

INTEGRATION OF COST ESTIMATING
WITH CRITICAL PATH
SCHEDULING

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PREFACE

Interest in the automation of the various functions of project management has grown rapidly in recent years due to the advent of the microcomputer. While most of the effort has been directed at individual functions little attention has been given to linking the data from one function to related functions.

The development of a microcomputer program which links the estimating function with the scheduling function was undertaken at Oklahoma State University in partial fulfillment of the requirements for the Ph.D. degree. The program development has provided extensive information concerning the feasibility of linking a variety of project management functions.

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CHAPTER I

INTRODUCTION

The construction industry has traditionally been recognized for its competitiveness. The approach of selecting contractors by the competitive bidding process in particular has created a large amount of interest in the ability to both quickly and accurately determine construction costs. Thus, the processes of estimating and bidding are of prime interest to construction contractors. In addition, contractors are becoming more aware of the importance of competent scheduling for the proper management of a project during construction to maximize profits. Contractors also realize that an accurate compilation of information during construction is necessary for preparation of estimates and schedules for use on future projects. Thus, a comprehensive project management system is necessary to efficiently manage a construction project.

The requirements of a project management system should include the following subsystems: estimating (cost budget), scheduling (time budget), and tracking (performance budget). Much of the information required by each of these three subsystems is common to all of them. In general, for any single project, the estimating process precedes the network scheduling and tracking functions.

Although there are numerous microcomputer programs that can perform each of these subsystems independently, none of the currently available programs perform all three functions as an integrated unit. Complete coverage of all three of these topics is beyond the scope of this investigation. This research addresses a semi-automated method which integrates only the estimating and scheduling subsystems and results with the Estimating and Critical Path Method Precedence Network Interfacing Program (ESTCPM).

Objective and Scope

The objective of this research is to develop a semi-automated system that integrates the construction estimate with the project schedule. The development of an integrated process involves a three step operation; development of the estimating cost budget, extracting line items from the cost budget for allocation to activities in the schedule, and computation of the time and cost schedule. The emphasis of this work is on interfacing the estimating process with the scheduling process. Implementing this interface requires the following:

1. Accounting for all the items of the estimate in the schedule.
2. Establishing a common system of units.
3. Allowing a single activity in the schedule to contain multiple items from the estimate.
4. Allowing a single Item in the estimate to be distributed to multiple activities in the schedule.

5. Determining the critical estimated items within each scheduled activity.

Developing this interface involved writing a general problem description that emphasizes the desired major features. The program data and file structures were developed to identify the major program variables and files. The systems analysis approach, employing the pseudo-code method, was used to design the algorithm. The program was implemented from the pseudo-code and the debugging, analysis, and optimization processes were then used to enhance the executable program. The final development step consisted of writing documentation for the program, with brief instructions on the program's operation.

Included in the scope of this dissertation are a discussion of the research required to develop the integration method and a discussion of areas in which further improvements can be made. The research was accomplished in the following sequence:

1. General problem definition.
2. Construction of a flow control diagram showing the major subroutines and control devices.
3. Development of a data dictionary containing the required data structures to organize the information into an efficient database.
4. Construction of a data flow diagram showing the flow of information through the program.
5. Development of the pseudo-code demonstrating the detailed instructions of each procedure.

6. Conversion of the pseudo-code into the chosen programming language.
7. Documentation of the program.

Features of the ESTCPM Program

The ESTCPM program allows prompt access to information and requires a minimum of user interaction with the computer. This is accomplished by using sophisticated data and file structures which yield the quickest possible retrieval and storage of data. Some of the structures available are B+ trees, hashing, and data compression. The B+ tree structure provides rapid performance and has a structure well-suited for historical cost databases. Also, the B+ tree structure does not require maintenance by the user as opposed to the hashing method.

A user friendly program alleviates errors by intercepting erroneous input or by providing the user with adequate information to avoid errors. The program was developed around one input procedure which reads a range of data types and provides all the necessary system operations for the editing processes. The procedure performs range checking to insure input data will be compatible with the program variables. A help and error system provides the user with adequate information to run the program. The help system is context sensitive and help topics are specific to each data entry form.

The program stores information on multiple projects and creates a database of completed projects. The data structures used for

grouping the information created by the program were carefully considered to create a efficient and compact database. The database structures discussed in C. J. Date's book (11) provide for a minimum amount of data duplication and allow intricate data manipulation by the program.

Chapter II presents a review of the literature applicable to previous and current usage related to the automation process which was developed in this research. This chapter also lists some of the available software for both estimating and scheduling. A discussion of integration theory is presented in Chapter III. This chapter introduces the concept of the project cycle and the three major components of the research: the estimate, the schedule, and the interface. Chapter IV presents the design philosophy incorporated in the program structure. Chapter IV also contains information on modular design which was used in the program development and discusses the rational behind the selection of the chosen programming language. The file retrieval system and data input system are also developed in chapter four. Chapter V presents the details of the program implementation and contains a brief outline of the major procedures used in its development. Chapter V also presents the input displays from the program and demonstrates the links between the database files. Chapter VI summarizes the work presented in this dissertation and presents information on areas of further study. The areas for further study involve both continued research on the problem discussed in this dissertation and development of new areas of research related to this dissertation. Appendix A contains the Data Dictionary which

includes all the file and data definitions. Appendix B contains functional data definition diagrams which are graphical representations of the Data Dictionary. Appendix C contains an example problem to demonstrate the interfacing theory. The example contains a complete estimate and schedule. Several program screen copies are presented to help demonstrate the interfacing process.

CHAPTER II

REVIEW OF LITERATURE

A literature review was conducted to ascertain what the construction industry desires in an integrated estimating and scheduling software system and to identify available software that is utilized for project management. The literature review concentrated on microcomputer based software and those industry views which are applicable to a microcomputer based system. This chapter summarizes a number of articles and discusses the potential advantages and disadvantages of integrated estimating and scheduling software.

Review of Current Methods

Although many articles in construction trade journals indicate the need for integrated software, currently integrated software has only been developed for the mainframe computer with restricted proprietary usage. At present microcomputer based software has concentrated on job costing, project control, estimating, accounting and scheduling as stand alone programs. Two articles, in particular, summarize the construction industry's attitude towards integration. The advantages and potential problems of integration are discussed in an article by Paul Shiring (65). Shiring emphasizes that work items must be spread over several scheduled activities and that linear

distribution of costs do not accurately represent real work situations. Shiring views resource allocation as a valuable tool for "what if" analysis in the schedule and that the constraints imposed on the estimate by resource allocations can usually be overcome. A major advantage of integration is the ability to provide reliable updated forecasts of the final project cost and completion dates early in the construction process. The major objection to this type of software is the level of detail necessary to develop a schedule which incorporates all of the items in the estimate.

A mainframe program written by Philip Dixon (13) for the management of construction of a nuclear power station integrates the estimate with the schedule in order to track project progress through earned man-hours and to improve accuracy for cash flow demands. The crew compositions were updated to predict the number of man-hours required for completion. Dixon also states that the major advantage to integration is a database of completed projects which can be used to predict performance in future estimates.

In addition to predicting performance for future estimating, an automated program that fully integrates the estimate with the schedule eliminates the requirement of handling the same data numerous times. This is extremely important when one considers the number of line items in an estimate and that each line item contains at least ten entries.

† The importance of construction automation prompted the National Science Foundation (NSF) to create a special program in construction automation. This issue was addressed extensively at the NSF sponsored

workshop, "Construction Automation: Computer-Integrated Construction," held at Lehigh University in April 1987. The primary goal of this workshop was to set the direction for exploring automation and systems integration in the construction industry. The workshop emphasized that the computer can be used as a means of integrating the total construction process from initial design to the end-of-life of a project. Although automation was the topic of the conference, the issue of linking the estimate with the schedule was not addressed.

The Business Roundtable, a group of large multi-builder owners, was established in 1972 to address the issue of cost effectiveness in the construction industry. The results of their study are contained in twenty-four separate reports. Report A-6 addressed the issue of Modern Management Systems and states that "computerized estimating technologies are not fully used in the construction industry" (35).

The Construction Industry Institute (CII) was formed in 1983 to define and coordinate research activities on or relative to the concerns expressed in the Business Roundtable Reports. The CII between 1983 and 1987 established 11 separate task forces to study specific research topics. One of these task forces addressed the topic of cost/schedule controls from the perspective of engineering design. Their study did not involve linking the estimate to the schedule. The CII recently surveyed the leading construction research universities to establish what investigations were being conducted in the construction area. The results of this survey (68) indicate that no research, with the exception of this dissertation, is currently being conducted on interfacing the estimate with the

schedule.

Numerous articles have been written that discuss the value of artificial intelligence (AI) and expert systems (ES) for automation of computer aided design (CAD) with estimating. In particular, the recent CII survey (67) indicated 11 separate research efforts in this area. Two related AI projects were: (1) a knowledge based approach to schedule progress reporting conducted by Professor Robert D. Logcher of the Massachusetts Institute of Technology, and (2) resource constrained scheduling using a knowledge representation system also conducted by Professor Logcher. The first project deals with updating a schedule during the construction phase of a project. The second project uses a branch and bound technique, basic to AI algorithms, to optimize resources within a Critical Path Method (CPM) schedule. These two research efforts indicate an interest in automating the construction management and control processes but still did not address the estimate and schedule link.

State-of-the-Art Programs

A complete review of the available estimating and scheduling software would be extensive due to new software constantly being introduced. Therefore, this review encompasses only the most popular microcomputer based software packages for the following two distinct groups; scheduling programs, and accounting/estimating programs. Some of the features that can be found in the various estimating and scheduling programs listed in Table 1 include:

- a. Sorting of output reports.
- b. Bar chart display of scheduled activities.
- c. Resource allocation to activities.
- d. Early and late start schedules
- e. A unique code assigned to each estimated item.
- f. Reports list estimated costs and cost to date.
- g. A cost database

Many estimating programs also provide job costing systems which concentrate on controlling a project's finances, and consequently lack the ability to deal with a project in terms of the work performed. The majority of estimating systems organize data in the Construction Specifications Institute's (CSI) format. Ponce-Campos and Ricci (47) discuss a more logical format called the Work Breakdown Structure (WBS) which allows a system of resources to be maintained as part of the estimating system.

Each of the listed software packages is a stand-alone process, i.e., there are no combined estimating and scheduling programs. Of all these programs only Means considers the topic of linking the estimating and scheduling formats. Mean's approach to integration is through their new book on estimating assemblages. Mean's Astro program has a database of estimated assemblages or components which are modeled from their Mean's Cost Guide (19). These estimated assemblages form the activities of the schedule. The Astro package at best provides a bar chart type of analysis of a project, and it does not perform any CPM Schedule calculations.

TABLE 1
 ABBREVIATED LISTING OF CURRENTLY
 AVAILABLE ESTIMATING AND
 SCHEDULING PROGRAMS

Scheduling Programs	Estimating Programs
GAROCPM	Access
Harvard Total Project Manager	Accubid
MacProject	AEMAS/CMAS
MicroTrak	Basic Estimating
OPENPLAN	BETSY
PertMaster	Bidtek General Contracting Est.
PLANTRAC	CES-II
PMSII	Construction Estimating System
PMS80	Construction Est. Pricing/System
Primaveria	Contracting Control Package
PRISM	Contractor
Pro-Ject-6	D&S Systems
Project	Datasonic Takeoff/System
PROJECT/2	Deneb
Project Planner	Dodge Design Estimator
Project Scheduler Network	EAS EST/ESPRI
Project Scheduler 5000	The Elecon
PROMIS	Esccomate
Quick-Plan	ESTI MATE
QWIKNET	Estimator and Framing Calculator
SuperProject	ETALE II and Close II
TimeLine	The PEER System
VisiSchedule	Quick Est
VISION	Profit Builder
	RPG II
	R. S. Means Astro
	SDSI Estimating System
	System 20/20
	Tops IV and EST MAT
	Work-in-progress

Shortcomings of Available Programs

Most estimating systems are options of an accounting package to attract customers from the construction industry. Unfortunately, these estimating packages are written with the same strict rules which are applied to accounting programs, i.e., concentration on the financial aspects of projects. While some estimating packages are stand-alone systems, they force the user to follow a specific format that is tied into a global database. Several of these packages have very advanced features such as project modeling and completed project databases. In an attempt to provide quick access to data, some programs have used the hashing method for data storage which requires the user to perform file maintenance such as sorting and file reorganization. Many estimating programs are based upon the Construction Specification Institute (CSI) format which forces an estimator to use a format that does not necessarily follow the company's procedures for actually building a project.

Common among the available scheduling programs are features which limit the number of activities in the schedule and the duration of the project. These limits are a result of the languages used and the creator's restricted knowledge of sophisticated programming techniques. Also, many programs suffer from their developer's basic misunderstanding of the construction industry. These programs are tailored to the apparent limitations of the machines for which they were designed. The computer's memory and speed limitations need not

be a factor in the performance of any given program with the ever increasing computer operating speeds and new high limits on computer hard disks. Many of these scheduling programs also do not consider the entire project cycle and do not provide a method for updates and revisions.

Because these software packages are not designed to be interfaced they do not provide the vital links between the estimate and the schedule. Double entry of resource and estimating information is required which creates considerable work when changes are required.

CHAPTER III

THE INTERFACING THEORY

The idea of integrating estimating and scheduling is not new. ICES- Project (Integrated Civil Engineering System), which was developed in the 1960's by the Massachusetts Institute of Technology, includes a facility for allocating resources and sub-networking. The user can build a table of company resources and then distribute them throughout the project. He can determine the total resource demand on a given day or for the entire project. Sub-networking allows the user to create multiple layers of responsibility in his CPM diagram which can be used by different levels of management. These two facilities provide a tremendous amount of information but they do not solve the many problems of the estimate and schedule interface.

Some of the difficulties involved in interfacing the cost estimate with the CPM schedule are as follows:

1. Items in the estimate must be spread over multiple activities in the schedule.
2. Each activity in the schedule must consist of multiple items from the estimate.
3. The cost of each item in the estimate must be fully distributed to the entire schedule.
4. The data must be handled twice when separate estimating and scheduling programs are used.

5. An auditing system must be set up to account for the distributed costs.
6. The number of items in the estimate always exceeds the number of items in the schedule, therefore, items in the estimate must be reformatted to match the schedule.
7. The estimate is cost intensive while the schedule is time intensive.
8. For any given item in the estimate the cost is fixed; however, there are multiple times associated with the given cost, depending upon the crew size.

These problems require an arduous hand system of journals and ledgers to trace the numerous items. This level of complexity compels most contractors to create a schedule which only contains rough approximations of the actual activity costs and durations.

