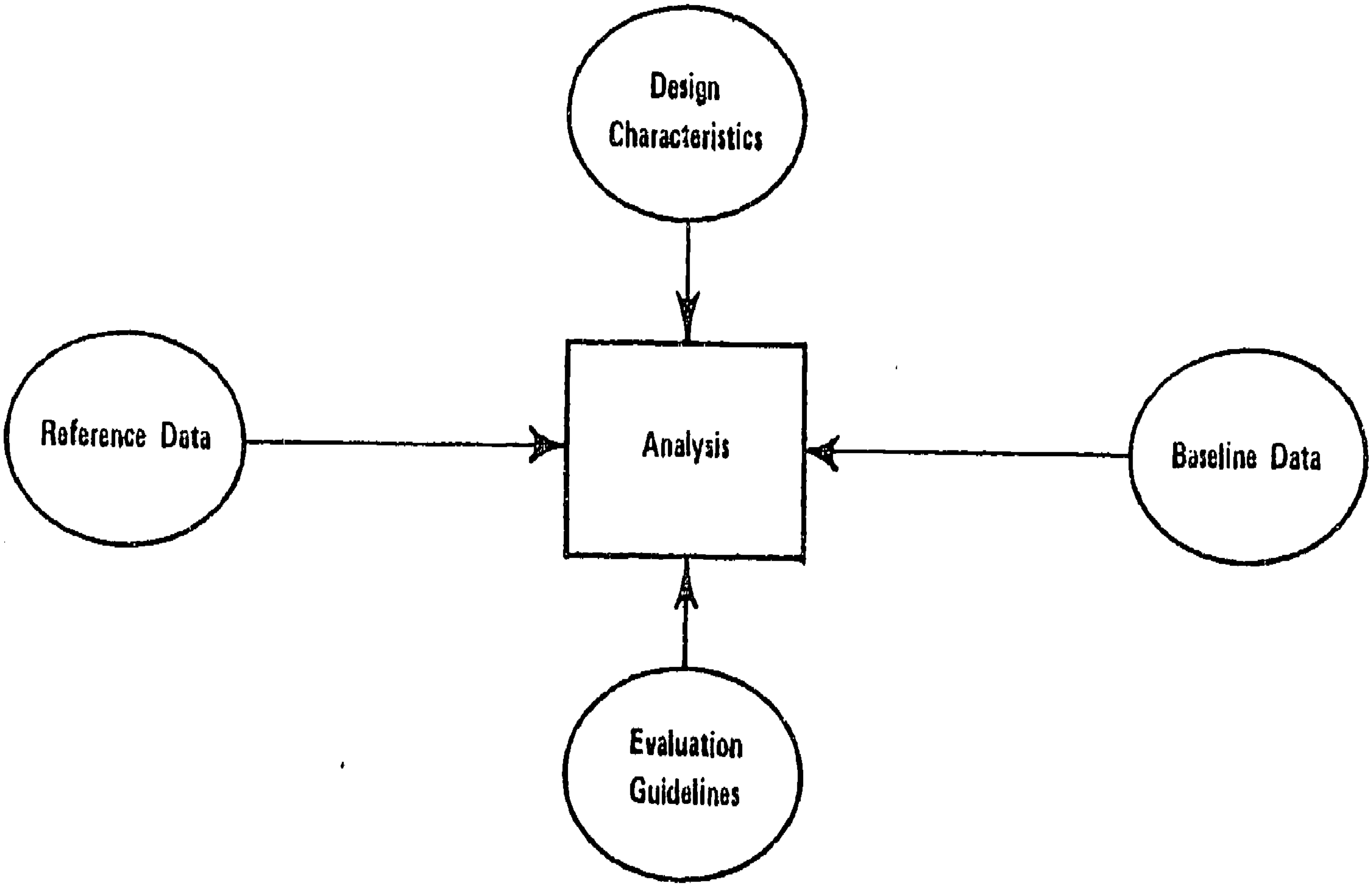
- There is no change in the equipment configuration of any sensor with the exception that most control, display, and interface units are assigned to the core. The core elements of the DAIS architecture consist of the multiplex bus and interface units, processors, integrated controls and displays, and the software. Therefore, computational devices such as navigation, mission, and bombing computers or processors were also assigned to the core. The appropriate RMCM model parameters were adjusted to account for this transfer of functions.

