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A SYSTEMS APPROACH FOR ACQUIRING AN AUTOMATED MAINTENANCE MANAGEMENT SYSTEM

by

Jennifer L. Goold

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APPROVED:

B. Blanchard, Chairman

P. Ghare

B. Schinbeckler

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Committee Chairman: Ben Blanchard
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(ABSTRACT)

A systems engineering life-cycle approach is used to evaluate two automated maintenance management systems (AMMS) for the Facilities Service Branch (FSB) of the XYZ company. The two systems are evaluated based on operational performance and life-cycle costs, including acquistion/development costs and operation and maintenance costs. A recommendation is made based on criteria provided by FSB.

The Faciltties Service Branch is currently using tedious, manual methods to track cost, schedule, and project status data on over 2,500 individual projects performed within the department. In addition, FSB maintains equipment history for over 1,300 systems and their components in hardcopy format. An automated system is desired to replace the outdated paperwork methods and reduce the

amount of human effort required for the maintenance and dissemination of equipment and project related data. The system requirements are provided by FSB staff and management.

The two systems evaluated are an IBM PC based system and a Wang VS100 mainframe based system. The implementation of the PC based system involves the purchase and modification of an off-the-shelf software package and the installation of five desk top personal computers in a networked configuration. The Wang mainframe option involves the development of approximately 40,000 lines of COBOL code and the use of five Wang terminals already in place in the FSB office area.

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SECTION ONE

INTRODUCTION

The XYZ company supports a computer-based project in northern Virginia which employs over 2,000 people. The project is broken down into six major functions as shown in Figure 1: Operations, Hardware Maintenance, Software Maintenance, Engineering Support, the Data Center and the Facilities Service Branch.

The Facilities Service Branch, FSB, has several responsibilities centered on keeping the physical engineering plant operating safely. The FSB organizational chart is shown in Figure 2. The entire branch consists of 95 people divided among six subfunctions: Advanced Planning, Environmental Control, Maintenance, Modifications, Construction and Grounds keeping. FSB's responsibilities include:

1. Preventive maintainance of over 1,300 pieces of equipment at the plant to include special cooling systems for several large computer networks, air handling units, chillers, etc. The twenty-five person preventive maintenance team performs this maintenance on an average of thirty pieces of equipment each

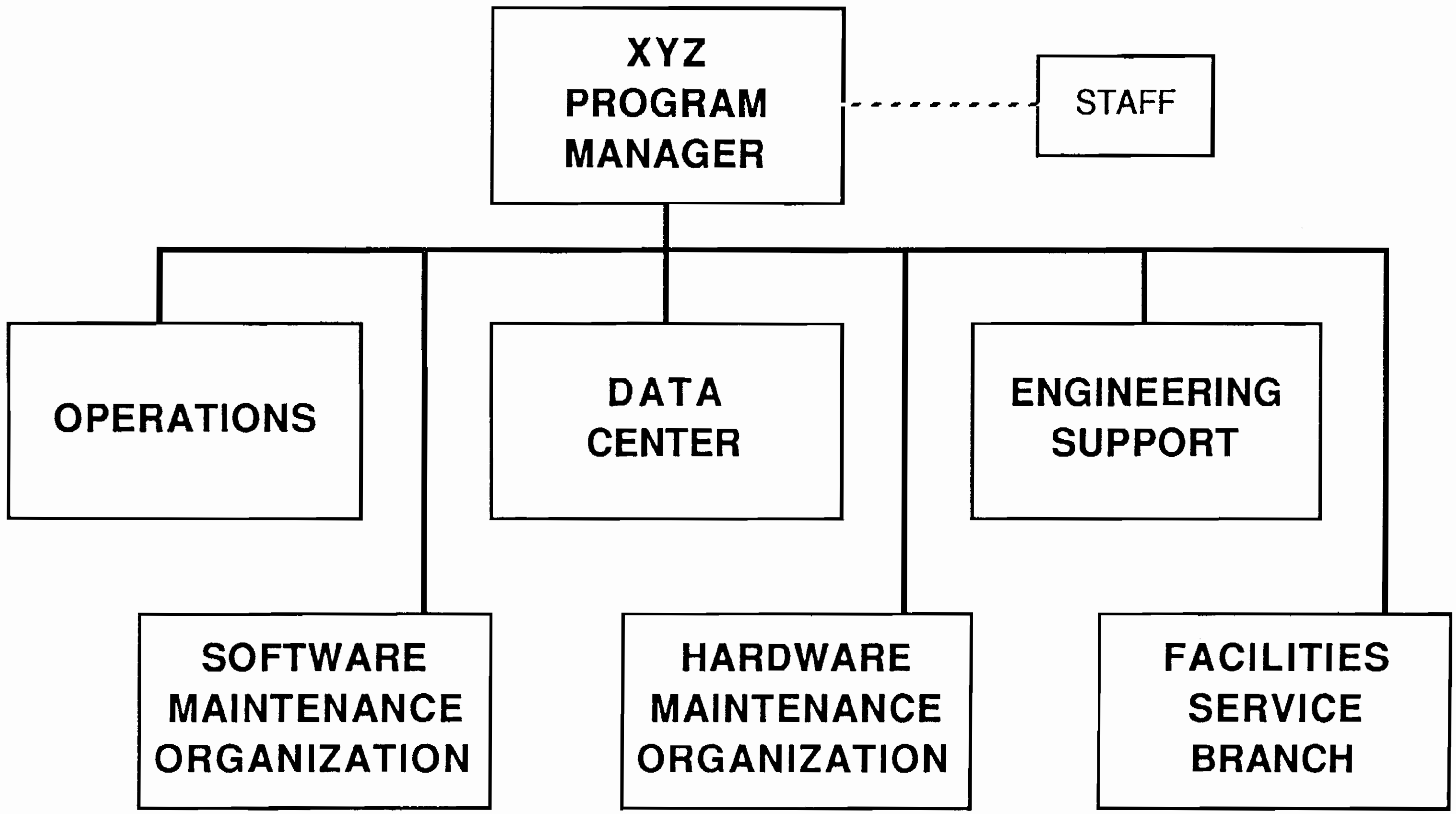

FIGURE 1. XYZ organizational chart

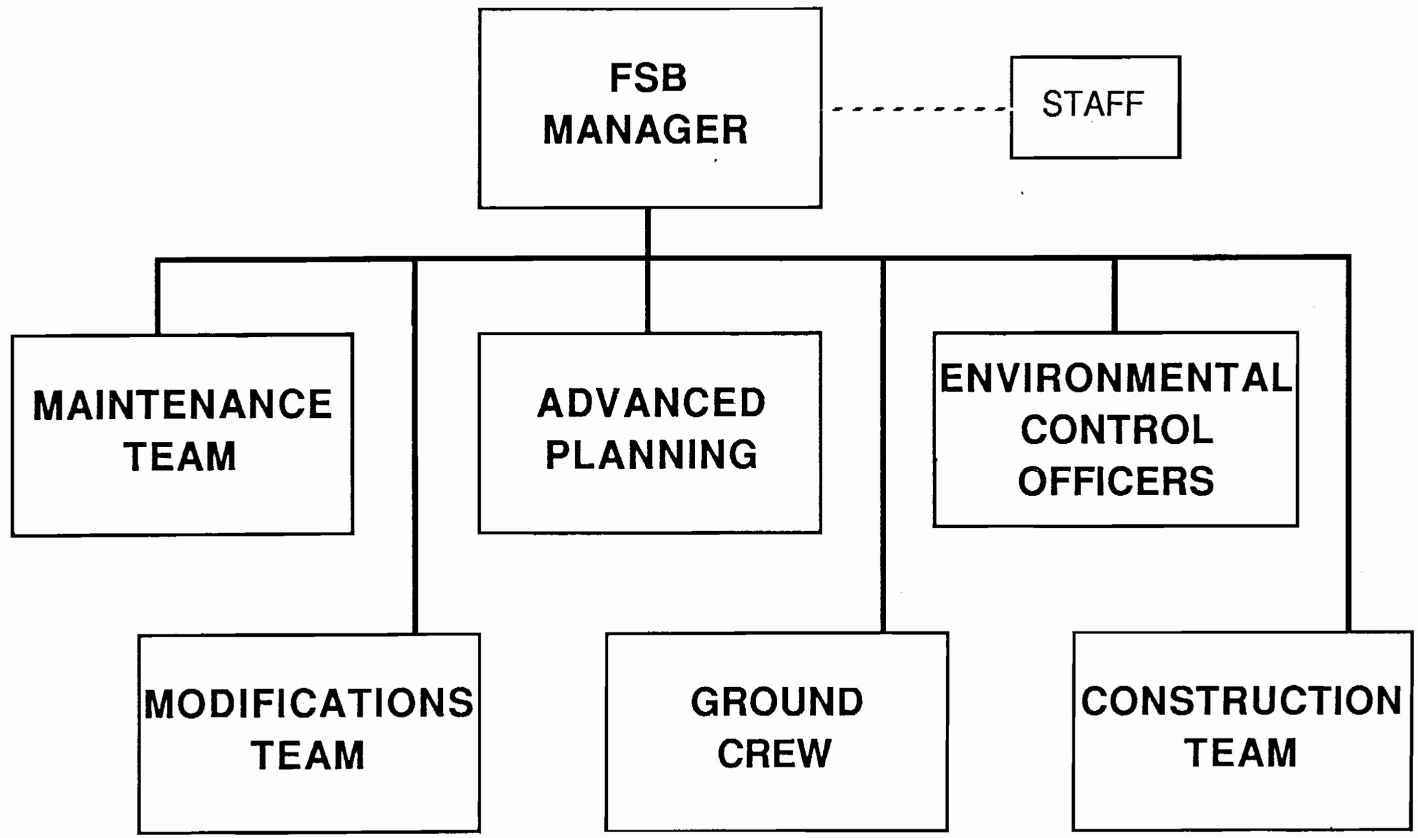

FIGURE 2. FSB organizational chart

week. The number of pieces of equipment to be maintained is expected to grow at a rate of 8% per year over the next ten years.

2. Design and construction of all new development for the plant. The physical size of the nothern Virginia facility has grown and is anticipated to keep growing at a minimum of 10% each year. The construction team, made up of 14 people, is responsible for this development.
3. Implementation of all changes to the present building layout. A modifications team of 8 people average 260 hours per week modifying the existing structure and office layout. Between the modification and construction projects, there are a minimum of forty projects ongoing at any one time.
4. Immediate response to all facilities related problems or "trouble calls" (corrective maintenance) throughout the plant. An average of 48 trouble calls are responded to each day. A trouble call may be as simple as a five minute bulb change or involve several hours repairing a failed chiller.
5. Landscaping and upkeep of outside grounds. This includes

gardening type work as well as response to inclement weather (plowing, salting, etc.).