Due to the difficulty involved in producing a full cost and schedule integration, the advantages of a semi-automated interfacing system becomes apparent. First, interfacing provides the relationships necessary for the interdependencies between the estimate and the schedule. Second, the items contained in the estimate are based upon the resources of the company, and integration will serve to distribute those resources to the project activities. Third any changes in the scope of the contract can be easily assigned to the estimate and the schedule, reflecting an accurate effect on the project cost and duration. Finally, interfacing completely accounts for the estimated project costs which will provide the required detail for project cash flow predictions.

The interfacing process provides one link in the total project management system. The idea of this link suggests that some method of data flow exists throughout the project. The data initially gathered during the estimating process usually exhibits one of two formats: (1) the Construction Specification Institute's format (CSI), or (2) the work breakdown structure (WBS). In either of these formats the data is incompatible with the CPM schedule and impedes the data flow through the project. The cost and duration for a given activity in the CPM schedule is typically determined by the person creating the schedule who often is not involved in developing the estimate. These costs and durations usually have little correlation to the cost budget established by the contractor's bid, thereby making accurate cost controls of a project unrealistic. A project cycle should be considered as a part of a construction company's total management system. The basic elements of the project cycle are the cost estimate and the CPM schedule. This chapter will discuss what constitutes a suitable estimate and a suitable schedule and how to merge these two elements.

The Project Cycle

The project cycle should more accurately be called the project monetary cycle. This cycle deals with the distribution of costs during a project's life. The cycle consists of five phases:

1. Estimating phase (Cost Budget),
2. Bidding phase,

3. Scheduling phase (Time Budget),
4. Tracking phase (Performance Budget), and
5. Accounting phase.

The relationship between these five phases can be seen in Figure 1. The first phase of the cycle is the estimating process and consists of: (1) Material, (2) Labor, (3) Equipment, (4) Subcontract work, and (5) General and Job Overhead. These elements are usually expressed in terms of unit cost, such as dollars per cubic yard, and can be broken down into units specific to the company's operations.

The second phase, Bidding, consists of the items which form the estimate plus the following additional cost items:

1. Contingency,
2. Risk,
3. Bonds and Insurance,
4. Taxes, and
5. Profit

The third phase, Scheduling, provides the time budget for the cycle by introducing the sequencing of the project activities. These activities are composed of a group of estimated items which collectively contain the total cost and time required for each work activity.

The Tracking and the Accounting phases are very similar but differ in that the Accounting phase lags behind the Tracking phase but consists of a more accurate project analysis. This lag results from time required by the billing cycle and delays inherent in processing information in an accounting reporting system. The real time data

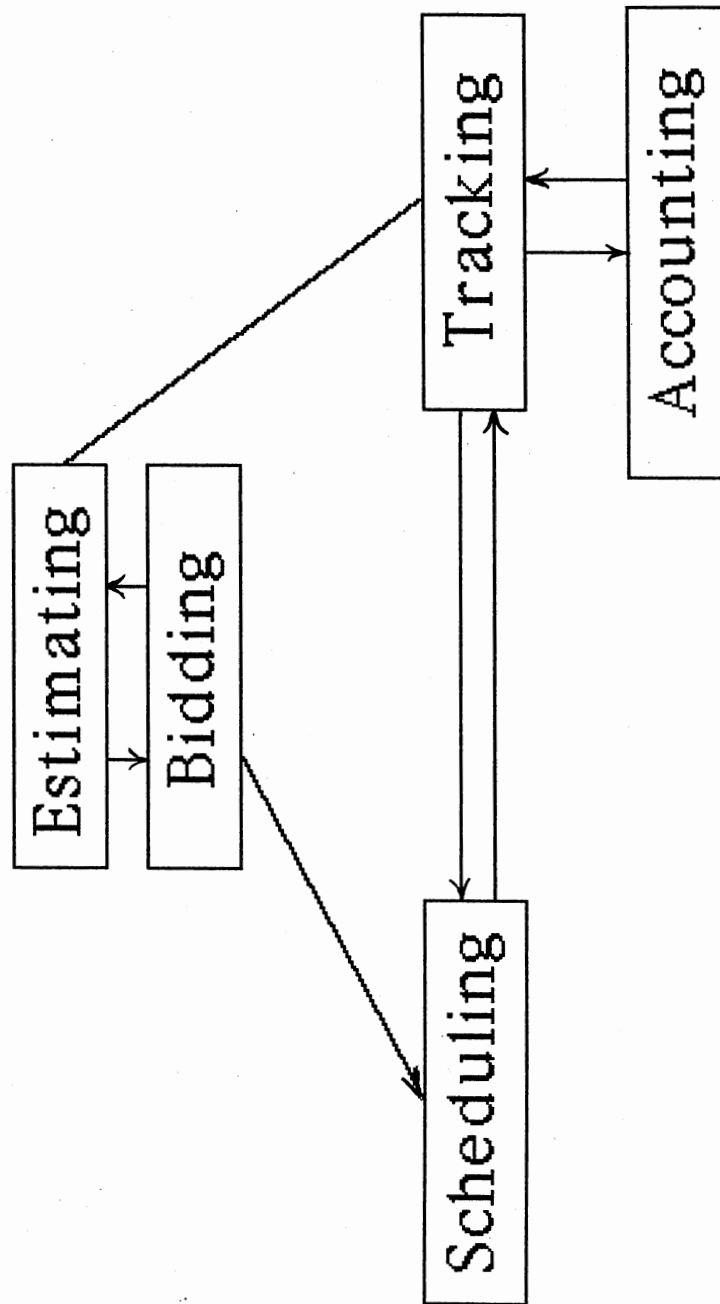


Figure 1. Project Cycle

collected in the field can be used for predicting performance during project construction while the accounting data is needed to verify progress payments and final project costs.

The Interfacing Data

The focus of this study is to present a method for including estimating data into a CPM scheduling format. The actual data required for many of the monetary phases stems from the two basic processes of estimating and scheduling. The estimating process provides the Cost Budget and the Production Budget for each work item. The schedule provides the overall Time and Performance Budgets required of each resource. Both processes constitute planning and control tools that are susceptible to many changes. Any useful program must also be able to adapt to these constant changes.

The interfacing process must not only create links between the data created in the estimating and scheduling processes, it must create an accounting system to manage all distributions. This grouping of data and sharing of information indicates the need for some sort of database management. The following paragraphs will describe the characteristics of an estimating and scheduling database and will develop the interfacing procedure required to manipulate this database.

The Estimating Process

The objective of an estimate is to calculate the anticipated cost of each item of work contained in a project. To make improvements in the estimating process one must know which items in his cost budget are incorrect and why they are incorrect. Improvements can only be made if the cost budget is converted into a form which is compatible with work performance. Consequently, the cost of each item can be evaluated and a better estimate calculated. Improved estimates can be made using the performance data gathered on completed projects.

The basic elements employed in producing a product are material, labor, and equipment. The manufacturing industry determines performance by measuring the production rates of labor and equipment. Methods have been developed by Peurifoy (47) and others for calculating the hourly costs and performance of construction labor and equipment.

Even though the construction industry appears to produce a unique product with each new project, the basic elements remain the same. Only the production rates or time required to perform each item of work are different. These differences are usually due to the way activities interact with each other. Some delays and problems originate from outside sources such as weather and late material deliveries. These external sources cannot be controlled but their effect on the project can be minimized if the interdependencies between scheduled activities are understood. These interdependencies will not be understood until the data describing the project can be

collected and analyzed in a consistent manner.

Two attempts to unify data produced in the estimate have been developed. First, the CSI format is a database of items which corresponds to the order found in the written specification. The shortcoming of this format is its incompatibility with the way the material is combined into the work. The second format the WBS format is closely tied to the manner the work will actually be performed.

The Scheduling Process

The objective of the scheduling process is to determine the sequencing of the items of work developed in the estimate and to predict how variations in production rates will affect the flow of work during the project. The scheduling process can also be used to predict how projects will affect each other with respect to resource allocations and weather delays. The CPM method provides critical information about the sequencing of activities in a project. This sequencing can be very sensitive to fluctuations in the available resources, which can delay the project or significantly increase its cost. Estimators should be involved with the scheduling process because the interaction between work activities can drastically diminish expected production rates. Thus, a schedule and sensitivity analysis should be included as part of the estimating and bidding processes.

The two major pieces of information required by the schedule from the estimate are the activity cost and duration. This information is

created in the estimate and needs to be distributed to the schedule on an activity by activity basis. The third major piece of information, sequencing of activities, is unique to the scheduling process and is provided by the user based upon their knowledge of the work and their company's operating procedures.

The Interfacing Process

The interfacing process involves the linking of the previously discussed information related to the estimate and schedule. An automated interfacing process is an interaction between the user and the program. The user makes necessary decisions during the creation of the schedule to provide for flexibility which reflects the user's own methods and ideas. Without the interfacing process the user is required to input data twice, once for the estimate and once for the schedule. Many times double entries result from different parties accessing and managing the data. For example, in a medium sized company, the estimating process is performed in the office and the scheduling process is usually performed at the construction site. When the schedule is created without regard to the estimate, information can be overlooked and this leads to an incomplete cash demand analysis. A usable interfacing process is a system that accounts for the estimated costs and durations.

The interfacing method used by the program developed in this research involves a three step process. First, the user must develop the estimate, using quantities developed from a quantity take-off.

The program contains a database for the prices of materials, labor, and equipment and performs the necessary calculations to derive a cost for each item. Second, the user must establish activities and their precedence in the schedule. Third, the user must assign the items from the estimate to each activity using a percentage of the total quantity available. The activity duration is assigned from combinations of the durations of the estimated items.

CHAPTER IV

PROGRAM PLANNING AND PREPARATION

This chapter covers the philosophy of modular design, structured programming, the choice of a programming language, and a brief description of the two toolbox development systems used to create ESTCPM, which is the focus of this research. ESTCPM evolved using the systematic approach presented by Blaise Liffick (30). Liffick's method comprises a series of steps used to define the programming problem, determine the data required, decide what input/output operations are involved, and set the hierarchy of the various calculations and program operations. Liffick suggests defining problems in a broad sense and then dividing the problems into identifiable modules. He defines a module as a section of the program that performs exactly one function. Liffick also suggests that modules should be independent from each other so that if a module is removed from the program only its particular function will be affected. Liffick's method as applied in this dissertation is discussed under the heading "ESTCPM System Definition."

Two software products: Turbo Database Toolbox by Borland International (74) and Turbo Magic by Sophisticated Software (72) were used in the development of ESTCPM. The contributions of these two products are discussed under the heading "Program Enhancement Software." A historical cost database that was developed as part of

the author's work for the master's degree was incorporated into ESTCPM. A short program was created to convert the historical cost database into a format compatible with the new ESTCPM file retrieval system. The historical cost database was also modified to provide a link to the cost database system.

Modular Design

A module is an individually identifiable set of program instructions which have a common purpose. The advantage of modular design is that each module can be tested independently of the other modules to insure reliability and accuracy. The concept of modular design can be implemented using the top-down method, the bottom-up method, or a combination of both. With the top-down method, a broad problem definition is outlined and then specific procedures are written until the details of the program are complete. The bottom-up method develops procedures to perform specific tasks and then develops the more general procedures which manage the completed system.

A combination of the two methods was employed to develop the ESTCPM program. A broad problem definition was established and the program goals were prescribed at the onset. Once the program direction was formed, various methods for completing the task were explored. The input procedures for handling data, menus, errors, and the help system were written and tested. A broad approach was then incorporated to design the screen displays and menus. Finally the

file handling system was developed to control the input and output to the network of data files.

ESTCFM System Definition

The first step in the design of the ESTCFM system was development of the a Visual Table Of Contents (VIOC) shown in Figure 2. This diagram shows the major components of the program system. The VIOC diagram indicates the system is conceptually separated into three parts by function. These three functions are estimating, scheduling, and the interface required to integrate the estimating and scheduling processes. Beneath these three functions are related subordinate tasks which were further broken down as the program was developed. The VIOC diagram is also useful for identifying redundant tasks in the program system.

The next step involved identification of the data items that would be processed by the program system. A formal presentation of this data is shown in the Data Dictionary of Appendix A. The first portion of the Data Dictionary establishes the rules used to create the relationships between the various data items. The Data Dictionary was constructed using the top-down method as can be seen in the first section, which is composed of the files required by the system. These files are then defined by record references which consist of the individual data items. Finally, the data items were broken down into their data types and the data types were defined by the limits of their actual variable content.

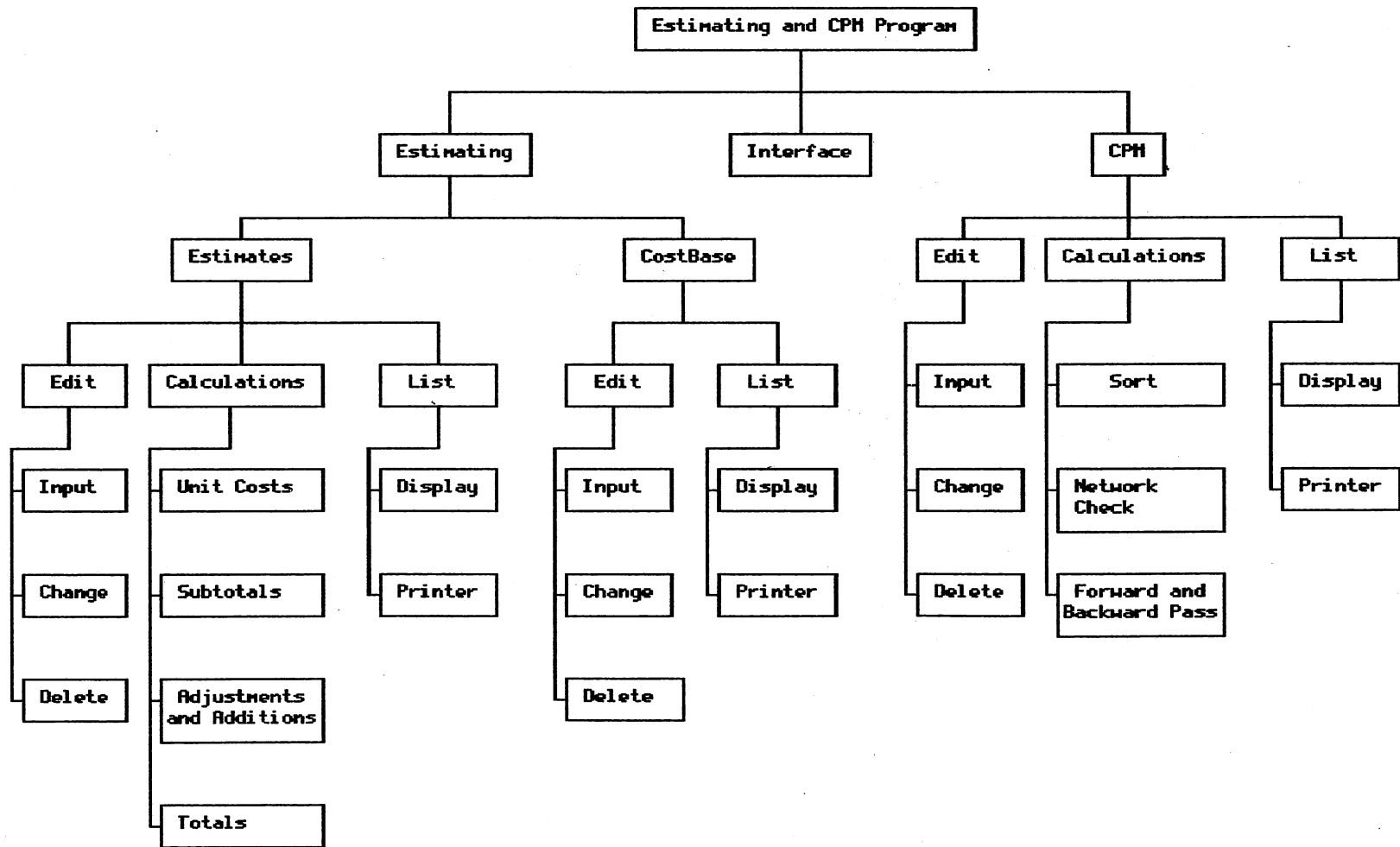


Figure 2. Visual Table of Contents

Simultaneously with the development of the Data Dictionary, a Flow Control Diagram (Figure 3) was developed. The Flow Control Diagram is based upon a single input filter which categorizes the input as commands, errors, data, or background operations. The Command Dispatcher determines if the pressed key is a single key operation, a request for a menu, a function key, or one of the cursor editing keys. After the program completes the desired command it returns to the User Filter/Process Scheduler so it can accept more input from the user. The error system detects what error has been committed, makes the necessary corrections, and notifies the user. The data input system classifies the type of data requested by the program and restricts the input to the characters which correspond to the requested data type. The background dispatcher determines which operation has been requested and carries out the request.