- Controls, displays, and processors are integrated as much as is feasible and consistent with the DAIS architecture. Additional software is assumed to exist to aid in integration and reduce redundant hardware within the core equipment.

- Minor analog-to-digital and digital-to-analog redesigns have been postulated to permit a sensor/core interface. This interface is the function of the RTUs and does not affect the sensors.

- The DAIS design lends itself to the inclusion of a Central Integrated Test System (CITS) to isolate malfunctioning LRUs on the flight line. CITS results in an improved built-in test (BIT) capability which reduces the number of occurrences of cannot duplicate discrepancies (CND) both on the flight line and in the shop.

- DAIS avionics support equipment differs from that for non-DAIS in the number of tests it can perform and the accuracy of these tests. The mean time to repair (MTTR) times per task at the LRU level are considered to remain the same for both DAIS and non-DAIS airmen. However, there are some reductions that are made in crew sizes because troubleshooting is facilitated by the use of CITS and the automatic test stations.



a. General Block Diagram Form

$$\left[\begin{array}{l}\text{Baseline}\\\text{Parameter}\\\text{Value}\end{array}\right] = \left[\begin{array}{l}\text{Reference}\\\text{Parameter}\\\text{Value}\end{array}\right] + \left[\begin{array}{l}\text{Impact on}\\\text{Parameter by}\\\text{Design}\\\text{Characteristic}\end{array}\right] \bullet \left[\begin{array}{l}\text{Difference}\\\text{in Design}\\\text{Characteristic}\end{array}\right]$$

b. General Equation Form

Figure 2.3 Generation of Baseline Data

- Maintenance technicians for DAIS are assigned to either the flight line or shop. This approach is made possible because of the BIT/CITS capabilities at the flight line and the test station capabilities in the shop. Training one to three AFSCs to perform all flight line tasks and similarly training six different AFSCs to perform shop tasks on each of the six test stations reduces the training of extraneous information and thereby reduces overall training times.

- Training for personnel is to be limited to "need to know" subjects. For example, assume that the test stations are capable of isolating malfunctions at the functional or modular level. If the LRUs for a subsystem are repaired mainly by removing-and-replacing the shop replaceable units (SRUs), it is likely that the technician need not receive the in-depth training in "knowledge of electronic principles" which constitutes a major portion of the current course curriculum. Each course was tailored to the tasks demanded of an AFSC assigned to maintain particular subsystems for both DAIS and non-DAIS configurations.

These ground rules were used in the synthesizing process of developing the DAIS data bank from the non-DAIS avionics data banks. This process entailed analyzing the failure and maintenance histories for each LRU. Where failure modes had been altered, replaced, or abolished as the result of the reconfiguration of the hardware, new values were calculated for the resulting reliability (such as mean flight hours between maintenance actions) and maintainability (such as mean time to repair, maintenance event probability of occurrence, manpower, and SE requirement) parameters. The details of the method used to calculate these R&M values are described in other documents [6,10,11]. The R&M values developed for each configuration were stored in computerized data banks to serve as inputs to the RMCM.

STEP 3: Exercise TRAMOD Computer Program.

Once the effect upon R&M characteristics of the DAIS design was determined, the corresponding influences upon maintenance personnel training requirements were analyzed. The same system design guidelines established for the maintenance analysis were also applied to training. The length and cost of existing courses were used as reference data.

Skill and knowledge requirements were provided as input to TRAMOD in the form of an equipment/behavior matrix. Historical and theoretical training data banks [12,13] were generated for the Conventional Avionics and DAIS configuration, respectively. All candidate activities to be trained were assigned values for five characteristics: (1) criticality, (2) frequency, (3) learning difficulty, (4) taxonomic grouping and level (cognitive and psychomotor), and (5) nesting (a parameter used to collate tasks that are best taught as a group). The total set of tasks were screened, as shown in Figure 2.4, according to a user-defined selection criterion.