A physical layout of XYZ's facility is illustrated in Figure 3. The facility consists of two buildings set approximately 75 feet apart from each other. The main building is apporximately 170,000 square feet in size while the utility building is approximately 10,000 square feet. The 1,300 pieces of equipment are scattered throughout both buildings with a large portion of the mechanical equipment housed in the basement of the main building.

A staff of three FSB personnel maintain manual records of cost, schedule, and project status data on all work performed within the department. A history of all facilities-related equipment systems and their components is also maintained in hardcopy format. The manual procedures are quite tedious and the data is becoming unmanageable. While the facility continues to grow, there has been no increase in staffing nor are there any plans to increase staffing over the next three years. The accuracy of the current records do not meet XYZ's standards and the hardcopy records are constantly being lost and

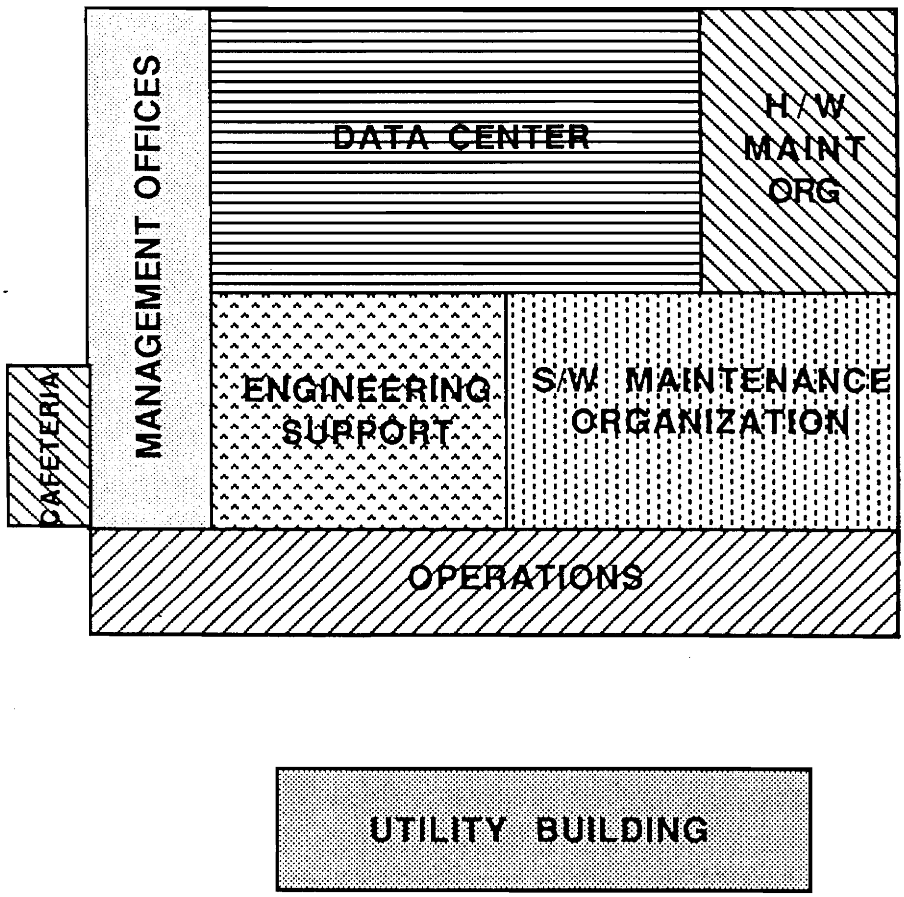

FIGURE 3. XYZ facility layout

damaged.

FSB management has several reports that are required on a regular basis; some as often as every day. The process for generating these reports is completely manual. The FSB staff must use the hardcopy records as a source of data, adding machines to compile the data, and calendars to determine the preventive maintenance schedules. Approximately 25 hours are spent each week compiling the data for these reports. The weekly preventive maintenance schedule (which includes a listing of the PM tasks for each piece of equipment) takes over six hours to prepare. The equipment history report requires between one and three hours to prepare, depending on the age of the piece of equipment is (i.e. how much history data exists). In an emergency situation, where immediate action is required on a discrepant piece of equipment, anything over one hour is unacceptable. In addition to the time delay, there is some degree of human error involved in compiling the reports and the hardcopy records are becoming cumbersome and bulky to store.

FSB management wishes to automate their procedures for maintaining and disseminating this equipment and project related data. The goals of such an automated system are to reduce the amount of human effort and time required for the aforementioned functions, to improve the accuracy of the data maintained, and minimize the amount of storage space required to maintain the required information.

After a preliminary search of the solutions available for an automated maintenance management system (AMMS), two approaches are worthy of further evaluation. The two systems are designed and presented employing the system life-cycle approach to systems engineering [1]. The life-cycle approach serves as a comprehensive method of selecting the AMMS best suited for FSB's needs while minimizing costs. The systems that were eliminated from further evaluation were eliminated because of prohibitive costs or because maintenance requirements would not be consistence with site standards.

The life-cycle approach begins with the initial identification of a need and extends through planning, research, design, development, evaluation, consumer use, and ultimate product phaseout. Figure 4 represents the overall AMMS life-cycle with the operational life beginning at year two and continuing through year eleven. Figure 5

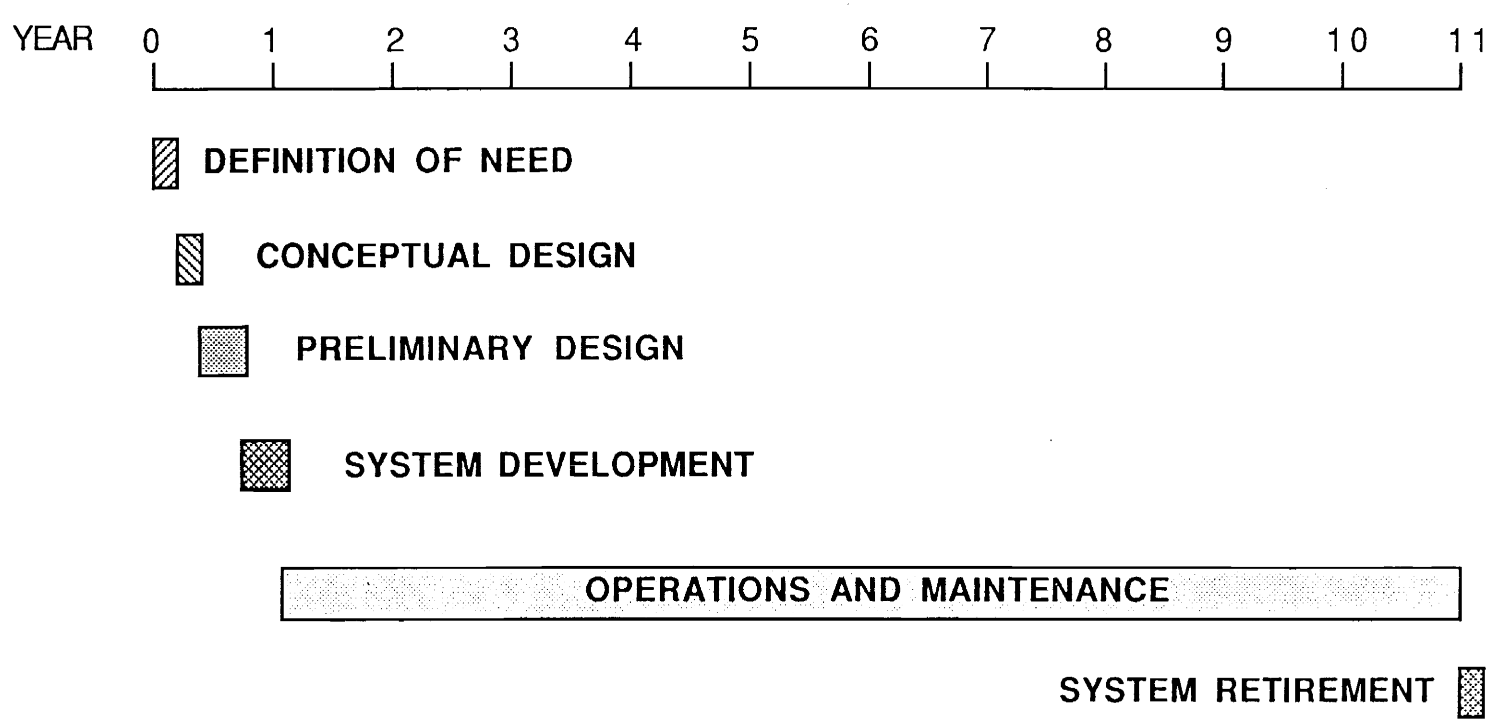

FIGURE 4. AMMS life cycle

further defines the acquisition and system development phases of the AMMS life cycle [1].

The better of the two options presented is selected by FSB management based on the following weighted criteria: effectiveness, cost, and timeliness of implementation.

1.1 ASSUMPTIONS

Several assumptions are made to facilitate/simplify the life-cycle analysis. The effects of these assumptions are addressed in the Conclusion section of this report. The assumptions are:

1. A discount rate of 8% is an accurate reflection of the economy for the next ten years.
2. The lines of code estimated for writing the AMMS software in COBOL is reasonably accurate.
3. One hundred lines of code can be written and debugged in one man-day.