The Data Flow Diagram shown in Figure 4 is developed from the Data Dictionary and shows how the data is grouped together and how the data flows through the program during processing. The circular figures represent data files, the rectangles represent data processing, and the double lines indicate data flow. Data enters the diagram through the manual calculation of the quantity takeoff and keyboard entries such as the schedule information. The ESTCPM program database was developed using the Data Flow Diagram and the Data Dictionary. It consists of fourteen data files, fourteen primary index files and eleven secondary index files. The information contained in the data files and the primary and secondary indexes are defined in the Data Dictionary of Appendix A.

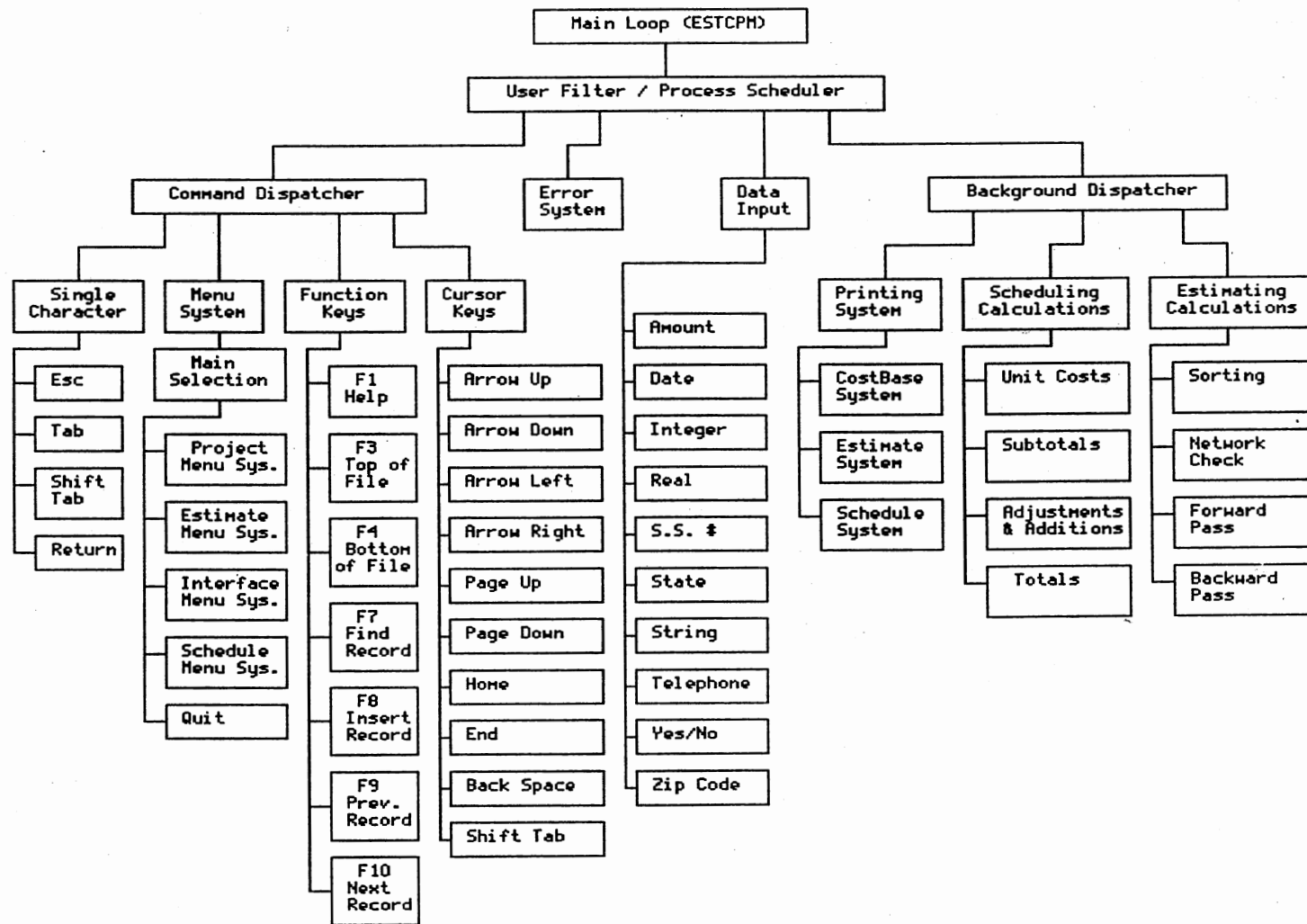


Figure 3. Flow Control Diagram

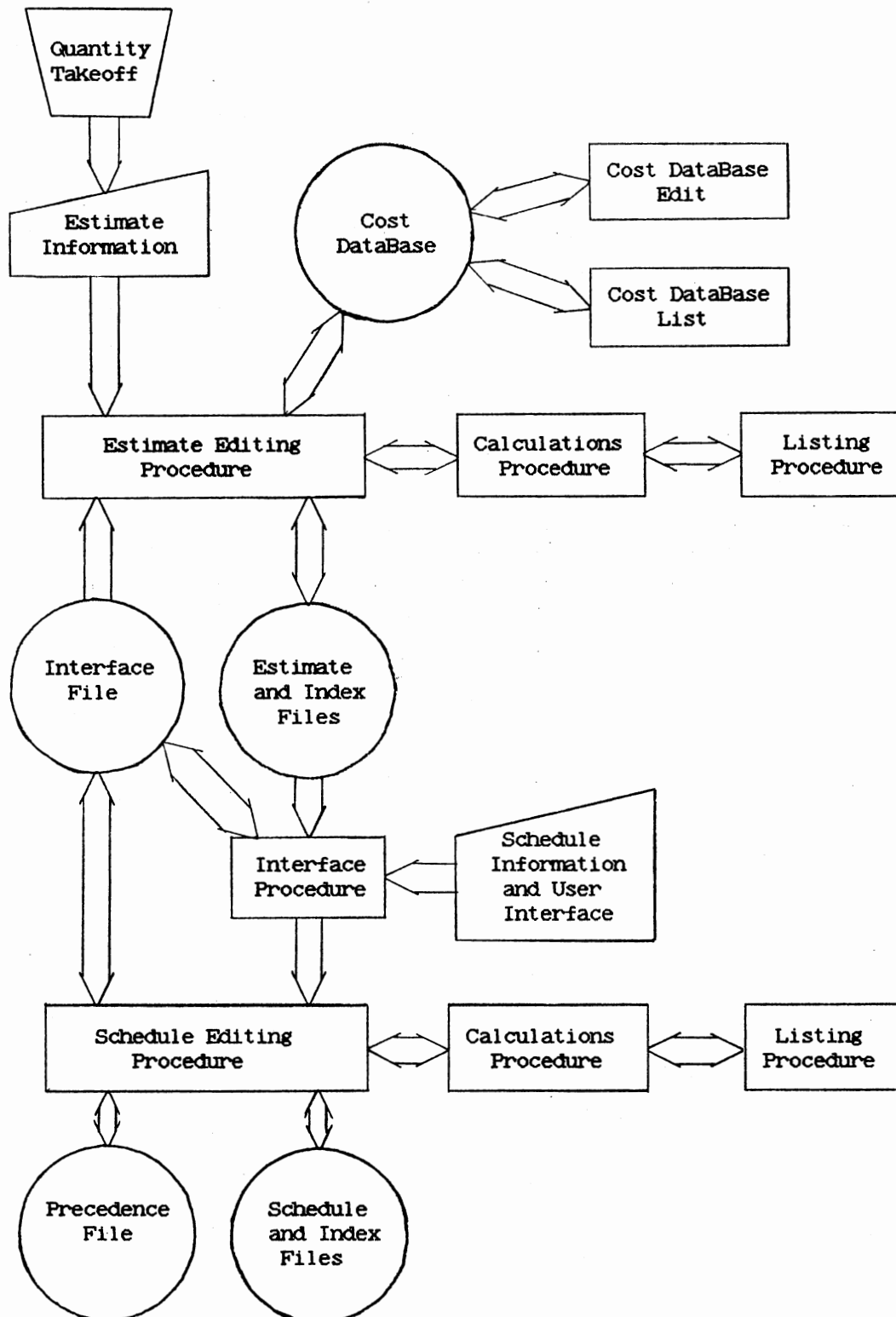


Figure 4. Data Flow Diagram

When the preliminary ESTCPM program design was completed the actual program implementation was considered. The preliminary program design was divided into four major components which were then divided into modules. The modules were then defined according to their intended functions. The four major components of this program are identified as the input/output and control system, the estimating system, the scheduling system, and the interfacing system. Central management of the program is through the input filter procedure which reduces the possibility of the user introducing an input error. This input procedure consists of several subprocedures which were integrated into the program as a unit.

Structured Programming

Structured programming is a process by which a program system is defined in a macro level of detail without the disclosure of detailed programming. This process makes the program easier to read and decipher. Structured programs usually consist of a small main program which accesses subroutines to execute the program's objectives. Structured programs are built from control structures which do not contain the GOTO statement. These structures are the Repeat-Until, While-Do, If-Then-Else, For-Do, and Case-of.

Choice of Languages

Several languages were considered for the development of the

ESTCPM program. Their advantages and disadvantages were evaluated with respect to the best possible performance and the most user friendly algorithm. Table 2 lists the languages considered and discusses their advantages and disadvantages. Spreadsheet programs were not considered for this research due to their slow performance and poor ability to manage database files. Database management programs were not considered because they are slow due to their generic approach to databases.

Turbo PASCAL (73) was chosen as the programming language for its clarity and power. The Turbo PASCAL (73) language has many features which were required for the ESTCPM program such as speed of compilation and available toolboxes. Toolboxes consist of tested source code which performs a specific task and can be included into a program without modification. Toolboxes which are usually available for most languages perform such tasks as file manipulation, screen handling, data input, and specialized calculations.

Program Enhancement Software

The Turbo database Toolbox and Turbo Magic software packages incorporated into the ESTCPM program system were used as support software to develop and enhance the interfacing system. The decision to include these two software packages was based upon their similarity to the author's own master's degree work.

Due to the large amount of information that must be handled in an interfacing process, an efficient search, sort, and retrieval system

TABLE 2
 ADVANTAGES AND DISADVANTAGES OF
 VARIOUS PROGRAMMING LANGUAGES

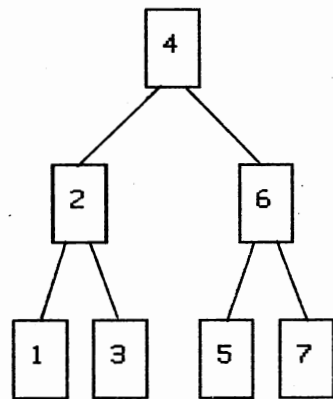
Programming Language	BASIC	FORTRAN	COBOL	C	Pascal	Prolog	Turbo Pascal
String Handling	G	P	F	G	G	G	G
Speed of Compilation	P	F	P	G	F	F	G
Speed of Execution	P	G	F	G	G	P	G
Portability	P	F	F	G	G	P	F
Graphics	G	F	P	G	P	G	G
Dynamic Allocation of Memory	N	N	N	Y	Y	Y	Y
Structured Data	N	N	N	Y	Y	Y	Y
Sturctured Language	N	N	N	Y	Y	Y	Y
Cost	L	H	H	L	H	L	L
Availability	H	M	L	H	M	L	H

G - Good H - High Y - Yes
 F - Fair M - Medium N - No
 P - Poor L - Low

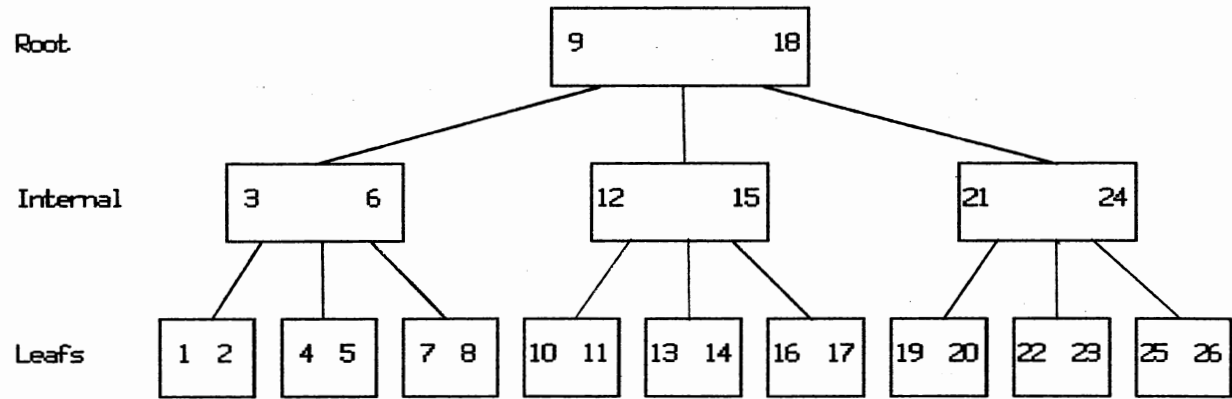
must be used. The B+ Tree data structure was selected for the development of the database system for ESTCPM. The B+ tree structure is named for its inventor R. Bayer. A complete discussion of B+ trees can be found in Niklaus Wirth's book (78). Tree structures are a simple way of organizing data for searching and retrieval. Tree structures consist of nodes and branches as shown in Figure 5. There are three types of nodes: the root or top node, interior nodes, and end nodes. A binary tree node can have zero, one, or two branches from each node. To find a particular piece of data in the binary tree, one node is searched at a time starting at the root or the top. Each node contains four possibilities:

1. The data sought is in the current node.
2. The data being sought is less than the current node, and is contained in nodes to the left of the current node.
3. The data being sought is greater than the current node, and is contained in nodes to the right of the current node.
4. The data sought is not in the current node, and the current node is an end node.