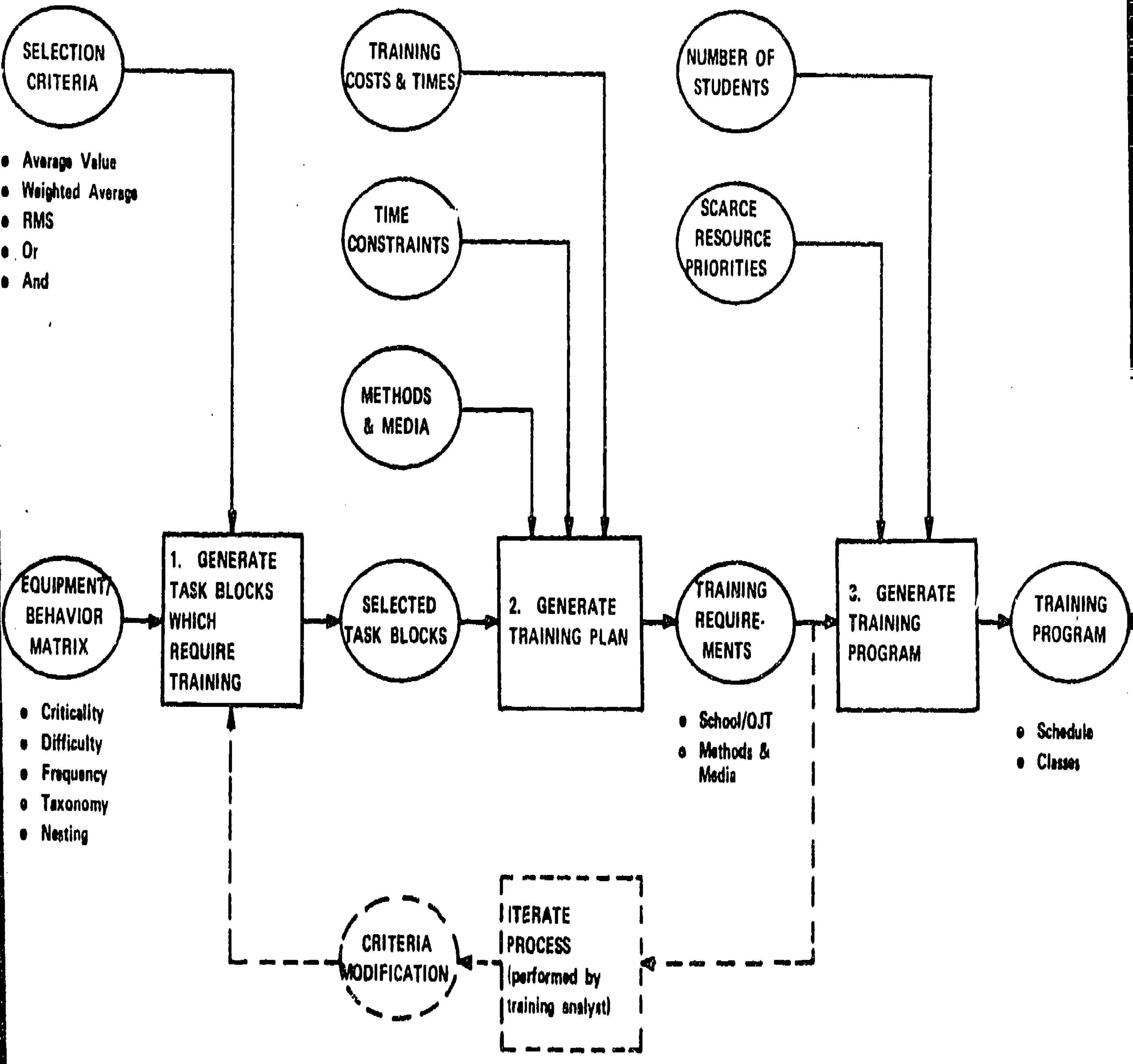


Figure 2.4 -- Training Requirements Analysis Model

A training plan was generated for the selected task blocks, subject to constraints of maximum allowable training cost and time. The plan provided: (1) the mix of formal school and on-the-job training (OJT) for the task blocks to be trained that minimizes cost; and (2) recommendations concerning methods and media. After reviewing the training plan, the user exercised TRAMOD in an iterative mode, modifying selection criteria, until all training requirements were satisfied and a training program could be generated. Course lengths and cost estimates were then provided as input to the RMCM.

STEP 4: Exercise RMCM Computer Program

The RMCM computer program, in conjunction with suitable input data banks, assesses the LCC impacts of various design, support, and training alternatives. The R&M data contained in the previously described maintenance networks and the cost data banks comprise the entire set of RMCM input data. Cost data banks were generated for the "historical" conventional avionics and the "theoretical" DAIS configurations. The following types of data are contained in these cost data banks.