1.2 ORGANIZATION OF REPORT

The organization of this report incorporates a Requirements

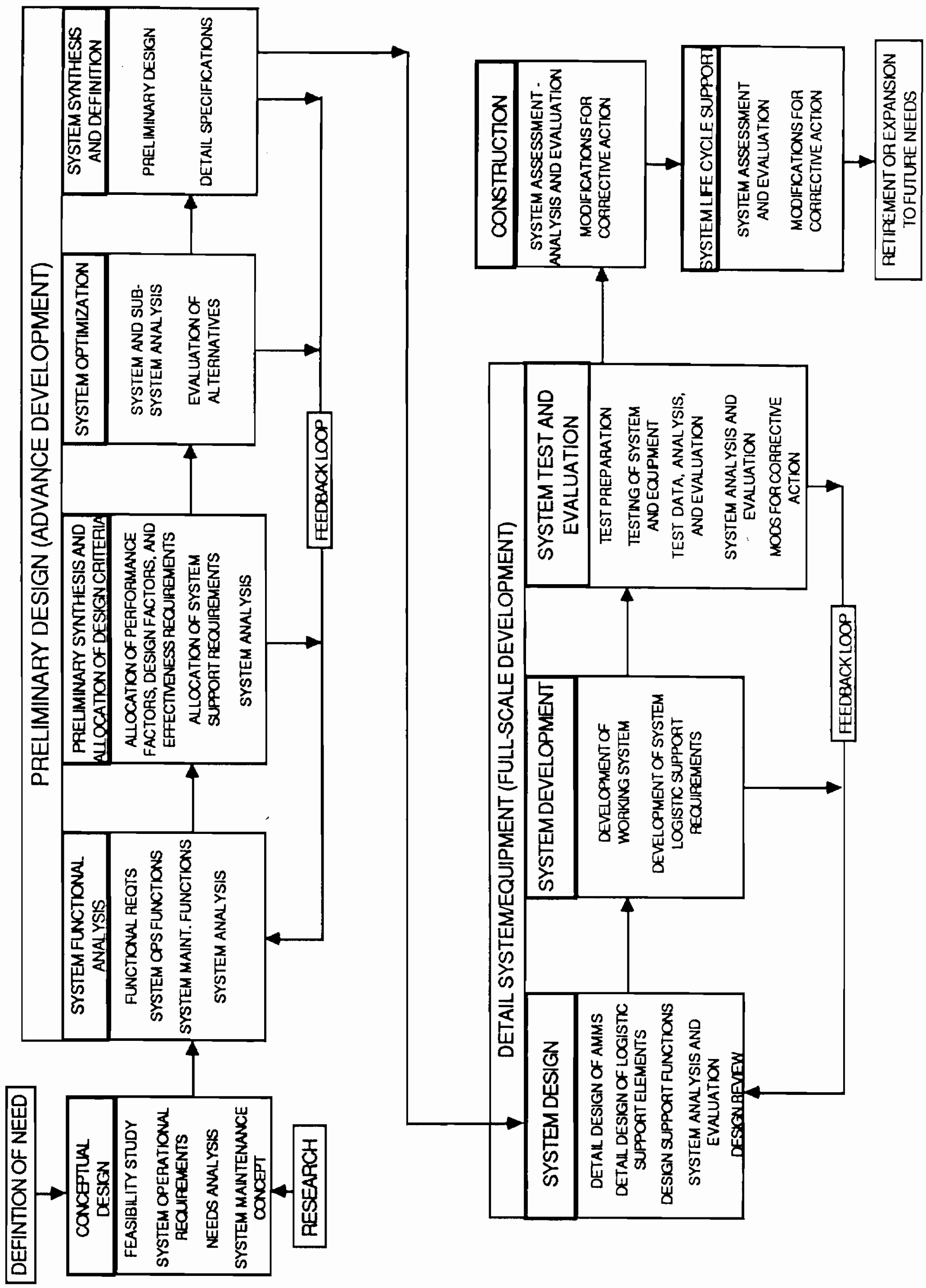

FIGURE 5. AMMS design evolution

section, an Analysis of the proposed AMMS solutions, and a section on Conclusions and Recommendations. The Requirements section provides the overall guidelines for system design. FSB staff has provided functional and environmental requirements as well as requirements for maintainability and system availability.

Section Three contains an analysis of the proposed solutions. For each system, the software and hardware configuration, the maintenance concept, implementation schedule, training plan and system availibility are described and an evaluation is made against the requirements. A life cycle cost analysis is presented for each system and a present cost comparison made. Recommendations to FSB management are in Section Four.

SECTION TWO

REQUIREMENTS DEFINITION

Conceptual design, the first step in the system life-cycle, is accomplished through a definition of system requirements. AMMS requirements have been acquired through several extensive interviews with FSB management and staff. Particular emphasis has been placed on discussions with the three staff members who are currently responsible for maintaining the data manually. The questions asked in the process of determining the technical parameters were designed to find out: what the system is to accomplish in terms of operations and functional performance characteristics, how the system will be utilized, when the system is needed, what the environmental requirements are, and who will be operating the system and for what period of time.

The interviews have led to a definition of system operating characteristics and requirements. The requirements are presented in terms of operational requirements, maintenance requirements, environmental characteristics, and operational availability.

2.1 OPERATING REQUIREMENTS

The management of FSB would like an automated system that tracks their equipment and project related data. The system should track the following information:

1. project identification number
2. project title
3. project start date
4. estimated and actual completion dates
5. estimated and actual material costs per project
6. estimated and actual manhours per project
7. project team and location within plant
8. equipment identification number
9. equipment title
10. equipment serial number
11. manufacturer
12. frequency preventive maintenance (PM) is done
13. date equipment was last PM'd
14. tasks involved in PM.

Table 1 illustrates the field size and type of each of the data types listed above.

The system must be capable of storing information for 5,000 pieces of equipment and 2,500 projects or work orders per year. FSB requires several different reports concerning PM schedules, project status, equipment history, material costs and applied manhours. The inputs and outputs for these reports are illustrated in Table 2. Each report must be generated in less than 5 minutes. The AMMS must be compatible with the Wang MS5 medium speed printer present in the FSB office area for report generation. The average system response time must be less than 4 seconds.

The system must be capable of archiving a years worth of project related data. Once archived, the ability must exist to switch back and forth from the database of the current fiscal year to any archived year. All equipment history data must be obtainable using the new automated system. There is no requirement to archive the equipment data, so one database for the equipment data is sufficient.

TABLE 1. Data type specification

FIELD NAME	SIZE	TYPE	FORMAT
PROJECT IDENTIFICATION NUMBER	7	ALPHA-NUM	YY-XXXX
PROJECT TITLE	30	ALPHA-NUM	
PROJECT START DATE	6	NUMERIC	YYMMDD
ESTIMATED COMPLETION DATES	6	NUMERIC	YYMMDD
ACTUAL COMPLETION DATES	6	NUMERIC	YYMMDD
EST. MATERIAL COSTS/PROJECT	8	NUMERIC	XXXXX.XX
ACT. MATERIAL COSTS/PROJECT	8	NUMERIC	XXXXX.XX
EST. MANHOURS PER PROJECT	4	NUMERIC	XXXX
ACT. MANHOURS PER PROJECT	4	NUMERIC	XXXX
PROJECT TEAM	10	ALPHA	
PROJECT LOCATION	15	ALPHA	
EQUIPMENT ID NUMBER	4	NUMERIC	XXXX
EQUIPMENT TITLE	20	ALPHA-NUM	
SERIAL NUMBER	10	NUMERIC	
MANUFACTURER	20	ALPHA	
PM FREQUENCY (IN DAYS)	3	NUMERIC	XXX
DATE EQUIPMENT WAS LAST PM'D	6	NUMERIC	YYMMDD
TASKS INVOLVED IN PM		WORD PROCESSING FILE	

TABLE 2. AMMS report types

REPORT TYPE	INPUTS	OUTPUTS
PM SCHEDULES	DATE RANGE EQUIPMENT TYPE	FOR EACH PIECE OF EQUIPMENT OF SPECIFIED TYPE DUE FOR PM IN THE DATE RANGE SPECIFIED: EQUIPMENT ID # EQUIPMENT TITLE SERIAL NUMBER MANUFACTURER PM FREQUENCY DATE LAST PM'D LIST OF TASKS
PROJECT STATUS	DATE RANGE PROJECT TYPE FIELDS FOR OUTPUT	FOR EACH PROJECT IN THE DATE RANGE SPECIFIED, OUTPUT THE SPECIFIED FIELDS
APPLIED MANHOUR	DATE RANGE WORK CATEGORY	FOR ALL PROJECTS IN WHICH WORK WAS APPLIED DURING THE SPECIFIED DATE RANGE: PROJECT TITLE PROJECT ID ESTIMATED HOURS DATES & NUMBER OF HOURS ACT. APPLIED
MATERIAL COST	DATE RANGE WORK CATEGORY	FOR ALL PROJECTS IN WHICH WORK WAS APPLIED DURING THE SPECIFIED DATE RANGE: PROJECT TITLE PROJECT ID ESTIMATED HOURS DATES & NUMBER OF HOURS ACT. APPLIED
EQUIPMENT HISTORY	DATE RANGE OF HISTORY DESIRED EQUIPMENT ID	FOR THE PIECE OF EQUIPMENT SPECIFIED, OUTPUT ALL PM AND CM ACTIONS TAKEN DURING THE SPECIFIED DATE RANGE

Functional flow diagrams, shown in Figures 6 through 13, are used to illustrate the operational requirements, the hierarchy of system functions and functional interfaces. The functional flow diagrams are prepared down to the level necessary to establish the requirements of the system. They are designated as top level, first level, second level and so on. The top level represents gross operational functions. The first and second levels show progressive expansions of the individual functions of the preceeding level. Functions identified in each diagram are numbered in a manner that preserves the continuity of functions and provides traceability throughout the system to the function origin.

2.2 HUMAN FACTORS

All software used in the AMMS must be either an off-the-shelf package proven in industry or must be developed by the Software Maintenance Organization incorporating the human factors guidelines contained in Systems Engineering and Analysis [1]. The exact requirements will be coordinated with the users during the software design phase but, at a minimum, the system must be designed so that it can be operated by a high school graduate with no experience