The binary tree structure only allows each node to contain one piece of data and it can only have two subnodes. In contrast the B+ Tree data structure allows each node to contain more than one data item and have multiple subnodes (Figure 5.) The B+ tree structure uses a page or group of data in place of each node to form the binary tree structure. A B+ Tree page is analogous to a binary tree node. Each page can be stored in the computer's memory and the data contained on each page is ordered. This method allows a rapid search



Binary Tree



B+ Tree

Figure 5. Comparison of Binary Tree with B+ Tree

through a database which is too large to fit in the computer's memory. A B+ Tree structure also requires a balancing algorithm to maintain equal distance from the root to the end nodes. A B+ Tree data management system would have had to be written as part of this research if source code had not been located elsewhere. The Database Toolbox written by Borland International (74) was selected for its ease of integration into the ESTCPM program system. The Database Toolbox contains procedures for adding, deleting, and updating records in the data files. The data files are referenced through index files to minimize the amount of required computer memory. Each file requires approximately sixty four kilobytes of memory with a maximum demand of three hundred twenty kilobytes.

The designing of input screens, for ESTCPM was accomplished by a trial and error process. The objective was to provide all the necessary information on the screen without making the display appear too crowded. Once the layouts for the data displays were finalized the input and control procedures were written. The Turbo Magic (72) input development system was incorporated into ESTCPM. Also many of the required calculations were incorporated into the procedures developed with the Turbo Magic input development system. This process required modifying a significant amount of source code to achieve the desired results.

Once the input system was completed, the database manipulation procedures were developed. A generic procedure was created to access the Turbo Database Toolbox which was used to handle the maintenance of the ESTCPM database files. The commands available for operation on

the database are: update or add records, find any record, find the first record, find the last record, delete a record, and clear a record in memory. After the database procedures were completed the CPM calculations for the schedule were conceptualized and placed in the ESTCPM program as comment lines.

The last step in developing the ESTCPM program was to integrate all the various procedures together for the final testing and debugging process. The overlay system and the main program were adjusted to accommodate and place all the procedures and data into the computer's memory in an efficient manner.

CHAPTER V

PROGRAM DEVELOPMENT

General Program Description

ESTCPM can be categorized under the general heading of a database management system. The objective of the ESTCPM program is to retrieve, update, manipulate, and integrate data from three separate information sources. These sources consist of a cost database system, project cost estimates, and project activity schedules. ESTCPM requires manual operations such as a quantity take-off combined with computer keyboard input and archive data files. The ESTCPM system allows the user to develop a critical path method (CPM) precedence schedule utilizing the information generated for a cost estimate without having to re-enter the information into the computer.

The organization of the ESTCPM data files is demonstrated in Figure 6. The figure references below the file names refer to the Functional Dependency Diagrams of Appendix B. Figure 6 shows the interconnection of data between the files and the Function Dependency Diagrams demonstrate the interconnection within files. The structure of the ESTCPM program consists of four separate operations: project selection, estimate input, schedule input, and the estimate schedule interface.

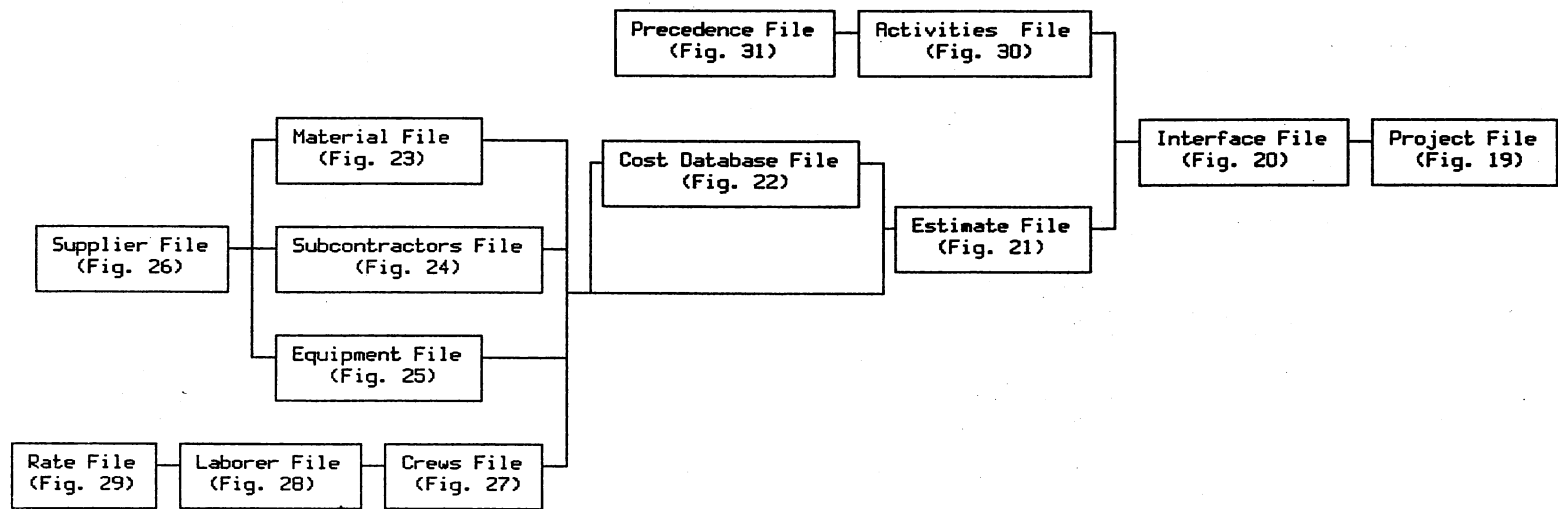


Figure 6. Interface Database File Structure

These four operations normally would be performed in the following sequences. The user would first utilize the project selection operation to identify all pertinent information regarding the general description of the project. The next sequence would be to utilize the estimate input operation to generate the project estimate. This would involve extraction of information from the cost database for creation of the estimate file. Next, the user would use the schedule input operation to create the schedule file of activity numbers, descriptions, and sequences of activities. Completion of this operation would create all the information necessary for the generation of the CPM schedule except for the activity durations and costs. The final sequence is development of the duration and cost of each activity in the schedule through the use of the estimate schedule interface operation.

Since the estimate schedule interface operation is the primary object of this research, it is discussed first. The remaining operations of project selection, estimate input, and schedule input are discussed on the succeeding pages.

Estimate Schedule Interface

The estimate schedule interface is the most important subroutine of the ESTCPM program because it is the focus of this dissertation. This subroutine links the data from the estimate to the data in the schedule and arranges it in an acceptable form. The interface procedure consists of an overlay Interface Data Form (Figure 7) which

Schedule Data Input Form

Job # : _____ Project : _____
Act. # : _____ Act. Descrip. : _____

Code	Description	Remaining	Total	%
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---
-----	-----	-----	-----	---

Interface Data

Order %	Description	Quantity	Unit	Cost	Product.	Duration
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	-----	-----	-----	-----	-----	Days
-----	Total	-----	-----	-----	-----	Days

F1 : Help Shf-F1 : Exit

Figure 7. Interface Data Input Form

displays the items from the estimate with their total quantities and the amounts which have not been distributed.

A file is created which contains information relating the estimate data to the activities of the schedule. The following information is contained in the interface data file:

1. The Project Number
2. The Activity Number
3. The Estimate Code Number
4. The Estimate Precedence Code
5. The Quantity of the Estimated Item
6. The Unit Price of the Estimated Item
7. The Production Rate of the Estimated Item

By creating a file which links the data from the estimate to the schedule, redundancies are eliminated and a minimum amount of data processing is required. Total duration and cost of each activity are calculated as estimated items are distributed. An order or sequence is assigned to each estimated item in an activity to reflect the sequence in which items are installed. If the user assigns the same order number to two estimated items in an activity, only the largest duration is used in calculating the total duration. By making the order number the same, the user has indicated the estimated items can be performed simultaneously. The entire cost of each estimated item is added together to determine the total cost of an activity.

Appendix C contains an example problem which demonstrates the interfacing process. The example consists of an addition to a low rise office building on the Oklahoma State University campus. The

addition contains 28 scheduled activities and 31 estimated items. The ESTCPM program lists the total estimated cost of the project which can be compared to the total cost distributed to the schedule. ESTCPM will also print a list of those items from the estimate which have not been completely distributed.

Project Selection

The project selection subroutine allows the user to select a project for manipulation. The user can select the project by entering the project number or project name. The project selection subroutine consists of two input displays (Figure 8). The data entered about the project in this operation are as follows:

1. Project number
2. Project title
3. Estimate and schedule revision numbers
4. Project location
5. The architectural and engineering firm name
6. The estimate and schedule completion dates
7. The person checking the work
8. The project adjustment factor
9. The material tax and percentage
10. The general overhead and percentage
11. The job overhead and percentage
12. The profit and percentage
13. The total project cost

Project Input Form	
Job # :	_____
Project :	_____
Estimate Revision # :	_____
Schedule Revision # :	_____
Location :	_____
R/E Firm :	_____
Estimate Date : __/__/__	Schedule Date : __/__/__
Checked By :	_____
F1 : Help	Shf-F1 : Exit

Misc. Project Data Input Form	
Job # :	_____
Project :	_____
Adjustment Factor :	_____%
Total Material Tax :	_____%
Material Tax :	_____%
Total General Overhead :	_____%
General Overhead :	_____%
Total Job Overhead :	_____%
Job Overhead :	_____%
Total Profit :	_____%
Profit :	_____%
Total Job Cost :	_____
F1 : Help	Shf-F1 : Exit

Figure 8. Project Data Input Form

The material tax, general overhead, job overhead, profit, and total project cost are calculated as the estimated data are entered. The user cannot change these values but can change the percentages for each estimated item. Once a project has been selected, the user can begin entering his estimate by choosing Estimate Input from the main menu.

Estimate Input

The estimate input utilizes a resource database system, historical cost database, and completed projects to create a new estimate. The operation is subdivided into two separate functions. The first function of the estimating subroutine allows the user to create, edit, or delete an estimate. The user can retrieve estimate items from the historical cost database by entering the item code or description. The user can add new items or change the values provided by the historical cost database. Data from comparable completed estimates can be retrieved and modified for the current project in a similar manner. These data can be viewed by the user before they are incorporated into the estimate. When the user has selected all the items that are required in the estimate, ESTCPM performs the necessary calculations. The user then has the option of printing the estimate, listing it on the display, or continuing to the scheduling procedure. The Estimate Input Form (Figure 9) and the Historical Cost Database Input Form (Figure 10) contain similar information. The following

Estimate Input and Edit Form

Job # : _____ Project : _____

Code : _____ Item Description : _____

Type #	Description	Quantity	Unit	Price	Cost	Product.
Mat'l	_____	_____	_____	_____	_____	_____
Labor	_____	_____	_____	_____	_____	_____
Equip	_____	_____	_____	_____	_____	_____
Sub	_____	_____	_____	_____	_____	_____

Item Subtotal

Adjust. Factor : _____

Material Tax : _____ % Item Installed : ___/___/___

General Overhead : _____ % Weather Cond. : _____

Job Overhead : _____ % Job Cost : _____

Profit : _____ % Estimated by : _____

Total Item Cost : _____

Unit Bid Price : _____

Memo : _____

F1 : Help

Shf-F1 : Exit

Figure 9. Estimate Input Form

Costbase Input and Edit Form

Code : _____ Item Description : _____

Type	#	Description	Unit	Price	Product.
Mat'l	---	-----	---	-----	-----
Labor	---	-----	---	-----	-----
Equip	---	-----	---	-----	-----
Sub	---	-----	---	-----	-----
Item Subtotal			---	-----	-----

Entered by : _____ Date Stored : __/__/__

Memo : _____

F1 : Help

Shf-F1 : Exit

Figure 10. Historical Costbase Input and Edit Form

information is included in both the estimated item and the historical cost database:

1. The Construction Specifications Institute (CSI) six digit code number
2. The item's CSI description
3. A material, labor, equipment, and subcontractor identification code
4. A brief description of the material, labor, equipment, and subcontractor for an item
5. The production units
6. The unit costs of labor, materials, equipment, and subcontracted work
7. The expected production rates per day
8. The person entering the information

A memo line provides the user with information regarding how the item costs were calculated. The user also enters the date of any transaction to establish a record which documents a particular item with respect to time. The estimate also contains the material tax, general overhead, job overhead, and profit for each item. The unit bid price is calculated from the total item quantity for unit bid contracts.

The second function of the estimating subroutine allows the user to manipulate a cost database of materials, labor, equipment, and subcontractors. The user can enter regularly used materials (Figure 11) and the suppliers (Figure 12) of these materials. This leaves an exact trail of how the estimate was developed and the specific

Material Data Input Form

Material Code : ___ Group Index : ___

Description : _____

Production Unit : ___ Price : _____ Production Rate : _____

Supplier Reference : ___

Vendor Name : _____

F1 : Help _____ Shf-F1 : Exit _____

Figure 11. Material Data Input Form

Supplier Input Form

Supplier Code : ___

Vendor Name : _____

Address : _____

Address : _____

City : _____ State : __ Zip Code : _____

Telephone # : (___) _____

F1 : Help _____ Shf-F1 : Exit _____

Figure 12. Supplier Data Input Form

materials incorporated into the project. Estimated crews (Figure 13a) consist of the various laborers employed by the company and can be entered as a resource. Figures 13(b) and 13(c) provide the data related to the employees background and wage rates, respectively. Information which is common among employees is grouped separately from the data on the individuals. An Equipment Input Form (Figure 14) allows the user to incorporate his company's equipment spread and production rates into an estimate. Equipment can be included into an estimated item individually or as a complete equipment group. A list of subcontractors (Figure 15) can be maintained providing a reference on the current project and for future estimates. If the cost of any resource changes during the estimating process, that change can easily be corrected in all items that are dependent on that resource.