- Recurring cost elements
- Nonrecurring cost elements
- Line replaceable unit (LRU) data
- Subsystem data
- Support equipment data
- Depot support equipment data
- Aircrew data
- Personnel training data, by AFSC
- On-Off equipment data, by AFSC
- Single-value variables for use in various equations

The hierarchy of cost elements used to compute total LCC is shown in Figure 2.5.

The functional flow diagram shown in Figure 2.6 provides an overview of the RMCM program operation. The R&M and cost data files, shown as card images in Figure 2.6, are used as direct input to the RMCM. Operable in either an interactive or batch processing mode, the model performs five principal functions.

1) Compute R&M parameter values based on the reliability and maintainability characteristics of the subsystems included in the R&M model data bank(s).
2) Compute operation and support costs, as well as LCC using cost and R&M inputs.
3) Perturb the values included in the (a) R&M and/or (b) cost inputs for sensitivity and trade-off analyses.
4) Provide terminal display of selected outputs computed for the before-and-after perturbation values, as well as the percent change in value.
5) Provide selective batch print output reports of the R&M and the Cost Model portions of the RMCM.

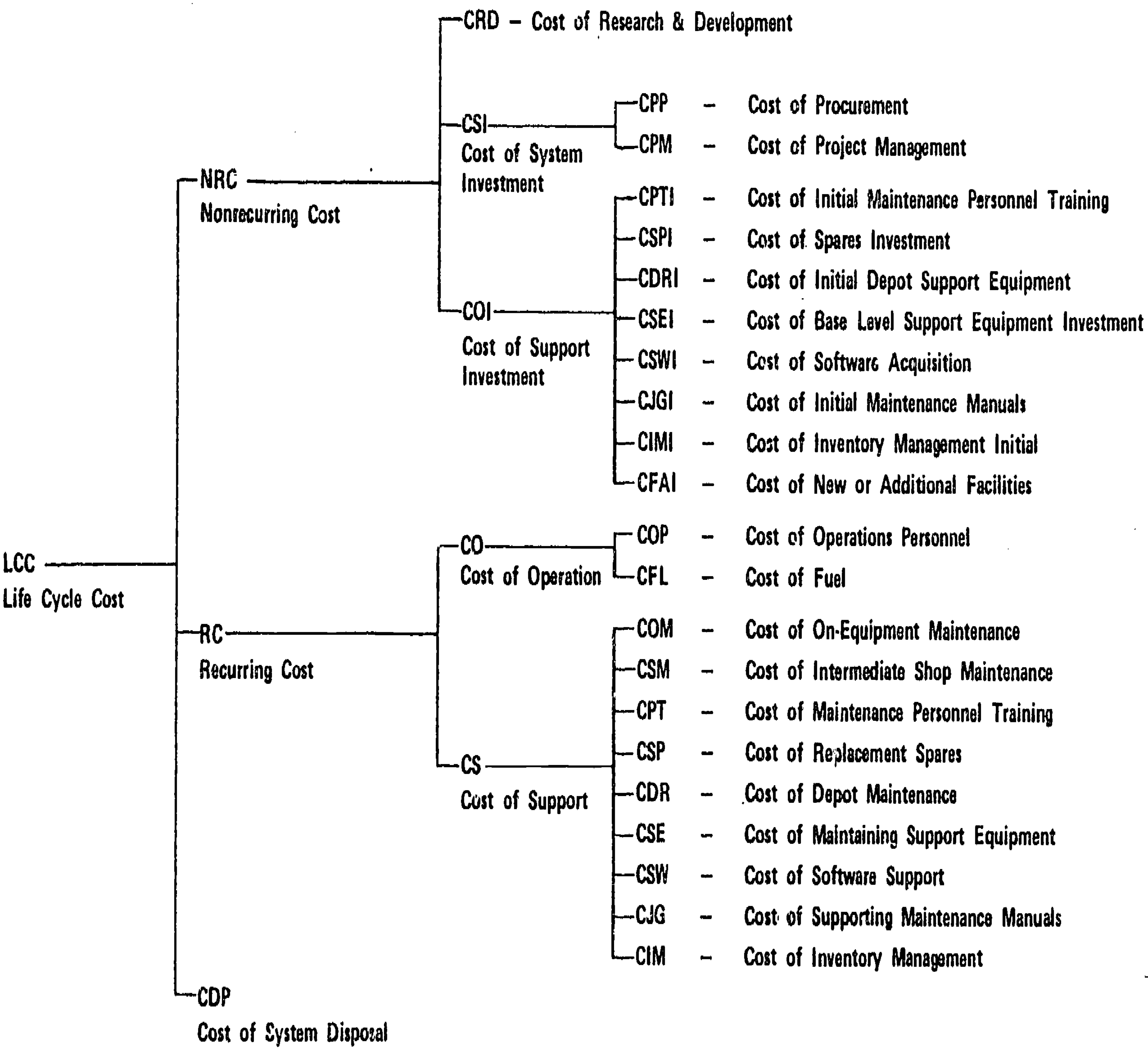


Figure 2.5 – Life Cycle Cost Hierarchy

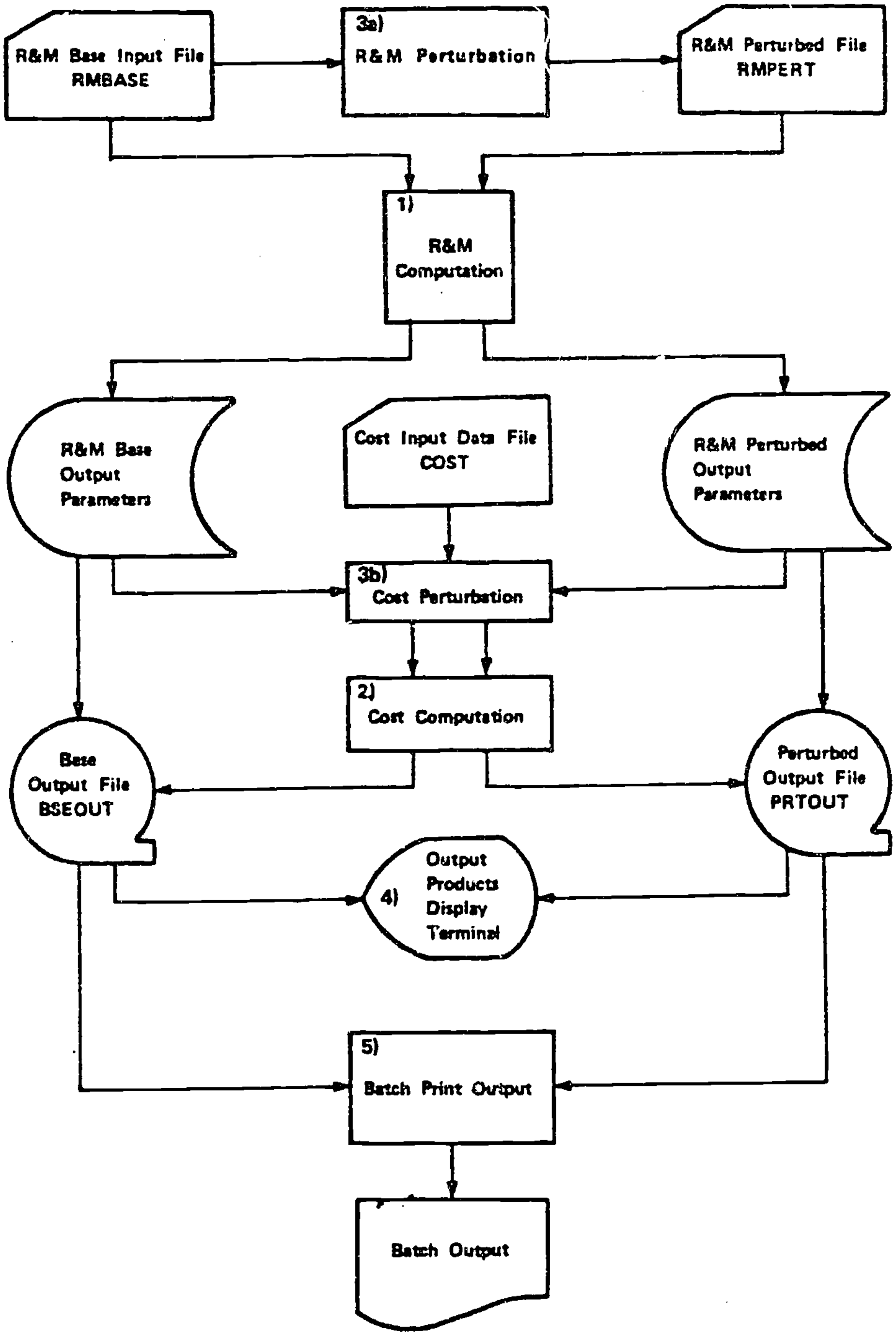


Figure 2.6 — RMCM Functional Flow Diagram: R&M & Cost Perturbations

The RMCM computer program can effectively be used for systematic manpower, training, and cost assessments, as well as sensitivity and trade-off studies of alternative designs. Examples of using the RMCM to evaluate design alternatives are provided in other available documents [10,11] where the LCC impact of retrofit and standardization are compared for both DAIS and non-DAIS configurations. Model outputs are presented in formats which provide general (top down) and detailed (bottom up) perspectives, as well as visibility at intermediate levels of system cost and resource impact assessment.