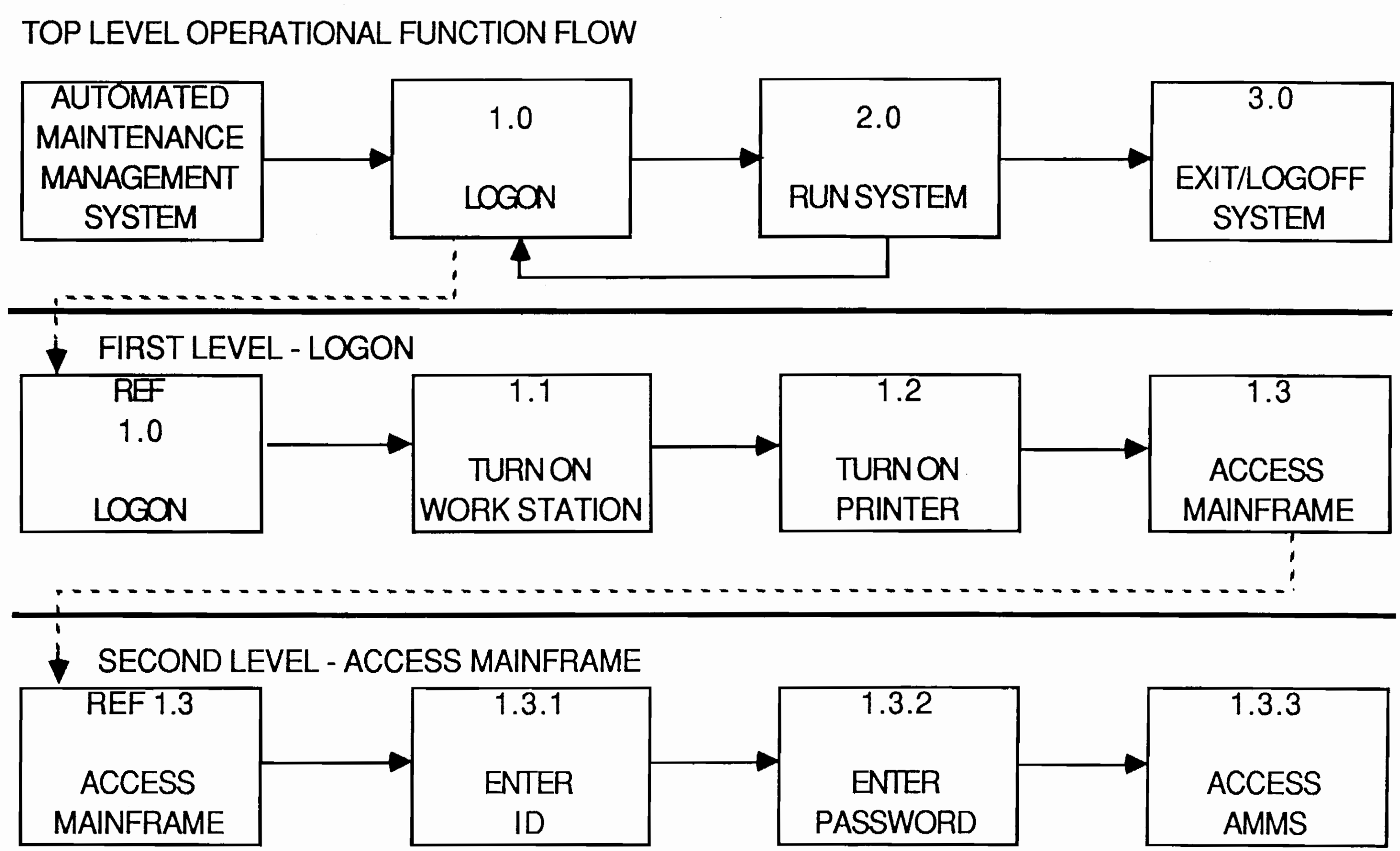

FIGURE 6. Operational function flow

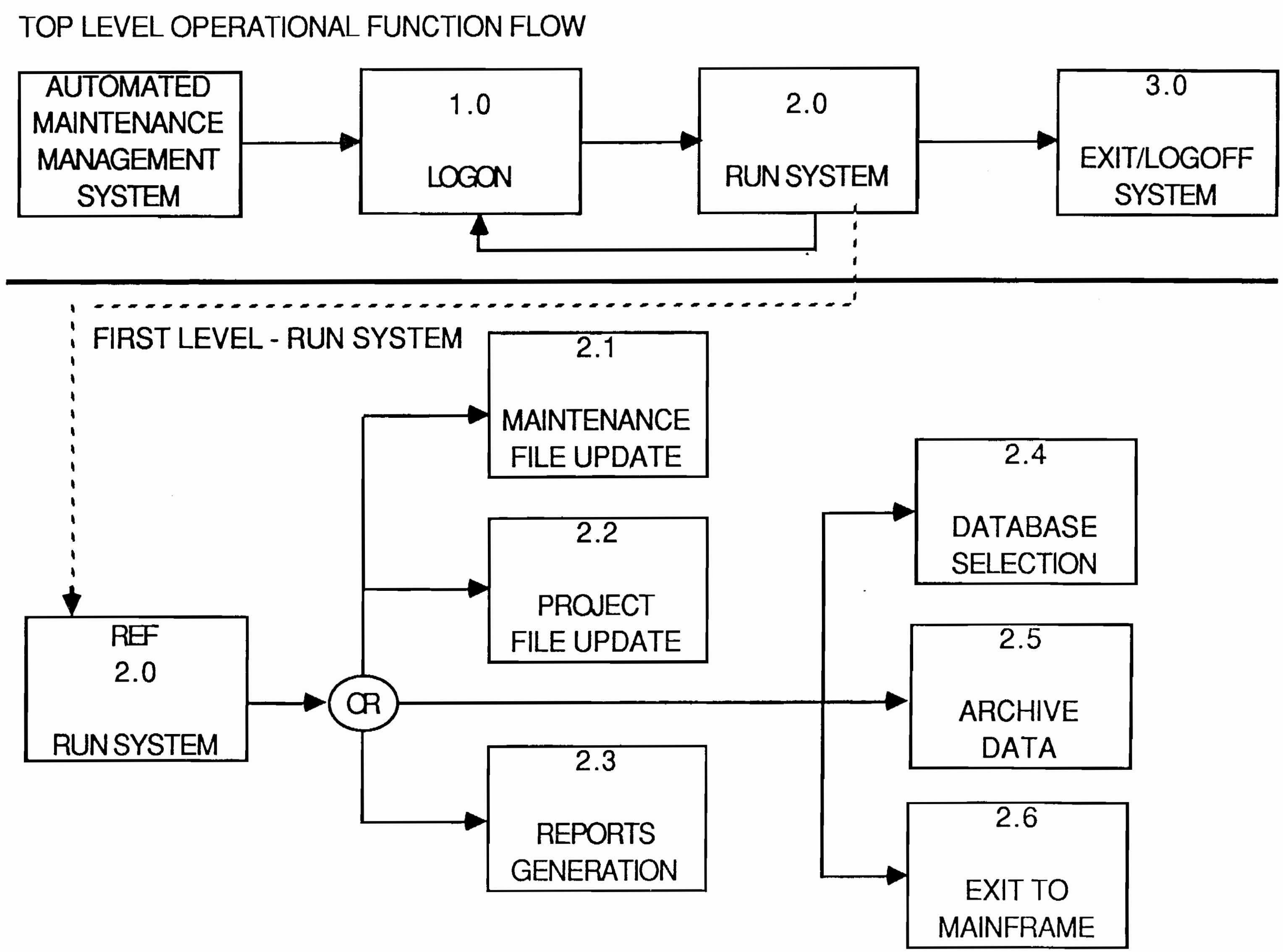

FIGURE 7. Operational function flow

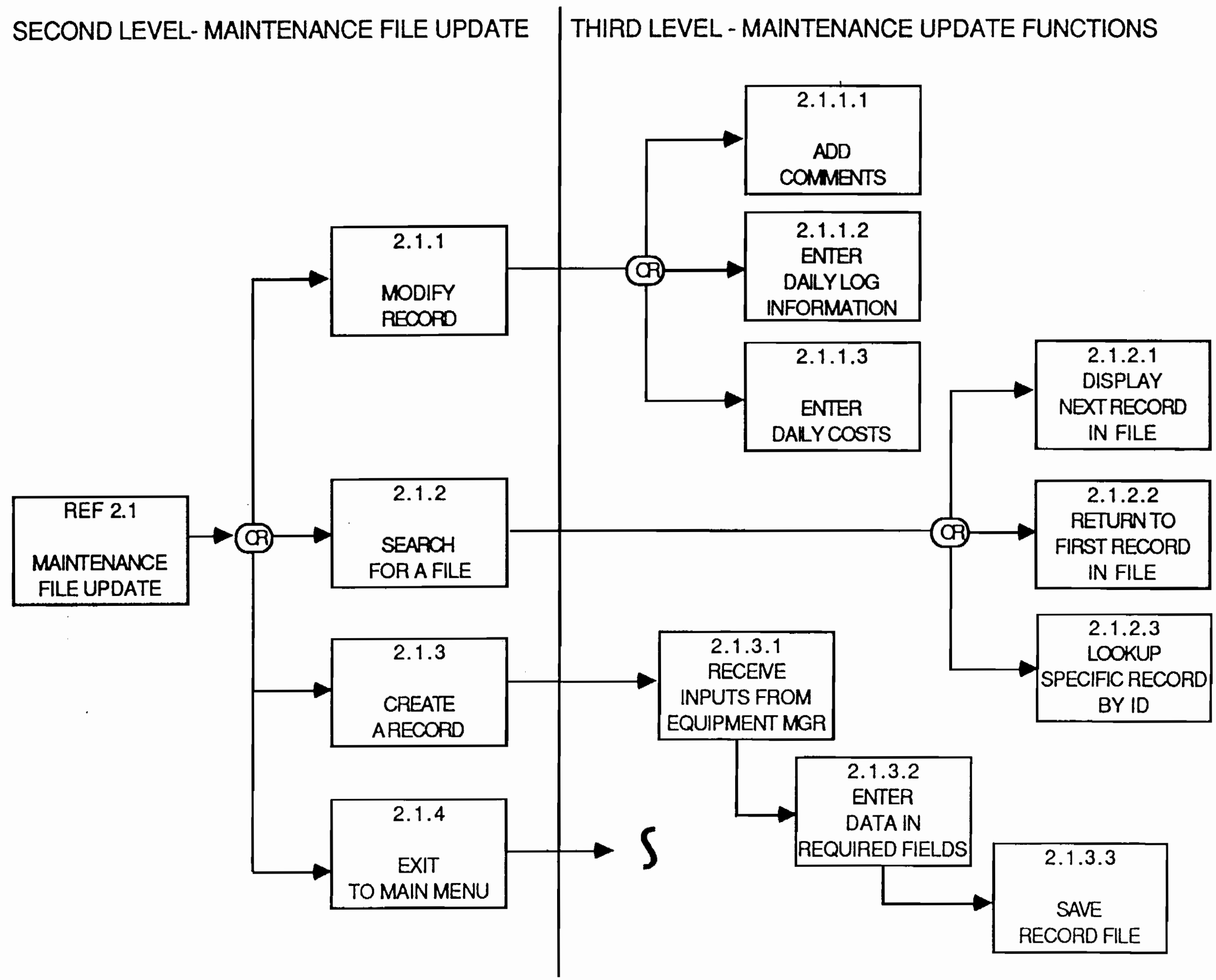

FIGURE 8. Operational function flow

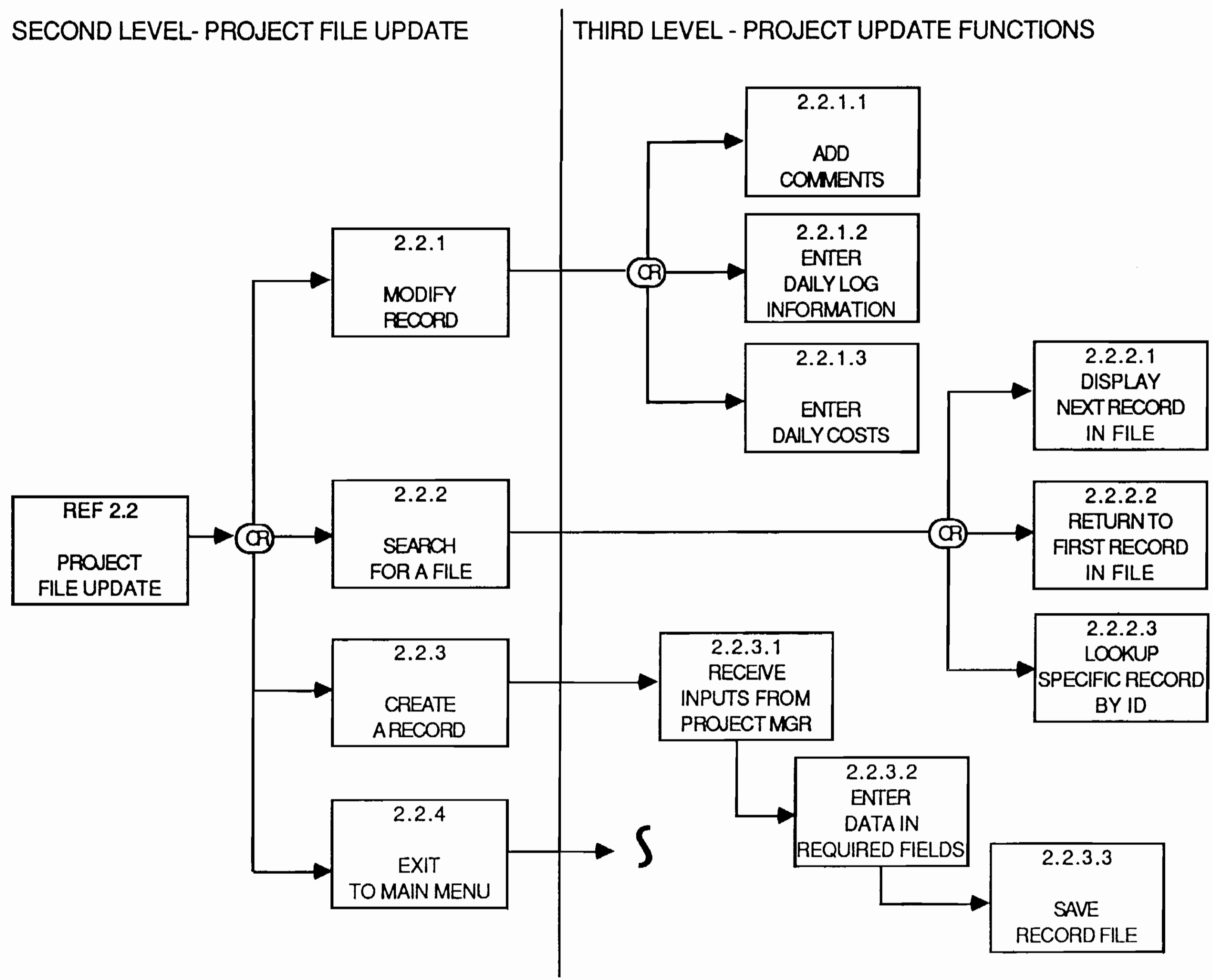

FIGURE 9. Operational function flow

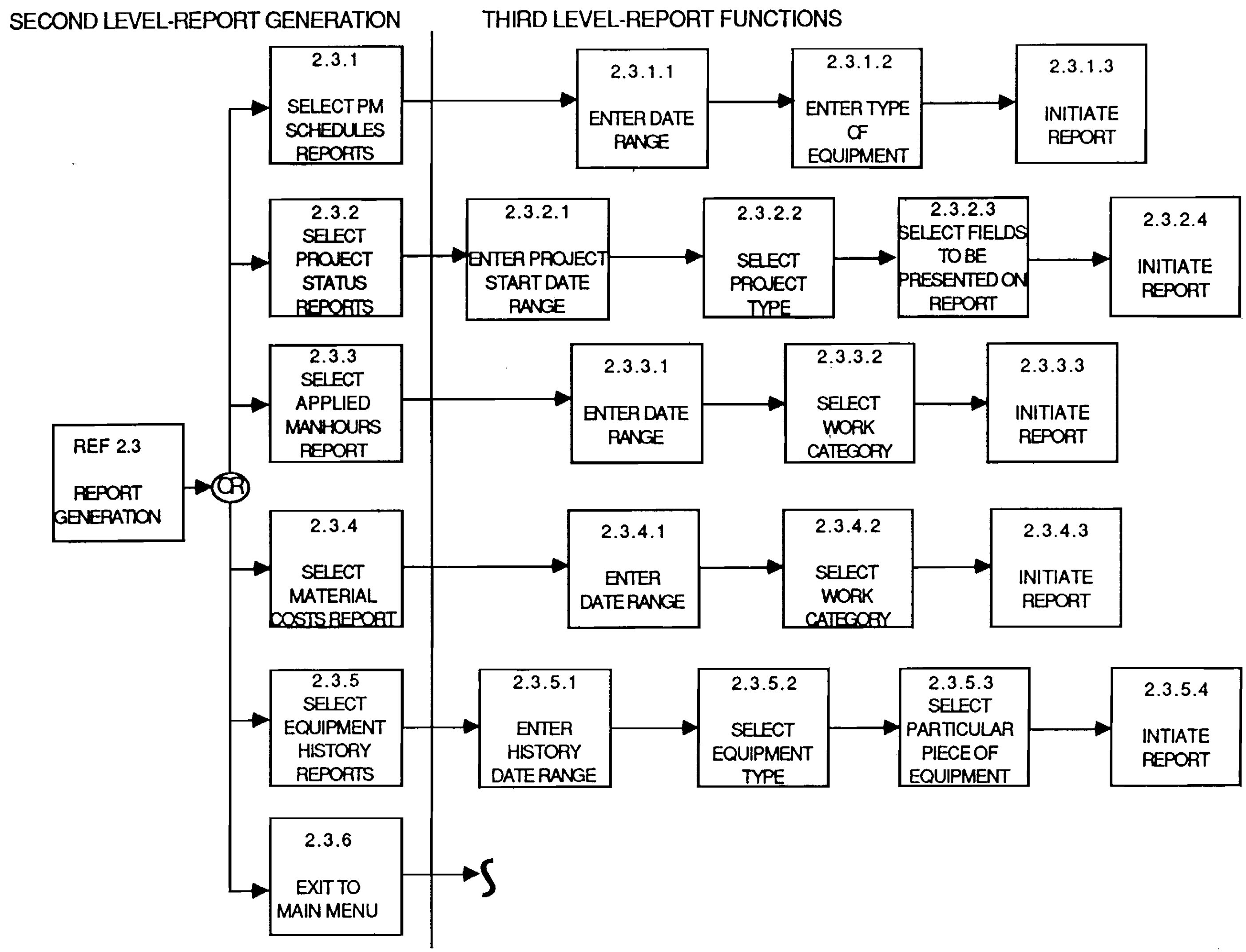

FIGURE 10. Operational function flow

SECOND LEVEL - DATABASE SELECTION

THIRD LEVEL - N/A

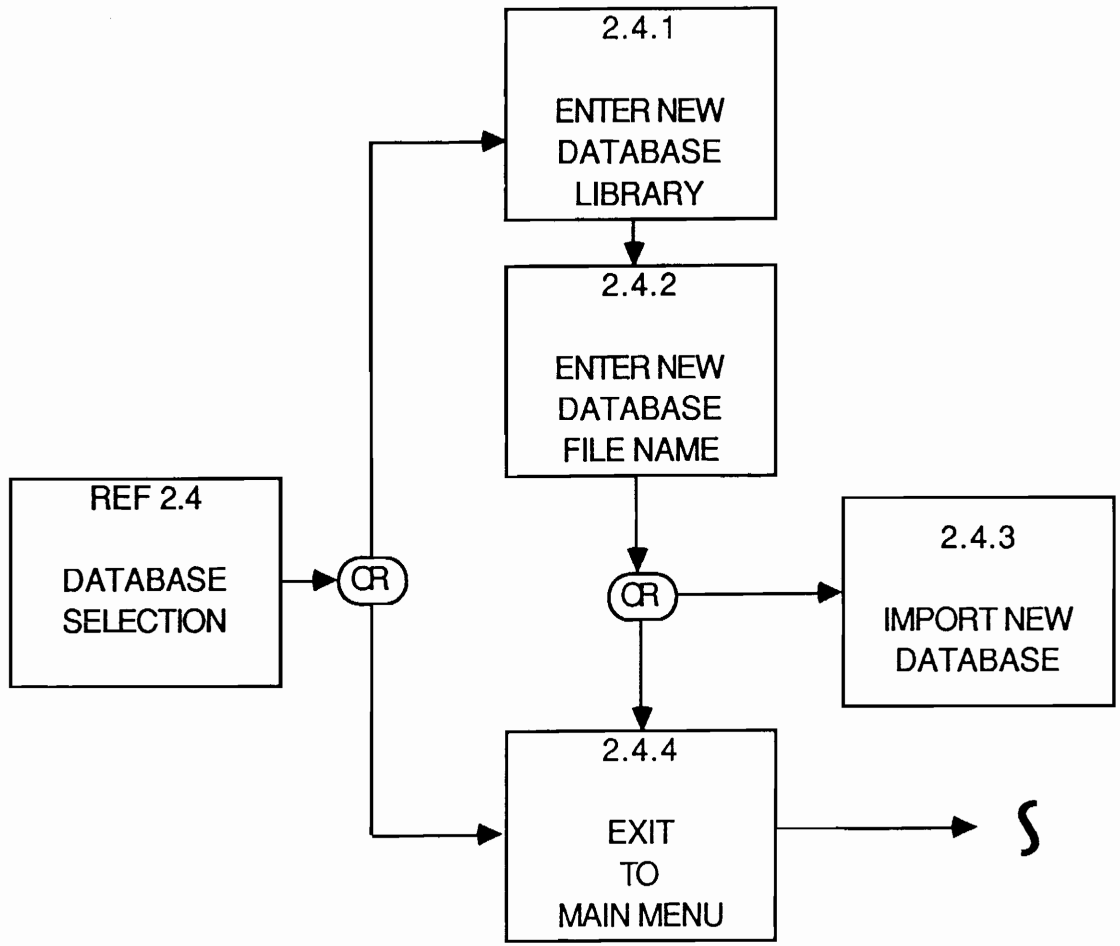

FIGURE 11. Operational function flow

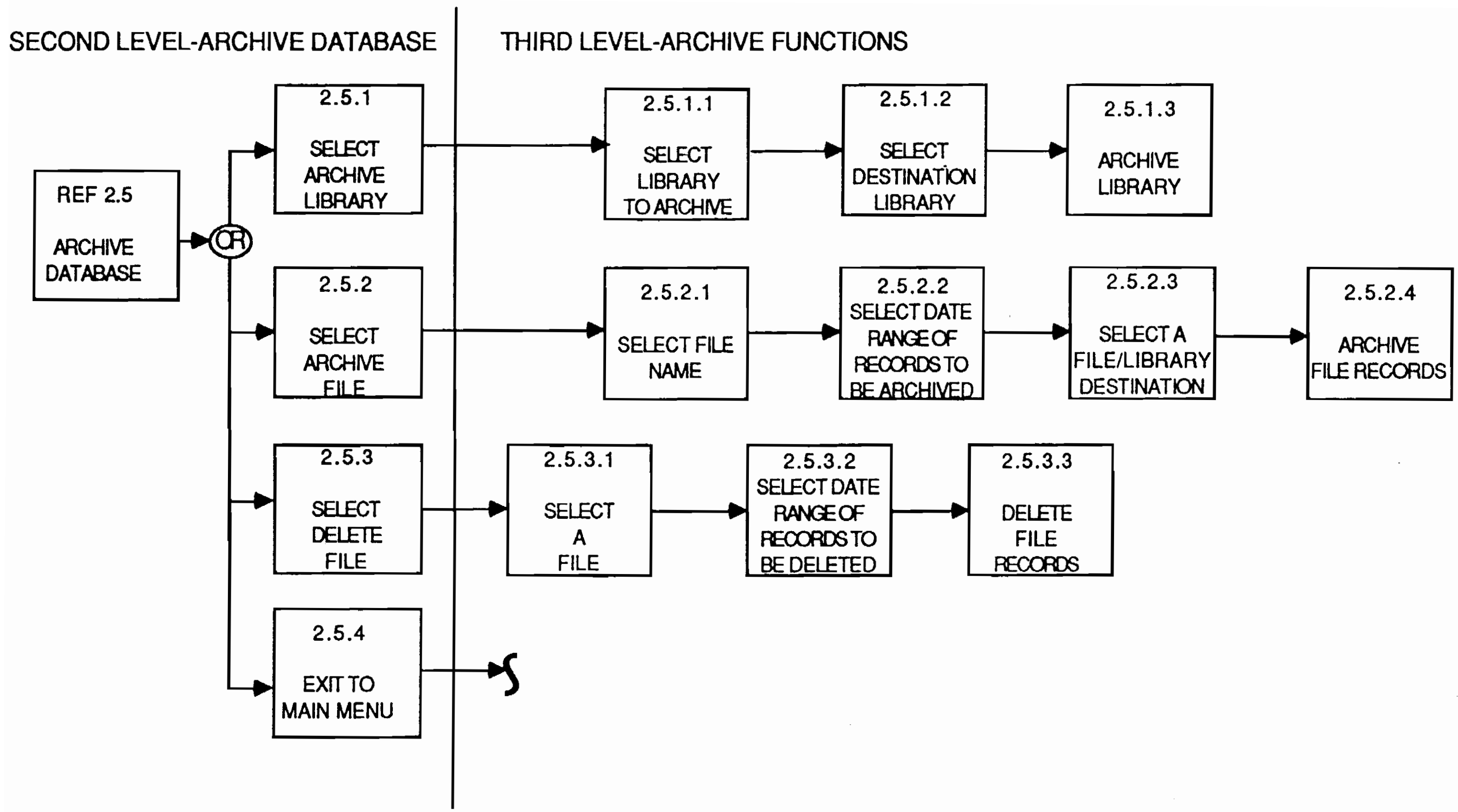

FIGURE 12. Operational function flow

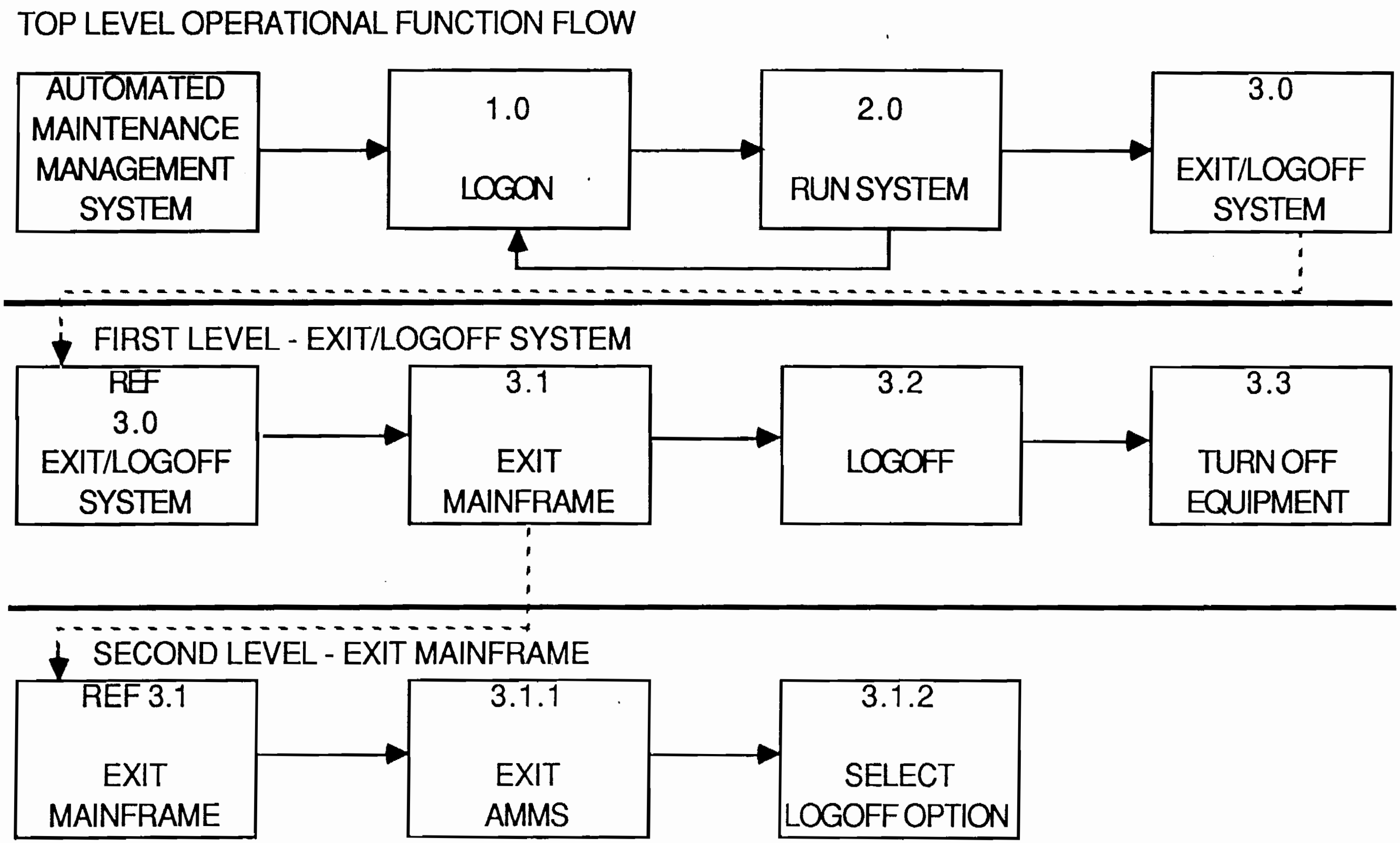

FIGURE 13. Operational function flow

operating computers prior to training. As the system design phase progresses, the hardware and software components of the system must be tested to ensure complete compatibility with the users. The system must be designed to minimize the chance of introducing human error while operating the system. The software must be sufficiently robust to protect the system from an incorrect user input. If a user makes an incorrect entry, the system should direct the user to the error and provide an error message at the bottom of the screen. The user should be allowed to re-enter the data or exit the program.

2.3 MAINTAINABILITY

The maintenance plan for an automated maintenance management system in FSB must be consistant with the already established site maintenance procedures. The XYZ company will not allow any hardware equipment/configurations on site that are not already serviced by the Hardware Maintenance Organization (HMO). Nor will the company allow any software to be operated that is not maintained by the Software Maintenance Organization (SMO) or by a reputable vendor that provides on-call service.

Maintenance is a direct result of system design. The FSB staff will do very litte maintenance work and therefore it is important that a high degree of maintainability be incorporated into the system design requirements. Organizational responsibilities shall be limited to periodic checks of software and hardware performance, visual inspection, and cleaning of the terminal screens and keyboards. Any software or hardware problems that are detected will be reported to HMO or SMO (intermediate level maintenance) for work-off. Because the intermediate facilities will be handling the bulk of the maintenance, built-in self-test provisions, accessibility and readily removable functional packages should be incorporated in the system design.