This second function is easily incorporated into the estimate by entering the appropriate material, labor, equipment, or subcontractor code. Information can also be retrieved by calling the resource input display from the estimate. When the resource is selected the user exits the subroutine and the data is entered into the Estimate Data Input display for acceptance or modification by the user. After all the items have been entered in the estimate the user can begin to define the schedule by selecting the Schedule Input option on the main menu.

Schedule Input

The scheduling, operation of the ESTCPM program, is divided into

Crew Data Input Form				
Crew Code : ___		Crew Name : _____		
Production Unit : ___		Price : _____	Production Rate : _____	
Job Class	Social Security #	Last Name	Hourly Rate	Production Rate/Hour
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
---	-----	-----	-----	-----
F1 : Help		Shf-F1 : Exit		

(a)

Figure 13. Crew Data Input Form

Employee Input Form	
Last Name : _____	Social Security # : ____-__-____
First Name : _____	Middle Name : _____
Address : _____	
Address : _____	
City : _____	State : __ Zip Code : ____-____
Telephone # : (____) ____-____	
Job Classification : ____	Effective Date : __/__/__
Hire Date : __/__/__	Termination Date : __/__/__
F1 : Help	Shf-F1 : Exit

(b)

Labor Rate Input Form	
Employee Last Name : _____	Social Security # : ____-__-____
Job Classification : ____	Effective Date : __/__/__
Job Description : _____	
Hourly Rate : _____	Monthly Rate : _____
Production Rate per Hour : _____	Units : ____
F1 : Help	Shf-F1 : Exit

(c)

Figure 13. Continued

Equipment Input Form

Equipment Code : ___ Group Index : ___

Equipment ID Number : _____

Description : _____

Supplier Code : ___

Vendor Name : _____

Original Cost : _____ Depreciation Method : Declining Balance

Production Unit : ___ Price : _____ Production Rate : _____

F1 : Help

Shf-F1 : Exit

Figure 14. Equipment Data Input Form

Specialty Contractor Input Form

Contractor Code : ___ Name : _____

Address : _____

Address : _____

City : _____ State : __ Zip Code : _____

Telephone # : (___) ___-____

Production Unit : ___ Price : _____ Production Rate : _____

Quantity : _____ Duration : ___ Days

Start Date : __/__/__ Finish Date : __/__/__

F1 : Help

Shf-F1 : Exit

Figure 15. Specialty Contractor Input Form

two independent procedures. The first procedure allows the user to create a schedule of activities separate from his estimate. The Schedule Data Input Form (Figure 16) allows the user to input the Activity Number, Activity Description and a memo line for details about each activity. The Schedule Data Input Form also displays the calculated duration and total cost after the estimated items have been distributed. Each estimate item which has been distributed to a particular activity is displayed in the bottom portion of the form. The Schedule Data Input Form also exhibits the early start, early finish, late start, late finish, free float, and total float of the given activity.

The second procedure allows for input of the schedule precedences. The Precedence Data Input Form (Figure 17) will accept any number of activities following a given activity number. The scheduled activities are recalled by the activity number or description and the list of following activities is supplied in the bottom portion of the display.

The time computations for the critical path method were not implemented in the ESTCPM program. A theoretical method was developed which would accommodate the intricate database file structure and was included as comments in the program. This theoretical method is a modified algorithm of the directed graph method which was developed to handle the extensive data sorting requirements. This theoretical method involves storing the schedule sequence data in a binary tree structure which eliminates the need for sorting. The information can then be retrieved and restored to the data files in a very efficient

Schedule Data Input Form

Job # : _____ Project : _____
 Act. # : _____ Act. Descrip. : _____
 Duration : _____ Days Total Cost : _____ Critical Path Item : _
 Previous Activities : _____ Following Activities : _____

Early Start Early Finish Late Start Late Finish Total Float Free Float
 ___/___/___ ___/___/___ ___/___/___ ___/___/___ _____ _____

Memo : _____

Order %	Description	Quantity	Unit	Cost	Product.	Duration
_____	_____	_____	_____	_____	_____	Days
_____	_____	_____	_____	_____	_____	Days
_____	_____	_____	_____	_____	_____	Days
_____	_____	_____	_____	_____	_____	Days
_____	_____	_____	_____	_____	_____	Days
_____	_____	_____	_____	_____	_____	Days
_____	Total	_____	_____	_____	_____	Days

F1 : Help

Shf-F1 : Exit

Figure 16. Schedule Data Input Form

Precedence Data	
Job # : _____	Project : _____
Act. # : _____	Act. Descrip. : _____
Duration : _____	Total : _____
Following Activity	
_____	_____
_____	_____
_____	_____
F1 : Help	Shf-F1 : Exit

Figure 17. Precedence Data Input Form

manner while not requiring the user to insure the following precedence numbers are greater than the activity number.

Database Characteristics

A database is an electronic collection of information which can be summoned upon demand. Utilization of a database system requires an integration of hardware, software, data, and the user. The ESTCPM database system is implemented on a microcomputer with 640 kilobytes of memory and a 20 megabyte hard disk. ESTCPM is designed for an RGB color monitor and a wide carriage dot matrix printer. Other hardware configurations can be used but require a separate installation procedure. This section discusses the various components of the ESTCPM database software system. Identifying the data that must be manipulated is the first step in the process of creating a database software system.

The Data Definition Dictionary

A Data Definition Dictionary is a detailed accounting of the data used by a database program. The Data Definition Dictionary for ESTCPM is shown in Appendix A. The data are categorized in a top-down sequence with the file definitions occurring at the top of the dictionary. Each file consists of a single record type and each record in a particular file is called a tuple. A record contains several data items which are grouped together based upon their

similarity. Each data item in a record is called a field and a data field for a particular record contains similar information. At the bottom of the Data Definition Dictionary are the physical limits on each of the various data items. The information in the Data Definition Dictionary identifies the various file structures required by the ESTCPM program.

The File Structures

The Data Definition Dictionary provides the conceptual database design which is the user's view of the data. The data must be stored on the disk in an efficient physical organization which doesn't necessarily correspond to the conceptual definition. The data structure developed for ESTCPM conforms to the "third normal form" for a database system. The "third normal form" is a format for organizing the data manipulated by a database program to reduce duplicate data entries in the various files. The "third normal form" is verified by arranging the data into the Functional Dependency Diagrams of Appendix B and visually eliminating redundancies. C. J. Date (11) explains that several levels of data organization or normal forms exist which improve the efficiency of data retrieval and reduce the number of redundancies in the data files. All the data for the ESTCPM program must be maintained on a hard disk drive due to the number and large size of the files required by the system. Data are transmitted to and from the disk drive on a continuous basis which requires a hard disk drive for timely operation. If the data are not stored in an

efficient structure a considerable amount of time will be dedicated to the reading and writing process. The data are spread across fourteen different files and ESTCPM is required to open and close each of these files when a new piece of data is required. The efficiency of the database system is a function of how the data is collected in the various data files.

ESTCPM Program Features

This section contains a more specific discussion of the service procedures found in the ESTCPM program system. The service procedures include the Overlay System, the Input System, the Error System, the Help System, Miscellaneous Procedures, and the database system. The source code and documentation can be found in the ESTCPM source code reference manual(68).

Overlay System

The ESTCPM program incorporates an overlay system to manage the various operations. The four major operations need not coexist in memory, therefore, they can share the same memory addresses. This method also allows for the addition of other major sections as they are developed. An overlay is a method which allows a program designer to create programs much larger than can be accommodated by a computer's memory. The technique consists of collecting a designated set of procedures and functions into one or more files separate from

the main program. The main program sets aside computer memory and automatically reads one procedure at a time as they are called. This method is demonstrated in Figure 18. The overlay memory area reserved in the main program is only as large as the biggest overlay procedure. Smaller procedures obviously occupy only part of the reserved area. Overlay procedures must be carefully planned to avoid calling procedures in the same overlay file. A disk access is required each time an overlay procedure is called. Therefore, the use of an overlay system slows the execution speed. The procedures included in overlay files for ESTCPM were selected to cause delays only at the end of major tasks.

Input System

An unique aspect of the ESTCPM program is the input system. Only two read statements exist in the input system; one for printable character input and one for the IBM extended key board input set. By only allowing character input into the system, ESTPCM is able to filter unwanted or illegal input, while allowing the user an unrestricted input style. For example, the user is warned when trying to enter commas with any numeric input.

The input procedure is significant to the operation of ESTCPM since much of the contact time of the user is devoted to data entry. The input of data is limited to as few read statements as possible because reading input is a major source of errors. The input procedure is capable of reading general input and pull down type menus

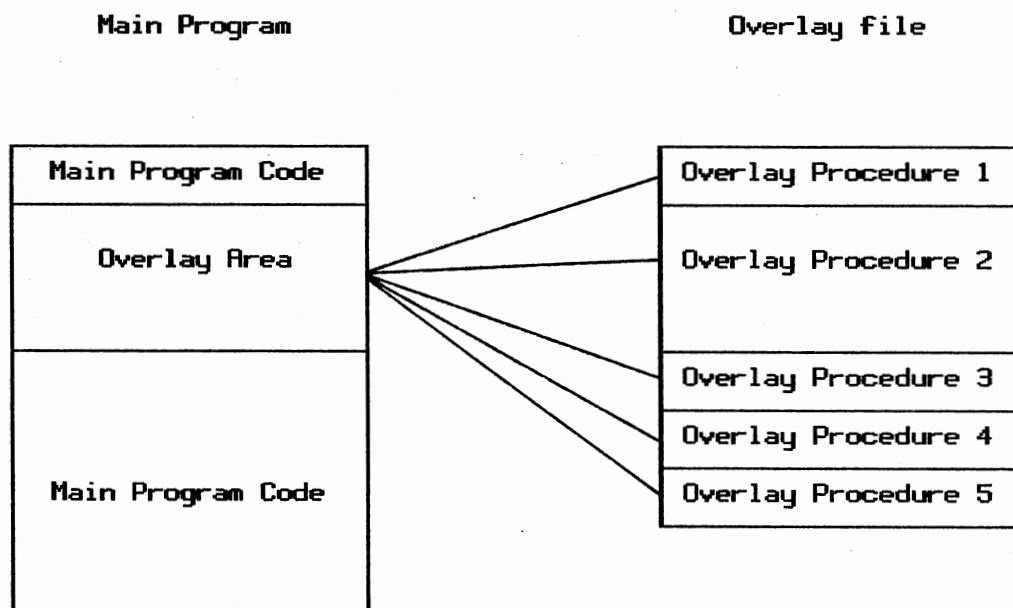


Figure 18. Principle of Overlay System

to make the system more user friendly. As an intelligent system, it processes each key stroke to determine what action is necessary. The input procedure allows the user to manipulate data with the usual editing processes found in a word processor. Several conversion procedures are required to transform the character input data into integers, reals, and strings. The ESTCPM program also transforms input into specific data types such as dates, telephone numbers, state abbreviations and zip codes. If the user attempts to input incorrect data, the ESTCPM program has an error handling system to inform the user of acceptable character input.

Error Handling System

The error procedure uses the bottom row of the display to print messages and useful information. The error messages are stored as typed constants within the procedure calling the error system. Errors can arise from four sources: user input errors, calculation errors, run time errors, and system I/O errors. User input errors result when the user accidentally enters incorrect data or does not understand what type of data the program requests during a particular part of the program execution. The program is not usually able to filter out erroneous data once the information is accepted by the input system. As part of the input procedure the data input is limited to specific data types and numeric ranges. For example, if the required input is numeric, the input procedure should only accept numeric characters. ESTCPM receives all data as a character type input and then converts

them to the desired data types providing a second check on the data integrity. Data that have been converted to a numeric type are checked to insure that they are in the acceptable range for that specific numeric type. Calculation errors can result from faulty computations such as, dividing by zero, negative or zero input to the natural logarithm function, or negative input to the square root function. Run time errors are a function of the operating system and the compiler used for the program. They can result from faulty logic in the program or from data type mismatches created from user input. System errors can be any of the following: disk I/O problems, printer malfunctions, data corruption, hardware malfunctions.

Miscellaneous Procedures

As with any program, ESTCPM requires a variety of support procedures to add to the syntax of the chosen implementation language. Some procedures which were necessary for the Pascal programming language are:

1. A procedure to fill a string with a constant
2. A procedure to upper case an entire string
3. Procedures to open and close data files
4. A procedure to increase the number of open files

The system initialization procedure, called by the main program, displays the initial screen, checks the data files for integrity and initializes the system variables. If the computer determines the data files have been corrupted, the system initialization procedure

provides a method for the user to recover as much data as possible.

Configuration of the system involves gathering information necessary to operate the program on a given computer system. The data required by this subroutine are supplied in two parts: (1) the program must evaluate the computer system and setup the required files for it to function, (2) the user must input information the program cannot ascertain by itself, i.e., printer type. As part of this operation ESTCPM checks all data files for integrity, and it opens and closes all files required by the various procedures. At the end of a session ESTCPM must perform cleanup operations to reset the display and to clear any hardware setting which would conflict with the operating system.

The help procedure is content sensitive and contains a help index where needed. The data are stored in picture data files which are retrieved and indexed as to their help content. The two subroutines which retrieve and output display screens also retrieve and output the help screens. The help screens were created using the Turbo Magic program and may be updated without recompiling the program.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Although the management of construction has traditionally been very competitive, many firms operate under techniques which have been developed by experience with little documentation or automation. A major complaint against more sophisticated management systems is the level of detail required and the amount of data that must be handled. A comprehensive project management system is necessary to provide the proper information required to manage a construction project. The ESTCPM database system develops a portion of a comprehensive system by providing a method to interface the estimate with the schedule.

Summary

The ESTCPM database system eliminates the double entry of information and provides an interconnection between the estimate and the schedule. The ESTCPM system provides an accounting process to insure the user that all of the cost items found in the estimate are completely distributed to the schedule.

Some of the features found in the ESTCPM database system are:

1. A user friendly interface
2. A historical cost database

3. A database of completed projects
4. A precedence schedule format
5. Data interfacing from the estimate to the schedule

The ESTCPM program addresses only one segment of the total construction management system. Other components need to be developed to provide a comprehensive management system which can link the entire project cycle. The construction industry has insisted that construction work is too unique to be managed by automated management systems similar to the manufacturing industry. This attitude has perpetuated the resistance to any kind of computerized organization and management.