Batch mode output reports available from the R&M and cost models of the RMCM are listed in Tables 2.1 and 2.2, respectively. These reports provide the data needed to perform a detailed comparative analysis of complex systems involving many parameters. Such outputs make it possible to study parameter interactions and generate printouts of runs made in the interactive model.

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 a percentage of the total MTTR for that subsystem.
3. Maintenance manhours (MMH) by task event per subsystem and its associated LRUs.
4. MMH by task event per subsystem and LRU as a percentage of the 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).

Table 2.1 - R&M Model Batch Mode Output Reports

1. System Cost Total system level costs and their percent contribution to the LCC are displayed for the original input data set, the perturbation, and their difference in terms of recurring, nonrecurring, and disposal cost categories.
2. Expanded Nonrecurring Costs The nonrecurring cost data from Report #1 is broken out by its basic cost elements in three categories: (1) research and development, (2) system investment, and (3) support investment costs (lump sum recurring and disposal costs are included). Percent contribution of each cost element to the LCC is provided with any difference between the original and the perturbed values.

Table 2.2 - RMCM Batch Program Output Reports

3. Expanded Recurring Costs The recurring cost data from Report #1 is broken out by its basic cost elements in two categories: cost of operation and cost of support (lump sum nonrecurring and disposal costs are included). Percent contribution of each cost element to the LCC is provided with any difference between its original and perturbed values.

4. Costs by Subsytem Contributions Values for the recurring cost elements per year and the nonrecurring cost elements are itemized as a function of each subsystem contribution and include each item percent of the total cost.