2.4 ENVIRONMENTAL REQUIREMENTS

The system must operate in the FSB office areas at the existing XYZ facility in northern Virginia. The FSB office is kept at a temperature of 66^{o} to 70^{o}; fluctuations of $\pm$ 20^{o} are acceptable for time periods less than eight hours. The system will not be operated in arctic or tropical areas.

2.5 SYSTEM LEVEL AVAILABILITY

The AMMS is required to be operational by the beginning of fiscal 1991 or October 1, 1990. The system is required to be operational for 10 years. Three FSB employees will need to use the system 8 hours a day, 5 days a week (2080 hours/year). The system is required to be operational 95% of that time with no more than 4 hours of downtime at any given time. Although only three personnel are required to enter data and generate reports on a regular basis, two additional FSB employees need to have periodic access to information stored in the system. The maximum time allowed for system start up is 10 minutes.

SECTION THREE

ANALYSIS

After investigating several automated maintenance management systems for matches with FSB's needs, two options remain feasible. The first option involves writing COBOL software to run on the Wang VS 100 mainframe computer presently on site. The second option is to purchase a PC based software package called MAXIMO and the hardware necessary to run as a local area network system. This section describes the two options in more detail, evaluates the systems against the requirements presented in Section Two and, finally, presents a life-cycle cost analysis.

3.1 DESCRIPTION OF OPTION A: A COBOL AMMS

The first option examined to fulfill FSB's needs for an AMMS is an implementation in COBOL code that will run on the existing Wang VS 100 mainframe. The software maintenance organization, SMO, has the expertise to support the development of such software. The startup time for running AMMS on the Wang is approximately 4 minutes; well within the maximum allowable startup time of ten minutes.