Recommendations

During the development of the ESTCPM program a variety of topics for further evaluation and investigation were identified. The literature search conducted for this research indicates a high interest in automated procedures to manage project data by automatically linking the processes from Computer Aided Drafting and Design (CADD) drawings to estimating, bidding, scheduling, and project tracking. It has also been suggested that this automation should include changes made to the data in old projects to improve the design and cost estimates of future projects. Future research should concentrate upon improvements to the estimate and schedule interface. Below is a partial list of four additional areas of research to be considered. These areas include improvement of the estimate schedule

link, creation of a schedule tracking link, creation of a tracking estimate link and the addition of Artificial Intelligence to the other processes.

Improvements to the estimate schedule interface could be derived by incorporating two additional methods with the manual distribution of estimated items to scheduled activities. First, the computer could distribute the costs from the estimate to a user developed schedule without user interaction. After the automated distribution, the user could make any necessary changes to suit the particular situation. Second, the user could create an estimate, and the computer could then create a schedule based upon the items contained in the estimate. The user would then review the results and make any necessary changes which would be recorded by the computer to improve the distribution of costs on the next estimate to schedule conversion. Both methods would require an Artificial Intelligence algorithm and would also require some modeling techniques.

The schedule tracking link will require the creation of a tracking system and some modifications to the scheduling subroutine. The information managed in the tracking process is very similar to the estimate, but it must be compatible with the schedule to make schedule updates meaningful. The close tie to the estimate and schedule would allow a user to determine if poor field production is a result of over estimating crew productions or poor planning. If it is determined that the estimated production rates are incorrect, the tracking estimate link would provide a method to improve predictions.

The tracking estimate link will require the development of a more

sophisticated database file structure. The new file structure called a temporal database (Developed in 1987) will provide the user with the added benefit of being able to reconstruct the project status at any point in time. With the complete project cycle computerized, the user would also be able to determine the effects of weather and other delays on the schedule.

The term Artificial Intelligence (AI) is an ornate description of a detailed data analysis involving relationships and characteristics of the data. AI methods are innovative in that the interpretation of the data can be changed based upon trends developed from the data analysis. Artificial Intelligence research is currently in the development stage and will require careful study and development to best provide for the needs of the construction industry.

These recommendations represent only a portion of the possible uses of the computer in construction management. The system could also be tied into a real-time data gathering system such as video cameras, bar code readers, and other sensing devices. A linked management system will also be required with any robotics activity on the project to ensure proper scheduling of activities to avoid interference of work that is performed at the same time.

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APPENDIX A

DATA DICTIONARY

DATA DICTIONARY
for
ESTIMATING AND SCHEDULING
PROGRAM

Rules	Meaning
$x = a$	the data item called x is defined by the specification a , where a is itself a data item to be defined or is a complete description of the data item's attributes.
$x = a + b$	the data item called x consists of both items a and b .
$x = [a/b]$	x consists of either items a or b , but not both.
$x = (a)$	the item specified by a is optional.
$x = \{a\}$	the item specified by a can occur zero or more times.
$x = y\{a\}$	the item specified by a can occur y or more times.
$x = \{a\}z$	the item specified by a can occur up to z times, inclusive.
$x = y\{a\}z$	the item specified by a can occur between y and z times, inclusive.

Project_File	= ProjectRec
CostDataBase_File	= CostBaseRec
CostDataBase_Index_File	= CostBaseRec.Code
CostDataBase_Index_File	= CostBaseRec.Description
Supplier_File	= SupplierRec
Material_File	= MaterialRec
Crew_File	= CrewRec
Labor_File	= LaborRec
Equipment_Spread_File	= EquipmentSpreadRec
Equipment_File	= EquipmentRec
Subcontractor_File	= SubcontractorRec
Estimated_Jobs_File	= EstimateRec
Estimated_Jobs_Index_File	= ProjectRec.JobNumber + EstimateRec.Code
CPM_Activity_File	= CPMNetworkRec
CPM_Activity_Index_File	= ProjectRec.JobNumber + CPMNetworkRec.ActivityNumber

CPM_Interface_File = CPMInterfaceRec
 CPM_Precedence_File = CPMPrecedenceRec
 Printer_Configuration_File = PrinterRec

ProjectRec = JobNumber = 1{String}6 - Primary Key
 + ProjectName = 1{String}40 - Secondary Key
 + EstimateRevisionNumber = Integer - Primary Key
 + CPMRevisionNumber = Integer - Primary Key
 + Location = 1{String}40
 + AEFirm = 1{String}40
 + EstimateDate = Date
 + CPMDate = Date
 + CheckedBy = 1{String}40
 + AdjustmentFactor = Real
 + MaterialTax = Real
 + MaterialTaxPercentage = Real
 + GeneralOverhead = Real
 + GeneralOverheadPercentage = Real
 + JobOverhead = Real
 + JobOverheadPercentage = Real
 + Profit = Real
 + ProfitPercentage = Real
 + TotalJobCost = Real

CostBaseRec = ItemCode = 5{String}6 - Primary Key
 + ItemDescription = 1{String}28 - Secondary Key
 + Description = DescriptionRec
 + Units = UnitRec
 + Code = CodeRec
 + Price = PriceRec
 + Production = ProductionRec
 + ItemPrice = Real
 + EnteredBy = 1{String}20
 + DateStored = Date
 + Memo1 = 1{String}68
 + Memo2 = 1{String}75

EstimateRec = JobNumber = 1{String}6 - Primary Key
 + EstimateRevisionNumber = Integer - Primary Key
 + ItemCode = 5{String}6 - Primary Key
 + ItemDescription = 1{String}28 - Secondary Key
 + Quantity = QuantityRec
 + Code = CodeRec
 + Price = PriceRec
 + Production = ProductionRec
 + Description = DescriptionRec
 + Units = UnitRec

	+ AdjustFactor	= Real
	+ Percentage	= PercentageRec
	+ ItemCost	= Real
	+ ItemInstalled	= Date
	+ Weather	= 1{String}20
	+ EstimatedBy	= 1{String}22
	+ Memo1	= 1{String}68
	+ Memo2	= 1{String}75
QuantityRec	= Material	= Real
	+ Labor	= Real
	+ Equipment	= Real
	+ Subcontractor	= Real
	+ Total	= Real
CodeRec	= Material	= 1{String}3
	+ Labor	= 1{String}3
	+ Equipment	= 1{String}3
	+ Subcontractor	= 1{String}3
PriceRec	= Material	= Real
	+ Labor	= Real
	+ Equipment	= Real
	+ Subcontractor	= Real
ProductionRec	= Material	= Real
	+ Labor	= Real
	+ Equipment	= Real
	+ Subcontractor	= Real
	+ Total	= Real
DescriptionRec	= Material	= 1{String}24
	+ Labor	= 1{String}24
	+ Equipment	= 1{String}24
	+ Subcontractor	= 1{String}24
UnitRec	= Material	= 1{String}4
	+ Labor	= 1{String}4
	+ Equipment	= 1{String}4
	+ Subcontractor	= 1{String}4
	+ Item	= 1{String}4
PercentageRec	= MaterialTax	= Real
	+ GeneralOverhead	= Real
	+ JobOverhead	= Real
	+ Profit	= Real
MaterialRec	= MaterialCode	= 1{String}3 - Primary Key
	+ GroupIndex	= 1{String}3 - Primary Key
	+ Description	= 1{String}40
	+ Unit	= 1{String}4

```

+ Price          = Real
+ Productivity  = Real
+ SupplierRec.SupplierCode

SupplierRec     = SupplierCode = 1{String}3 - Primary Key
+ VenderName    = 1{String}40
+ Address1      = 1{String}40
+ Address2      = 1{String}40
+ City          = 1{String}30
+ State         = 1{String}2
+ Zip           = 1{String}9
+ PhoneNumber   = 1{String}11

LaborRec       = SocialSecurityNumber = 1{String}9 - Primary Key
+ LastName      = 1{String}20 - Secondary Key
+ CrewRec.CrewCode
+ FirstName     = 1{String}15 - Secondary Key
+ MiddleName   = 1{String}15 - Secondary Key
+ Address1      = 1{String}40
+ Address2      = 1{String}40
+ City          = 1{String}30
+ State         = 1{String}2
+ Zip           = 1{String}9
+ PhoneNumber   = 1{String}11
+ HireDate     = 1{String}9
+ TerminationDate = 1{String}9
+ LaborRate.JobClassification
+ LaborRate.EffectiveDate

LaborRateRec   = JobClassification = 1{String}4 - Primary Key
+ EffectiveDate = 1{String}9 - Primary Key
+ JobDescription = 1{String}40
+ HourlyRate    = Real
+ MonthlyRate   = Real
+ ProductionPerHour = Real
+ Unit         = 1{String}4

CrewRec        = CrewCode = 1{String}3 - Primary Key
+ CrewName     = 1{String}40 -Secondary Key
+ Unit         = 1{String}4
+ Price        = Real
+ Productivity = Real

EquipmentRec   = EquipmentCode = 1{String}3 - Primary Key
+ GroupIndex   = 1{String}3 - Primary Key
+ Description   = 1{String}40
+ SupplierCode
+ Unit         = 1{String}4
+ Price        = Real
+ Productivity = Real
+ EquipmentNumber = 1{String}12
+ OriginalCost = Real

```

```

+ DepreciationMethod = Integer
+ Maintenance         = MaintenanceRec

MaintenanceRec = EquipmentCode      = 1{String}3 -Primary Key
+ EquipmentDescription = 1{String}40
+ ItemRepaired        = 1{String}30
+ Cost                = Real

SubcontractorRec = Code              = 1{String}3 - Primary Key
+ CompanyName       = 1{String}40 - Secondary Key
+ Unit              = 1{String}4
+ Price             = Real
+ Productivity      = Real
+ Duration          = Real
+ StartDate         = Date
+ FinishDate        = Date
+ SupplierRec

CPMNetworkRec = JobNumber            = 1{String}6 - Primary Key
+ CPMRevisionNumber = Integer        - Primary Key
+ ActivityNumber    = 1{String}6 - Primary Key
+ Description       = 1{String}40
+ Duration          = Real
+ TotalQuantity    = Real
+ TotalUnit        = 1{String}4
+ TotalProductivity = Real
+ TotalCost        = Real
+ CPMCalculations  = CPMCalculationRec
+ Memo1            = 1{String}68
+ Memo2            = 1{String}75

CPMCalculationRec = Early_Start = Real
+ Early_Finish    = Real
+ Late_Start      = Real
+ Late_Finish     = Real
+ Total_Float     = Real
+ Free_Float      = Real
+ Critical         = Boolean

InterfaceRec = JobNumber            = 1{String}6 - Primary Key
+ ActivityNumber  = 1{String}6 - Primary Key
+ EstimateRec.Code = 5{String}6 - Primary Key
+ CPMRevisionNumber = Integer      - Primary Key
+ EstimateRevisionNumber = Integer - Primary Key
+ PrecedencCode   = 1{String}3
+ Quantity        = Real
+ Price           = Real
+ Productivity    = Real

```

CPMPrecedenceRec = JobNumber = 1{String}6 - Primary Key
 + CPMRevisionNumber = Integer - Primary Key
 + ActivityNumber = 1{String}6 - Primary Key
 + FollowingNode = 1{String}6

SocialSecurity = {String}9
 TelephoneNumber = {String}10
 Date = Real
 Address = 1{String}40
 State = "AL".. "WY"
 ZipCode = {Number}5
 Amount = Real
 Array = [String|Character|Numbers|Symbols|Integer|Real|Boolean]
 String = {Characters|Numbers|Symbols}
 Digit = ".", "0".. "9"
 Character = ["A".. "Z"| "a".. "z"]
 Number = "0".. "9"
 Symbols = "!".. "/" , "[" .. "]", "{ .. }"
 Integer = {-32768..32767}6
 Real = {1 E-38..1 E+38}11
 Boolean = [True|False]