5. Cost by LRU Contributions Values for the recurring cost elements per year and the nonrecurring cost elements are itemized by each LRU's contribution, including each item percent of the total cost.

6. Reliability, Maintainabaility, and Availability by Subsystem Values are provided for the following principal parameters by subsystem identification code (ID) for both flight line and shop task totals: mean flight hours between maintenance actions (MFHBMA); mean time to repair (MTTR); MTTR per 1000 flight hours; maintenance manhours per 1000 flight hours (MMH/KFH); inherent availability; and, subsystem life cycle cost contribution.

7. Manhour Costs per Year by AFSCs and Subsystems Supported One output for each AFSC is generated by this report with the following output parameters itemized by subsystem: direct MMH/FH for flight line and shop; total labor for flight line and shop; and, the total cost for that total labor.

8a. Spares Requirements--Investment The principal parameters provided by this report, by LRU, are: the average number of spare LRUs and SRUs required per base for the shop and depot; unit prices for those LRUs and average price of the SRUs; and, total cost of LRU and SRU spares.

8b. Spares Requirements per Year--Replacement The output provided by this report includes the principal parameters needed to determine the annual replacement spares requirements determined as a function of the NRTS probability and the condemnation rate. This report provides values for LRU and SRU spares, including their units costs and total spares cost.

9. Support Equipment Requirements/Cost This reports the initial investment and replacement costs for SE test stations. The parameters influencing these costs are itemized by type of shop support equipment (SE). The values provided include: test station demand and repair

Table 2.2 - RMCM Batch Program Output Reports (continued)

9. (continued)
time, utilization rate, and quantity of each station required per base and their unit cost. Also displayed are costs for initial SE spares; interconnecting hardware and software if existing stations are used; and, other base level SE costs.