3.1.1 Software - The SMO has completed an initial design for the AMMS desired by FSB as well as an estimate of time and resources for their efforts. The software program has a main menu with five selections: selection of a database, maintenance file update, project file update, report generation and database archive. The user makes a selection off the main menu which points them in the correct software subsystem.

The Database Selection subsystem allows for selection of the database to be used by AMMS. When this option is selected, a choice of all the possible database names is presented on the screen for the user's choice.

The maintenance file update subsystem allows for the addition, deletion, modification and status of records in the maintenance database file. The maintenance file only stores preventive maintenance (PM) information. Any costs or man-hours recorded against a PM item are entered through the maintenance file update subsystem. The maintenance file has a tie to Wang's word processor, WP, which allows the preventive maintenance tasks to be stored. Up to 9999 maintenance records may be stored in the database.

The Project File Update subsystem allows for the addition, modification, deletion, and status of all records in the project database file. The project file stores information on all types of work except preventive maintenance work. Any costs or man-hours recorded against a project are entered through this subsystem. Up to 9999 project files may be stored in the project database file each year.

The Reports Generation subsystem provides for the extraction of data from the various AMMS database files to produce reports and schedules as specified by FSB in the Requirements section. The reports are estimated to run in less than three minutes; some of the reports will only require five or ten seconds depending on the date range selected. The reports will be automatically routed and printed at FSB's Wang MS5 printer.

The Database Archive Subsystem allows for periodic purging of historical data to hardcopy and/or other media. A daily backup of the transactions can be accomplished by the operator as required.

Validation of all data items will trigger an error message, flashing fields, and/or sounding of the terminal alarm. If any data is in error, the appropriate fields will be highlighted and the user will have the option to reenter the data in error or to terminate the current entry.