APPENDIX B

FUNCTIONAL DEPENDENCY DIAGRAMS

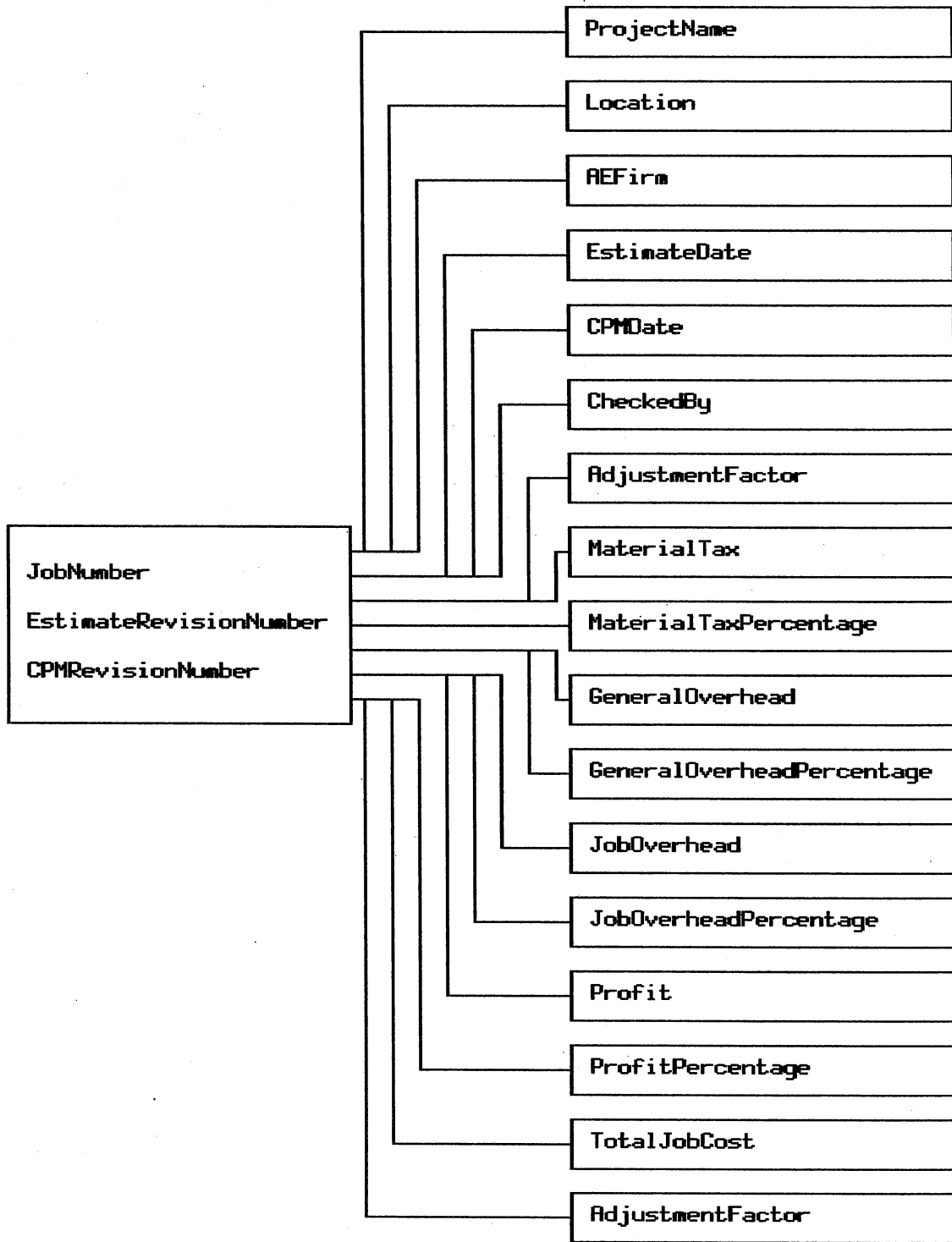


Figure 19. Functional Dependency Diagram of the Project File

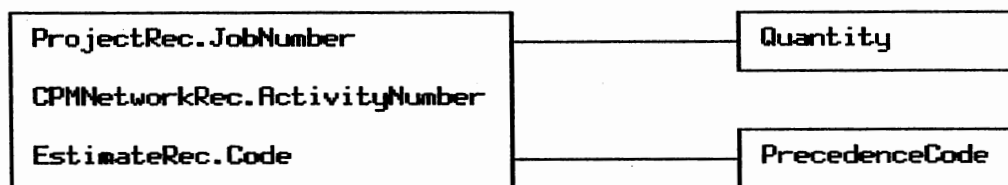


Figure 20. Functional Dependency Diagram
of the Interface File

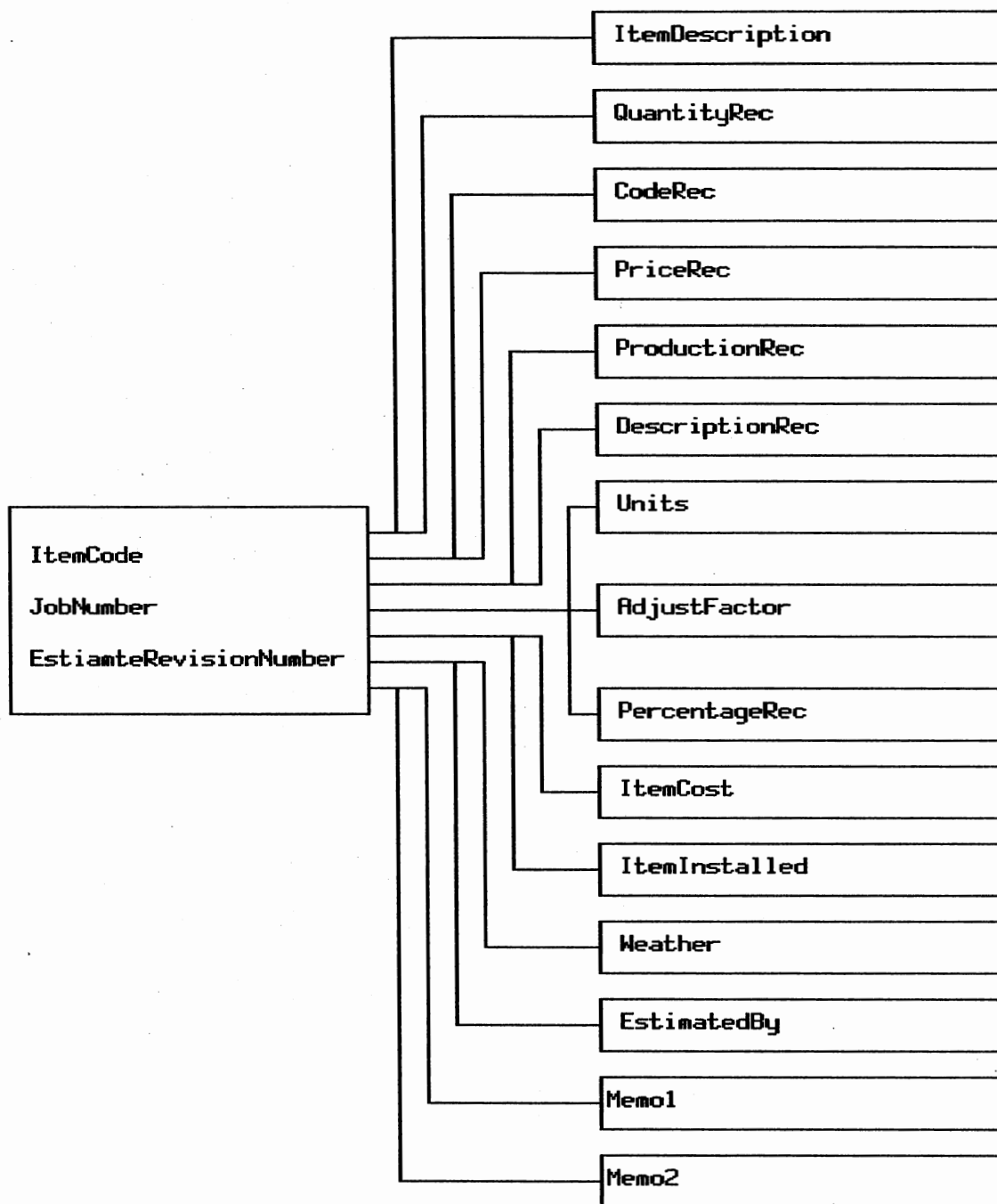


Figure 21. Functional Dependency Diagram
of the Estimate File

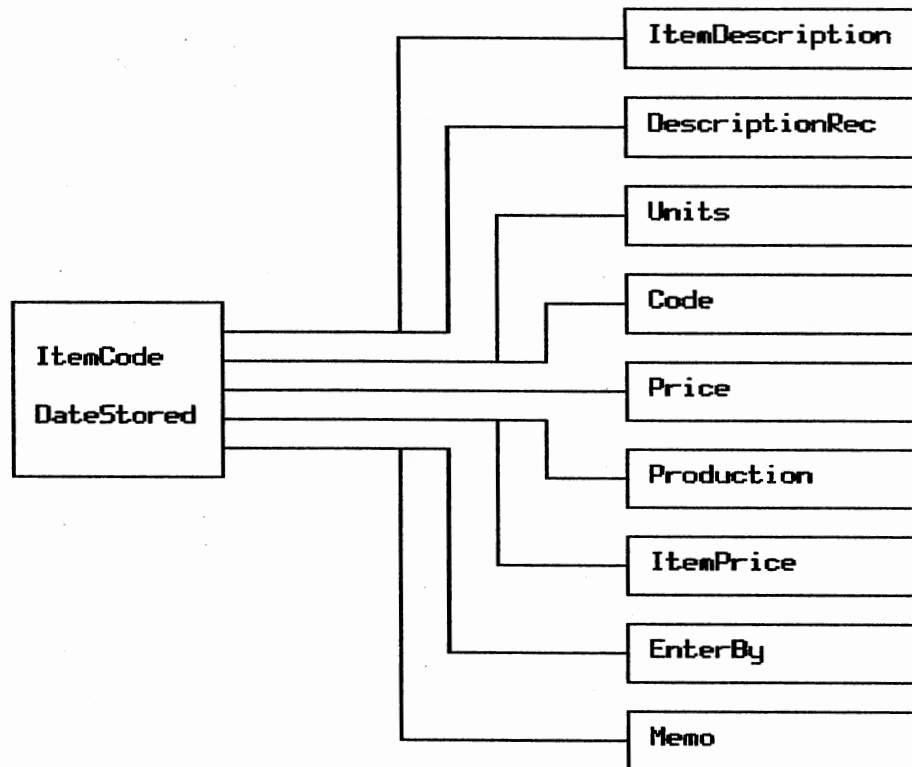


Figure 22. Functional Dependency Diagram of the Cost Database File

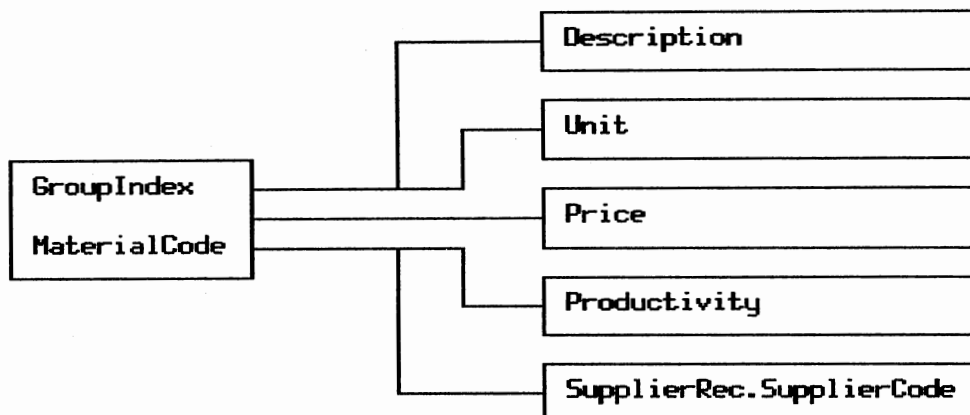


Figure 23. Functional Dependency Diagram of the Material File

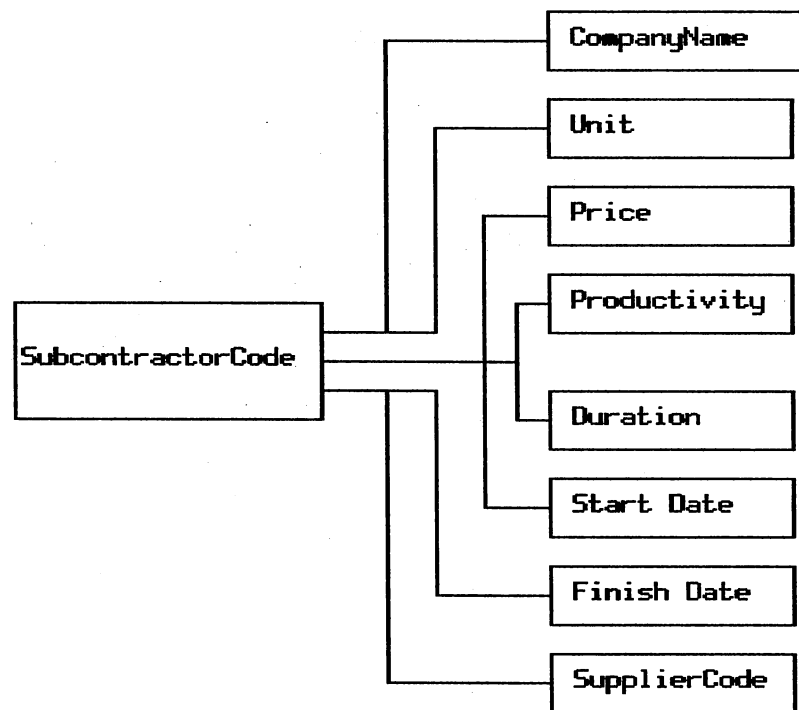


Figure 24. Functional Dependency Diagram of the Subcontractor File

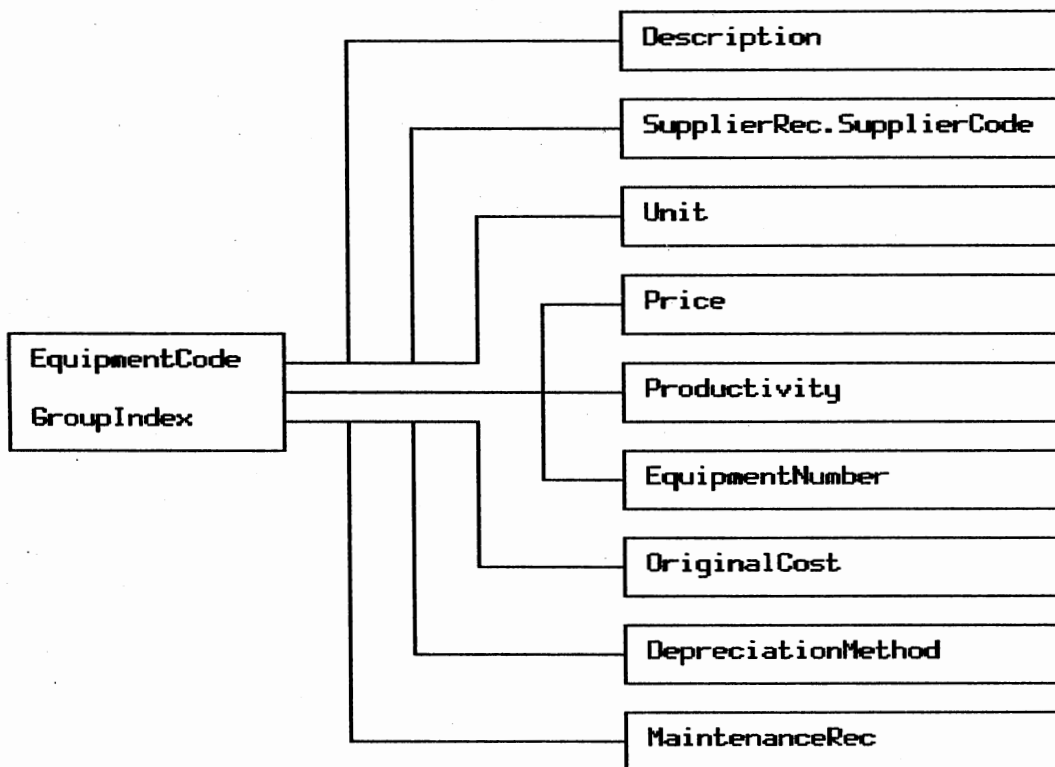


Figure 25. Functional Dependency Diagram
of the Equipment File

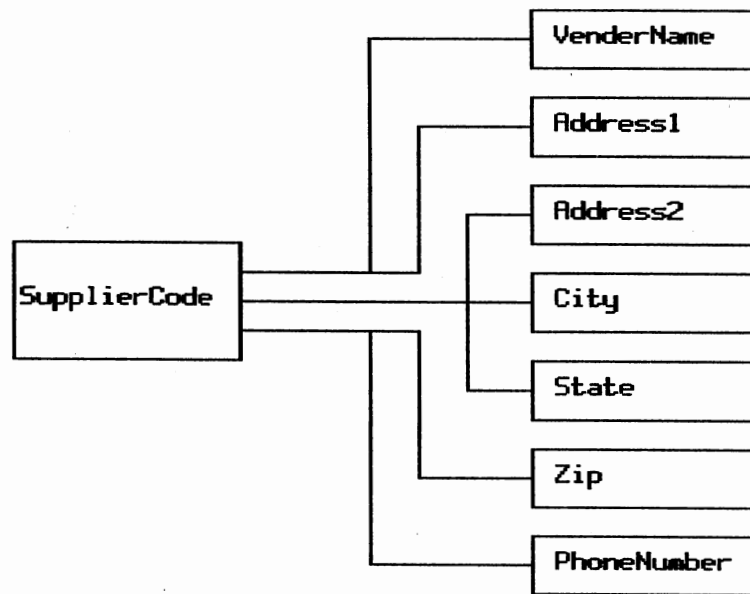


Figure 26. Functional Dependency Diagram of the Supplier File

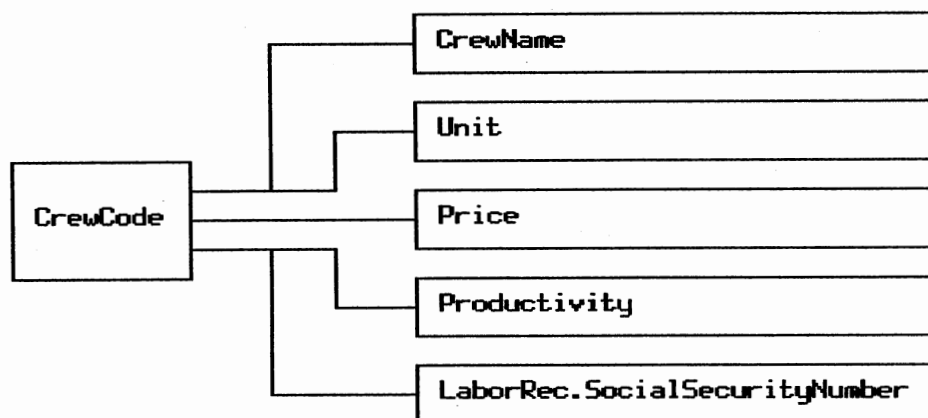


Figure 27. Functional Dependency Diagram of the Crew File

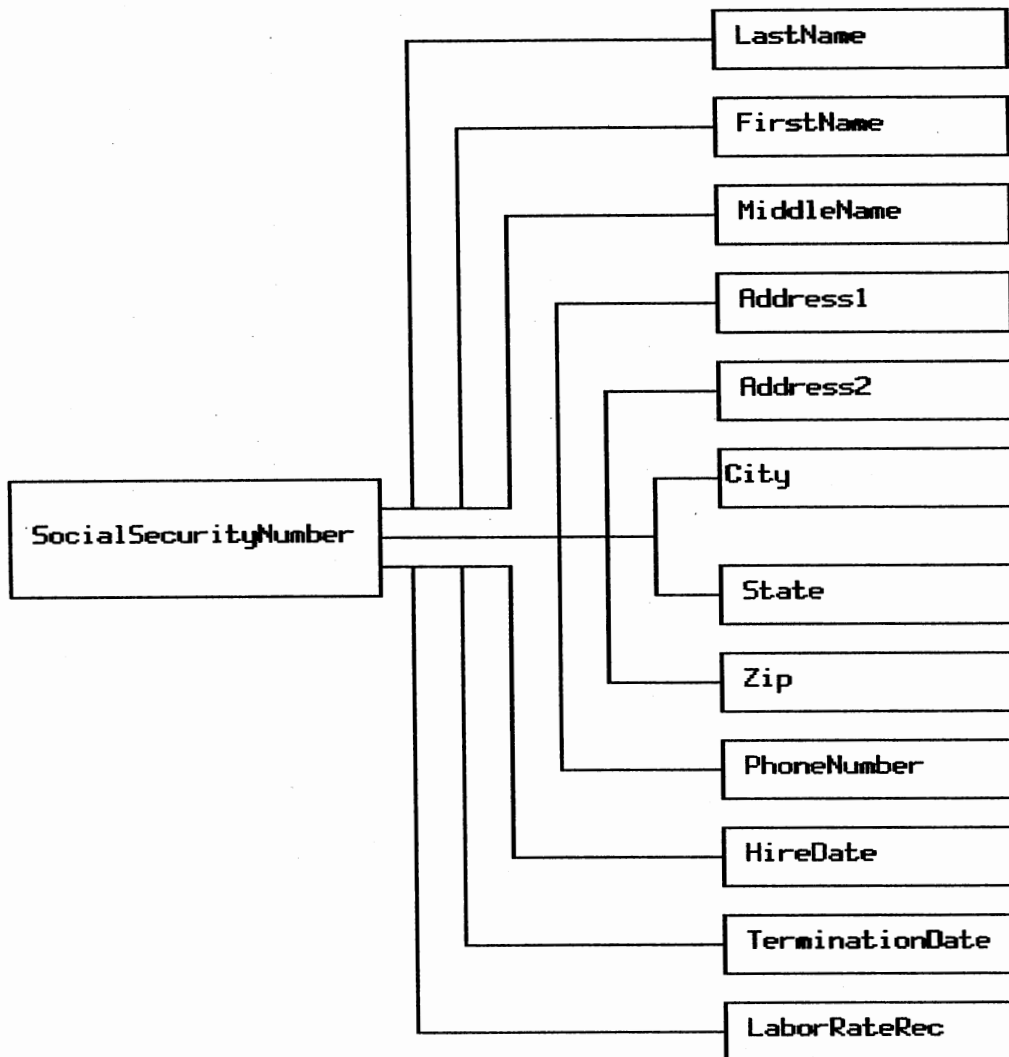


Figure 28. Functional Dependency Diagram of the Labor File

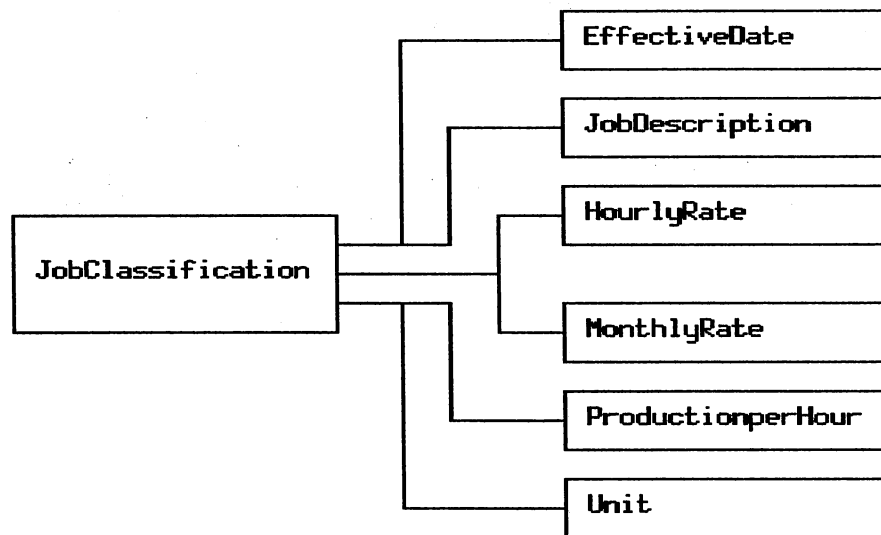


Figure 29. Functional Dependency Diagram
of the Labor Rate File

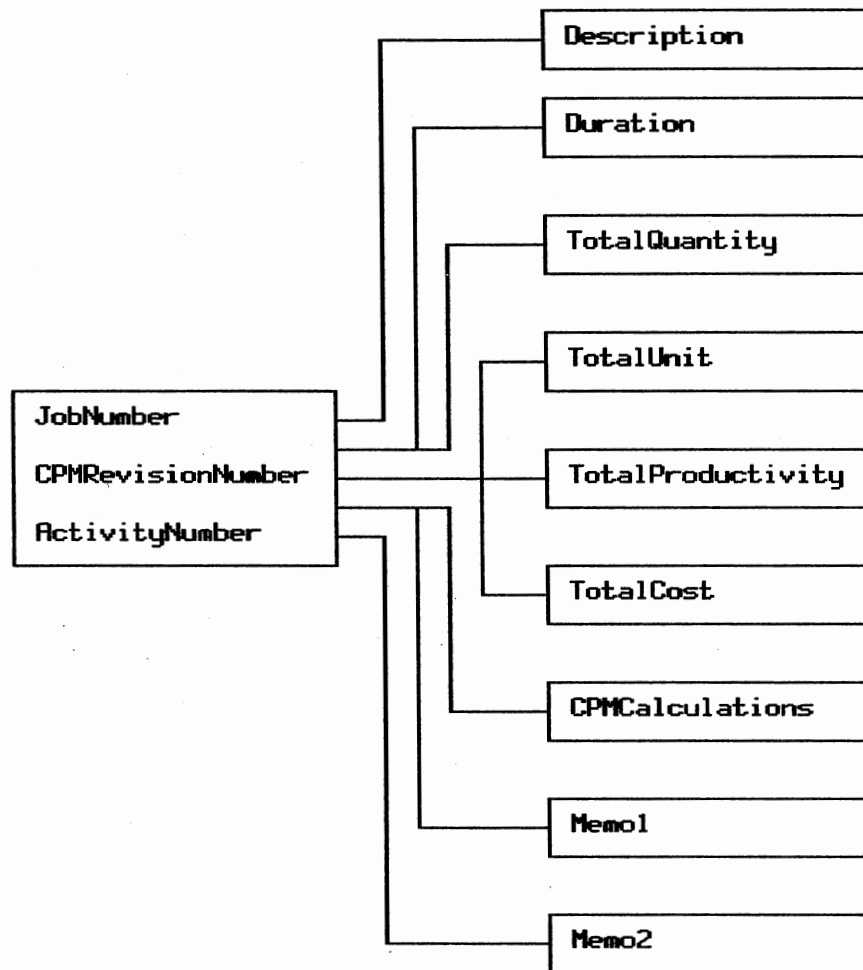


Figure 30. Functional Dependency Diagram of the Schedule File



Figure 31. Functional Dependency Diagram of the Precedence File

APPENDIX C

PROGRAM EXAMPLE SESSION

This example project is a tilt-up panel expansion to the Oklahoma State University (OSU) Fire Training building. The project was managed by OSU staff and constructed by subcontracts and in-house personnel. Table 3 is the list of estimated items that were developed for the project. The total project cost is \$60,226.50 and was completed during the summer of 1979. All the estimated items were distributed to the schedule which can be verified by comparing the total cost computed in table 3 with the total cost computed in table 4. Figure 32 shows the CPM network for the project with the activity durations and costs listed below each activity.

Figure 33 is a copy of the estimate schedule interface screen. In the middle of Figure 33 the estimate can be seen as an overlay display on the Schedule Data Input Form. An item is selected from the displayed estimate items by placing the cursor on the item code. The ESTCPM program then prompts the user for the quantity to be distributed and the order number. The order numbers allow the user to build a sub-network from the distributed estimate items. Figures 34, 35, and 36 are copies of the Estimate Data Input Form display and contain information about several estimate items distributed to the CPM schedule activity in Figure 33. The estimate item production rate and unit price are entered into the ESTCPM program on this display.

The cost and duration distributed to a CPM schedule activity are calculated from the estimate item's unit price, production rate, and the quantity entered for distribution in the estimate schedule interface subroutine. The ESTCPM program will add together all of the estimate items which are given different order numbers. If several estimate items are given the same order number, the ESTCPM program assumes these items will be constructed simultaneously and computes