10. <u>Cost of Training</u> The principal parameters displayed by AFSC in this report, by AFSC, are: length of course, cost of technical training schools and on-the-job training per person, average manpower requirements, turnover rates, and the resultant total training cost per AFSC.

Table 2.2 - RMCM Batch Program Output Reports (concluded)

The interactive mode, with its capability of perturbing R&M and cost factors, makes it possible to immediately note impacts for use when performing sensitivity and trade-off analyses on an on-line basis. The RMCM Users Guide [8], provides detailed explanations of its interactive capabilities.

III. CONCLUSION

The objective of this contract effort was to provide the Air Force with an in-house capability of assessing the life cycle cost impact of weapon system design alternatives. The product that resulted was the LCCIM modeling sytem which consists of computer programs and the analyses which the user must perform to generate input data. The modeling system includes a Functional Analysis and a Maintenance Analysis which generate the data banks used in exercising the RMCM and TRAMOD computer programs. The programs perform operations, independently or jointly, in a batch processing mode or interactively on a remote terminal. An interactive program to perform the training analysis is also available. With interactive capabilities and outputs which readily identify the driving inputs, the programs serve as powerful tools for trade-off purposes.

The systems approach employed in the modeling system consists of a structured process which provides for the efficient use of available information. That process recognizes the incompleteness and inexactness of the data existing during the Conceptual Phase of the WSAP which must be used to forecast outyear resource utilization and cost. Within this structured process, a statement of the basic need for the weapon system leads to the identification of the most comparable reference system. Modification of reference data to reflect technological advances, and advanced operation and support concepts produces baseline input data used to determine resource utilization in terms of man and machine requirements.

The modeling system provides powerful analytical techniques particularly suited for an investigative role in determining the design and support of systems to achieve essential capabilities at an affordable cost. This is true throughout a system life cycle, from conception to and including outyear modification. A "strawman" representation of the human reosurces requirements early in the WSAP significantly improves communication between the design, manpower, and training communities.

Output data can be examined at various levels of detail to identify dominant resource and cost drivers. Sensitivity analyses can be conducted within the modeling system to measure the effect of interrelationships among model parameters. As detailed system definition data become available, the modeling system transitions from its impact assessment mode of operation to one which enables the detailed analysis of system cost and requirements. Thus, the trade-off process can be followed to completion in comparing major system alternatives and in making a series of gradual parameter changes that lead to a set of design or support planning characteristics best satisfying the basic need at an affordable cost.

The analytic techniques described in this report have been incorporated into the AFHRL Project 1959 methodology, "Coordinated Human Resource Technology" [9]. This methodology describes the procedures required to insure that manpower, personnel, and training considerations are taken into account during all phases of the Weapon System Acquisition Process. Some of these analytic techniques subsequently have been tailored to the Navy's need as a prototype application of the HARDMAN (consideration of the MAN in the development of HARDWARE) Project [17].

A special study using the LCCIM modeling system was conducted for AFAL to evaluate the LCC impact of the DAIS concept. A comparison of the LCC of DAIS and conventional avionics suites for a close-air-support aircraft identified the impact of both design concepts on each cost element. A retrofit that added a new subsystem to each suite was evaluated in terms of its cost impact for the two concepts. In addition, the study evaluated the LCC impact of standardizing each concept across several types of aircraft.

Since the RMCM program of the LCCIM modeling system uses average values of parameters as inputs, assessments of resource utilization can be readily computed. These inputs can be easily converted to use by the Logistics Composite Model (LCOM), a Monte Carlo simulation. Although the LCOM program is expensive to run, it allows for nonlinear effects such as limited number of spares, test station queues, or a varying flight schedule. The RMCM and LCOM programs complement each other because the RMCM can be used to compare many candidate designs and then the LCOM can assess the nonlinear effects on the screened candidates.

The LCCIM modeling system has been designed to facilitate trade-off studies. Parameter values can be varied to deterine LCC sensitivities. Iterative runs in the interactive mode can be made for a series of gradual changes that lead to the most suitable set of design characteristics. A batch mode printout of the output products can provide detailed information on any resource category or cost element.

Although avionics is the only system evaluated in this study, LCCIM has been designed to adapt to other systems (such as landing gear). It is in the process of being tailored for use on shipboard equipment and could potentially be used to assess the LCC impact of equipment in the civilian sector.

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