The SMO estimates that the AMMS project will require 30,000 lines of COBOL code. There are four programmers who can be dedicated full-time to this project beginning on 1 April. The estimated completion date based on a development rate of 100 lines of debugged code per day per person is 1 August 1990.

3.1.2 Hardware - The COBOL program will run on the existing Wang VS100 mainframe computer located in the Data Center. The staff positions that will support the AMMS already have Wang terminals tied to the mainframe at their work areas. No additional hardware is required to support this implementation of AMMS.

3.1.3 Training - The training segment of SMO will provide the training necessary for the operators of AMMS. Because the software is developed inhouse and is developed to allow for segmented (periodic) testing, the users of AMMS are able to periodically train on the system. The training segment will provide a one day training session for all new users. The training segment is also available during working hours at the facility to assist with any operator problems/questions that may arise during the normal operations of AMMS. The training segment will produce and maintain a user's manual for AMMS operations.

3.1.4 Maintenance Concept - The Maintenance Concept provides FSB a plan of how the AMMS will be supported through its planned life cycle. The maintenance concept is developed on the basis of FSB's requirements as discussed in Section Two. The major levels of maintenance are shown in Figure 14. Maintenance occurs at three levels: the organizational level (FSB), intermediate level (SMO &HMO), and depot level (Wang Manufacturer).

The organizational level maintenance consists of minimal preventive maintenance actions performed at scheduled intervals. These activities include periodic checks of software and hardware performance, visual inspection, and cleaning of the terminal screens and keyboards.

Most of the maintenance for the AMMS system is expected to be at the Intermediate level. Intermediate maintenance shall be performed

CRITERIA	**ORGANIZATIONAL MAINTENANCE**	**INTERMEDIATE MAINTENANCE**	**DEPOT MAINTENANCE**
LOCATION	XYZ'S NOTHERN VA FACILITY	XYZ'S NOTHERN VA FACILITY	WANG MANUFACTURER
DONE BY WHOM	OPERATING PERSONNEL	H/W MAINTENANCE ORGANIZATION & S/W MAINTENANCE ORGANIZATION	MANUFACTURER'S TECHNICIANS
TYPE OF WORK	- VISUAL INSPECTION - EQUIPMENT CLEANING - OPERATIONAL CHECKS	- DETAILED INSPECTION & SYSTEM CHECKOUT - S/W DISCREPANCIES - EQUIPMENT REPAIR & MODIFICATIONS - MAJOR SERVICING	- COMPLICATED FACTORY ADJUSTMENTS - COMPLEX H/W REPAIRS - OVERHAULS & REBUILDS

FIGURE 14. Major levels of maintenance for COBOL implementation

by the hardware and software maintenance organizations. Services provided at this level include routine preventive maintenance, equipment calibration, resolution of all software discrepancies, equipment repair, and direct technical and engineering support, as required.

The most complex types of hardware maintenance shall be handled at the depot level. The Wang manufacturer will be responsible for extensive component overhauls as well as all hardware maintenance not resolvable at the intermediate level.

3.1.5 System Availability - In deriving the figures on system availability, it is necessary to examine how long the system is estimated to be down or not operational. The system is not available for use when it is undergoing maintenance. Two aspects of maintenance are considered: preventive maintenance and corrective maintenance. Preventive maintenance is required of the system every 6 months or 1040 operating hours. Each preventive maintenance action takes three hours and includes such tasks as mainframe servicing and cable checkout. The mean time between corrective maintenance actions, MTBF, is estimated at once every 900 operating hours and takes an average of one hour. The mean corrective maintenance action, Mct, is therefore one hour. The failure rate or reliability is defined as the reciprocal of MTBF and has a value of .0011. The mean time between maintenance, MTBM, is calculated using

$$\text{MTBM} = \frac{1}{(1/\text{MTBMu}) + (1/\text{MTBMs})}$$

where MTBMu is the mean time between corrective maintenance actions and MTBMs is the mean time between preventive maintenance actions. MTBM for the entire system is then 482.5 hours. With 482.5 hours between maintenance actions over 20,800 hours the total number of maintenance actions is 43. Forty-three maintenance actions at an average of 2 hours each means that there will be 86 hours of maintenance done during AMMS' operational life of 20,800 hours. This results in a maintenance man-hour per operating hour (MMH/OH) of .0042. The availibility of the AMMS is measured using the operational availability, Ao, given by

$$\text{Ao} = (\text{MTBM}) / (\text{MTBM} + \text{MDT})$$

where MDT is the mean maintenance downtime (2). The result is an operational availability of .9959 for the entire AMMS. This is more than sufficient to meet FSB's requirement of 95% availability.

3.1.6 System Retirement Plan - The design of this system ensures future expandability and flexibility to accommodate necessary adaptations. The system is required to have an operational life of ten years; if at this time the system cannot be modified to meet new requirements, the system's retirement will be coordinated with the introduction of a replacement system.

3.1.7 Schedule - The COBOL implementation of the AMMS is scheduled for delivery on 1 September 1990. The code is to be complete on 1 August, leaving two weeks for checkout and test and two weeks for data entry of all current project and equipment systems.

3.2 DESCRIPTION OF OPTION B: MAXIMO

The MAXIMO software package is developed by Project Software Development, Inc. (PSDI). The software runs on an IBM PS/2 or equivalent with up to 15 IBM compatible terminals in a networked configuration. The system start-up time and response time are both within FSB's specification at two minutes and three seconds, respectively.

3.2.1 Software - The "option B" implementation of an AMMS involves using an off-the-shelf software package developed by PSDI. The menu-driven software package, MAXIMO, may be tailored by PSDI programmers to meet FSB's needs. The database records and desired reports, as specified by FSB, are well within the scope of MAXIMO. The ability to change the database specification and the report formats is built into the program so that a user may create a new report format while running MAXIMO. Reports are created within two and a half to three minutes, well within the specified maximum time of five minutes.

The design of the MAXIMO software is somewhat different then the COBOL software design in that only one database is used to store both the project and equipment related data. This design is transparent to the user, however, when archiving data the entire database (including equipment records) is saved. MAXIMO has a word processor available that allows for a text document to be associated with every equipment and project record. This allows for a list of PM tasks on a piece of equipment or special instructions on a project file. PSDI is responsible for testing the modified MAXIMO software on hardware configured for FSB's operational use.

3.2.2 Hardware - The hardware specifications for the MAXIMO system were provided by PSDI engineers. With the relatively small number of users required for an AMMS, PSDI has proposed a star network configuration including a server, 5 user computers, and a printer. A star network connects user computers and peripherals to the server in a radial fashion. The primary advantage of a star network is that it is flexible, allowing PCs and other devices to be hooked together using ordinary twisted pair telephone wire.

Two Wang PCs that currently exist in FSB are used for two of the five user computers; a Wang/IBM emulation interface board and a LAN connection board are required to tie them into the network. The existing Wang MS5 printer is also used in the network configuration with the addition of a LAN connection board. The server and the remaining three user computers are IBM Personal System/2 Model 60 computers and are delivered with the MAXIMO system. The IBM PS/2's incorporate 1 megabyte of RAM, a 44 megabyte hard disk drive with a floppy drive of 1.2 megabytes. A 10-MB hard disk is required for the server station. PSDI is responsible for all installation and checkout of the hardware.

3.2.3 Training - A two day training course on the modified MAXIMO system will be provided by PSDI. The initial course accommodates five operators and FSB may send two operators each additional year. PSDI is responsible for providing a full compliment of user's manuals along with descriptions of any changes made to tailor the system for FSB.

3.2.4 Maintenance Concept - The Maintenance Concept provides FSB a plan of how the AMMS will be supported through its planned life cycle. The maintenance concept is developed on the basis of FSB's requirements as discussed in Section Two. The major levels of maintenance are shown in Figure 15. Maintenance occurs at three

CRITERIA	**ORGANIZATIONAL MAINTENANCE**	**INTERMEDIATE MAINTENANCE**	**DEPOT MAINTENANCE**
LOCATION	XYZ'S NOTHERN VA FACILITY	XYZ'S NOTHERN VA FACILITY	MANUFACTURER (PSDI)
DONE BY WHOM	OPERATING PERSONNEL	H/W MAINTENANCE ORGANIZATION & S/W MAINTENANCE ORGANIZATION	MANUFACTURER'S TECHNICIANS
TYPE OF WORK	- VISUAL INSPECTION - EQUIPMENT CLEANING - OPERATIONAL CHECKS	- DETAILED INSPECTION & SYSTEM CHECKOUT - EQUIPMENT REPAIR & MODIFICATIONS - MAJOR SERVICING	- COMPLICATED FACTORY ADJUSTMENTS - S/W DISCREPANCIES - COMPLEX H/W REPAIRS - OVERHAULS & REBUILDS

FIGURE 15. Major levels of maintenance for MAXIMO implementation

levels: the organizational level (FSB), intermediate level (HMO), and depot level (PSDI).

The organizational level maintenance consists of minimal preventive maintenance actions performed at scheduled intervals. These activities include periodic checks of software and hardware performance, visual inspection, and cleaning of the terminal screens and keyboards.

Most of the hardware maintenance for the AMMS system is expected to be at the Intermediate level and shall be performed by the hardware maintenance organization. Services provided at this level include routine preventive maintenance, equipment calibration, and direct technical and engineering support, as required.

The most complex types of hardware and all software maintenance shall be handled at the depot level. PSDI will be responsible for extensive component overhauls as well as all software and hardware maintenance not resolvable at the intermediate level.

3.2.5 System Availability - Preventive maintenance is required by the MAXIMO system every six months. Each preventive maintenance action takes approximately four hours. The mean time between corrective maintenance actions is 1200 operating hours and takes an average of four hours. The equations in Section 3.1.5 are used to calculate the values for mean time between maintenance, 557 hours, and operational availability, 99.28%. The operational availability is well above FSB's requirement of 95%.

3.2.6 System Retirement Plan - The system is required to have an operational life of ten years; if at this time the system cannot be modified to meet new requirements, the system retirement will be coordinated with the introduction of a replacement system. The system may be sold back to PSDI as a training system or the IBM terminals may be kept for XYZ's educational services.

3.2.7 Schedule - The MAXIMO implementation of the AMMS is scheduled for completion on 1 July 1990. The PS/2 terminals and the modified software package will be available on 15 May. One week is required for installation checkout and test of all hardware including the network cards and the cabling. After a successful test of the hardware, a three week checkout and test of the software is conducted by PSDI personnel with assistance from the FSB users. The last two weeks are spent entering project and equipment related data into the database files and conducting training.

3.3 LIFE-CYCLE COST ANALYSIS

The two alternatives are evaluated on the basis of a life-cycle cost analysis. The analysis consists of three stages: development of a cost breakdown struction (CBS), the life-cycle cost of each alternative, and a present cost comparison.

3.3.1 Cost Breakdown Structure

3.3.1 Cost Breakdown Structure - The cost breakdown structure is presented in Figure 16. The total system cost is broken down into three major areas: research and development, investment, and operations and maintenance.

3.3.1.1 Research and Development Costs. The research and development cost, C_r, includes basic one-time, non-recurring costs as well as program management costs. The major categories include:

TOTAL SYSTEM COST (C)

RESEARCH AND DEVELOPMENT (Cr)

Program Management (Crm)

Advanced R&D (Crr)

Engineering Design (Cre)
- system engineering
- network design
- reliability
- maintainability
- human factors
- producibility
- logistic support analysis

Eqmt Development & Test (Crt)
- engineering models
- test and evaluation

Engineering Data (Crd)

INVESTMENT (CI)

Manufacturing (Cim)
- s/w development
- tools & test equipment
- inspection & test
- quality control
- material (inventory)
- packing & shipping

Construction (Cic)

Initial Logistic Support
- program management
- initial spares/repair parts
- initial training
- test & support equipment

OPERATIONS & MAINTENANCE

Operations (Coo)
- operating personnel
- operator training
- operational facilities
- support & handling equip.

Maintenance (Com)
- maint. personnel
- spare/repair parts
- maintenance training
- maintenance facilities
- technical data

System/Equip Modifications

System Phase-out & Disposal

FIGURE 16. Cost breakdown structure

program management costs (C_{rm}), advanced R&D costs(C_{rr}), engineering design costs (C_{re}), equipment development and test costs (C_{rt}), and engineering data costs (C_{rd}).

Program management covers the costs associated with organizing and overseeing feasibility studies, research, equipment development and test, and engineering design. The administrative staff, marketing, procurement, and configuration management are also included in C_{rm}.

Advanced R&D primarily involves the feasibility studies conducted to determine the need for a particular product or requirement. The system operational requirements and the preliminary maintenance concept are also included in adavanced R&D.

The system definition and development is included within the engineering design cost, C_{re}. Areas that must be considered in C_{re} are systems engineering, electrical/network design, and maintainability.

Equipment development and test, C_{rt}, includes all efforts associated with the test and evaluation of engineering models. This cost includes fabrication and assembly labor, quality control, material procurement and logistic support.

The final cost under C_r, engineering data costs, includes all costs associated with producing and distributing all documentation. The documentation involves program plans, design data, test plans and reports, and operational and maintenance procedures.

3.3.1.2 Investment. The investment portion of the total system cost covers manufacturing, construction and initial logistic support costs. The manufacturing in this case means the development of software code or a local area network. There are no construction costs associated with either option because the facility is already in existence. The initial logistic support includes technical data preparation, initial training, and test and support equipment.

3.3.1.3 Operations and Maintenance. The operations and maintnenance costs, C_o, include all costs associated with operating and maintaining the system throughout its life cycle. Regardless of the alternative is chosen, the system will be operational for 10 years.

The operations portion covers the operating personnel, operator training, and support equipment. The maintenance portion includes maintenance personnel and support, maintenance training, maintenance facilities, and technical data. Also included under C_O are system/equipment modifications and system disposal.

3.3.2 Life Cycle Costs for Options A and B - Costs are determined for each of the categories discussed above. The summary of the costs for both alternative A (writing COBOL code for the mainframe) and alternative B (buying the MAXIMO system) are presented in Table 3.

The operations and maintenance costs are based on the system operating for ten years. Method A has a lower cost of $451,000 and method B will cost $487,000.

3.3.3 Present Cost Comparison - It is necessary to consider inflation in analyzing life cycle costs. Therefore, a comparison is made between present costs based on an annual interest rate of 8%. A summary of the present costs (by year) is presented in Table 4. The first year is dedicated to system development and years 2-11 are operational years.

The present costs allow a true comparison to be made between the two alternatives. "A" has a present cost of $315,801 and "B" has a present cost of $341,372.

TABLE 3. Life-cycle cost summary

COST CATEGORY	COST FOR OPTION A	COST FOR OPTION B
1. RESEARCH & DEVELOPMENT(C_r)	**60,000**	**75,000**
a. Program Management	30,000	30,000
b. Advanced R&D	5,000	5,000
c. Engineering Design	10,000	15,000
d. Equipment Development & Test	10,000	20,000
e. Engineering Data	5,000	5,000
2. INVESTMENT (C_i)	**60,000**	**55,000**
a. Manufacturing	50,000	35,000
b. Construction	0	0
c. Initial Logistic Support	10,000	20,000
3. OPERATIONS & MAINTENANCE (C_o)	**331,000**	**357,000**
a. Operations	300,000	300,000
b. Maintenance	18,000	32,000
c. System/Equipment Mods	8,000	20,000
d. System Phase-out & Disposal	5,000	5,000
GRAND TOTAL	**$451,000**	**$487,000**

TABLE 4. Present cost comparison

	UNDISCOUNTED COST			PRESENT COST	
YEAR N	DESIGN A	DESIGN B	P/F, 8, N	DESIGN A	DESIGN B
1	120,000	130,000	.9259	111,108	120,367
2	32,600	35,200	.8573	27,948	30,177
3	32,600	35,200	.7938	25,878	28,100
4	32,600	35,200	.7350	23,961	25,872
5	32,600	35,200	.6806	22,188	23,957
6	32,600	35,200	.6302	20,545	22,183
7	32,600	35,200	.5835	19,022	20,539
8	32,600	35,200	.5403	17,614	19,019
9	32,600	35,200	.5003	16,310	17,611
10	32,600	35,200	.4632	15,100	16,305
11	37,600	40,200	.4289	16,127	17,242
		TOTALS:		**$315,801**	**$341,372**

SECTION FOUR

CONCLUSIONS AND RECOMMENDATIONS

The MAXIMO and COBOL designs both meet all of the minimum requirements set forth by FSB. Therefore, the multiattribute decision analysis described by Canada and Sullivan is used to evaluate the two proposed systems and make a recommendation to FSB management [2]. The effects of the assumptions identified in Section One are also discussed.

4.1 MULTIATTRIBUTE DECISION ANALYSIS

The first step in the multiattribute decision analysis process is to determine the attributes or criteria the system should be evaluated against. The four attributes provided by FSB management and staff are fulfillment of the minimum requirements, life-cycle cost, flexibility and expandability, and timeliness of implementation.

The attributes are then ranked in order of importance and assigned weights; the most important attribute is assigned a weight of "10" (on a scale from 1 to 10) and the other subjective assignments are made relative to the first. The alternatives are then given scores for each attribute. The alternative that best fulfills the attribute receives a score of "10" and the second alternative receives a score appropriately lower than that. The weighted scores for each alternative are then computed by summing the products of the attribute weight and the alternative score for that attribute. The alternative with the higher weighted score is preferred. A summary of the decision analysis data for the selection of an AMMS is presented in Table 5.

The most important attribute, fulfillment of minimum requirements, is given a weight of 10. Because both alternatives meet all the minimum requirements, the scores are set equal at 10. Note that because both designs are assigned an equal score, this attribute does not effect the outcome of the analysis. The second most important attribute is determined by FSB to be cost. Option A, the COBOL implementation on the Wang has the lower cost and is therefore assigned a score of 10. Option B is given a score of 8 based on the FSB scale that for every increase of $15,000 over the lower cost, the score decreases by one. Flexibility/expandability is the third most important attribute and is assigned a weight of 7. The design of the COBOL option

TABLE 5. Multiattribute decision analysis

ATTRIBUTES	WEIGHT	SCORE-A	SCORE-B	WEIGHTED SCORE-A	WEIGHTED SCORE-B
MINIMUM RQTS	10	10	10	100	100
COST	9	10	8	90	72
FLEXIBILITY/ EXPANDABILITY	7	10	7	70	49
TIMELINESS OF IMPLEMENTATION	6	6	10	36	60
			TOTAL SCORE:	**296**	**281**

clearly makes it the preferred choice on the basis of flexibility; a score of 10 is assigned to option A whereas option B receives a 7. Although the MAXIMO software allows for custom-tailoring of the database fields and the report formats, the database capacity is fixed at 999 fields; the COBOL design uses multiple database files and does not have this constraint. The COBOL design allows the user to select the desired output each time the project status report is created. The MAXIMO software may be modified to generate 15 "pre-canned" reports, but no on-line flexibility exists.

The final and least important attribute is timeliness of implementation. Both options meet the no-later-than-date of 1 October 1990, however FSB is anxious to use their new system, so the sooner the better. The schedules presented in Section Three show that the COBOL option will be complete on 1 September 1990, whereas the MAXIMO option can be ready for operation on 1 July 1990. Because of this delta, FSB assigned the MAXIMO option a score of 10 and the COBOL option a score of 6. The score of 6 was assigned based on a scale developed by FSB; for every month beyond the preferred installation date, the score decreases by two points.

The weighted scores are computed and presented in Table 5. The totals show that the COBOL implementation of AMMS has a score of 296 while the MAXIMO implementation has a lower score of 281.

A simple sensitivity analysis is done on the scores assigned to the cost, flexibility, and timeliness attributes. Fixing the scores of the preferred options in each case at 10, a score is determined for the secondary option that would cause the MAXIMO option to have a higher score. In the case of the cost attribute, option B's score would have to increase to over 9.6 points in order for the total weighted score to exceed option A's 296 points. For the flexibility attribute, option B's score would have to increase to over 9.1 points. For the timeliness attribute, option A's score would have to be less than 3.5 points in order for the total weighted score to be less than 281.

4.2 EFFECTS OF ASSUMPTIONS ON RESULTS

Three assumptions are made in Section One to allow for a systems life cycle approach in selecting an automated maintenance management system. Because the life cycle cost of the two designs is relatively close, the assumption concerning an 8% interest rate over the next ten years is not significant. This number could be slightly higher or lower and not change the fact that the COBOL implementation has a more appealing present worth; a change in interest rate would effect the life cycle costs of both systems in a similar fashion.

The second and third assumptions, the lines of code estimate and the debugged lines of code estimate, could have significant impact on the development cost of the COBOL implementation. The software maintenance organization has estimated 30,000 lines of code to implement AMMS, but if this estimate ends up being low, additional costs could be incurred in the form of overtime or an extra programmer. Likewise, if the programmers run into a significant problem and are unable to keep to their schedule averaging 100 lines of debugged code per day per person, the development cost could increase.

In order for the present worth of the COBOL implementation to surpass the MAXIMO option, the development cost for the COBOL option would have to increase by 36%. It is therefore unlikely that the aforementioned estimates could be off enough to reverse the preferred implementation of AMMS based on cost.

4.3 RECOMMENDATION

The recommendation made to FSB management is to implement a maintenance management system in COBOL on the existing Wang mainframe. Although both options meet all the minimum requirements specified by FSB, the COBOL option is preferred over the MAXIMO option because of its flexible report generation capability, the ease in which the code may be altered for future requirements and its relatively low cost.

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