TABLE 3

LIST OF ESTIMATED ITEMS

```

*****
Code   Item Description           Quantity  ItemCost  Production
*****
1.  01235 Advertising for bids      20.00    314.33     0.00
2   20014 Trenching                  27.00    480.43    18.00
3   21390 Fill Sand                   14.00     64.90     2.00
4   22101 Site Grading                 1.00    594.77     2.00
5   22124 Pier Excavation              9.00    594.77     4.50
6   22810 Termite Control              1.00     92.28     1.00
7   31098 Dowel Rods 3/4"             1.00     83.60     1.00
8   32100 Jay Hawk Forms              120.00   156.78   300.00
9   32112 REINF STEEL                 1922.56  2341.76   250.00
10  33055 CONC - READY MIX, 3500PSI    65.00   2219.51    50.00
11  33401 Precast Roof TT Section       1.00   6084.94     1.00
12  33402 Precast Wall TT Section       1.00   9127.41     1.00
13  33627 Concrete Pumping for Slabs    33.00    343.77   200.00
14  51602 Framing System Channels for    5.00    452.89     5.00
15  55308 Plate Steel 1/4"             254.00   161.75    75.00
16  64201 Interior Framing             1127.57  1818.84   500.00
17  64203 Misc. Lumber                  485.00  1327.43   500.00
18  75101 Built-Up Bitu Roof - 4 Pl     1.00   6344.17     0.33
19  82204 OverHead Door                 1.00    594.77     1.00
20  84201 Solid Core Doors              10.00    641.20     4.00

```

TABLE 3. CONTINUED

```

*****
Code      Item Description          Quantity  ItemCost  Production
*****
21  92000 Misc. Hardware          1.00    1753.55    0.00
22  92601 GYM Wallboard 4' x 8'   96.00    1185.23    30.00
23  96820 Carpeting - Carpet, Acryl 177.00    3062.50    65.00
24  99100 Paint                   10500.00   859.74   2100.00
25  102340 Suspended Ceiling        1.00     902.09     0.50
26  150407 Heating & Air Unit        1.00   5584.91     0.50
27  150510 Office Building Plumbing  1.00   6896.49     0.20
28  150534 Duct Work                1.00     843.69     0.50
29  154024 Fire Protection           1.00     400.00     0.33
30  160723 Electrical Wiring         1.00   4385.64     0.20
31  161590 Light Fixtures & Bulbs    1.00     512.36     0.33
*****
Total                                     60226.50
*****

```

TABLE 4
LIST OF SCHEDULED ACTIVITIES

Act. #	Description	TotalCost	Duration
10	Move On	378.58	3.00
20	Clear and Grub	594.77	2.00
30	General Excavation	681.40	3.07
40	Drill Foundation	1756.77	3.28
50	Slab Piping	640.76	8.00
60	Grade Beams	2209.95	4.82
70	Install Slab	1201.42	3.44
80	CMU Walls	9127.41	9.64
90	Place Slab	3156.47	2.00
100	Door Frames and Windows	1394.09	5.00
110	Roof Trusses	6084.94	4.00
120	Roof Deck	6344.17	2.10
130	Shell Complete	0.00	0.00
140	Rough Electrical	2314.56	5.79
150	HVAC Ducts	843.69	5.00
160	Set Roof HVAC Unit	5584.91	2.00
170	Plumbing Fixtures	6255.73	6.00
180	Exterior Finish	812.00	6.00
190	Interior Walls	3004.07	14.51
200	Final Inspection	0.00	1.00

TABLE 4. CONTINUED

Act. #	Description	TotalCost	Duration
210	Landscape	230.00	2.00
220	Final Electrical	2071.08	4.02
230	Suspended Ceiling	902.09	2.00
240	Fire Protection	400.00	3.00
250	Light Fixtures	512.36	3.00
260	Final Trim	662.78	4.00
270	Floor Cover	3062.50	3.00
280	Move Off	0.00	1.00
		60226.50	

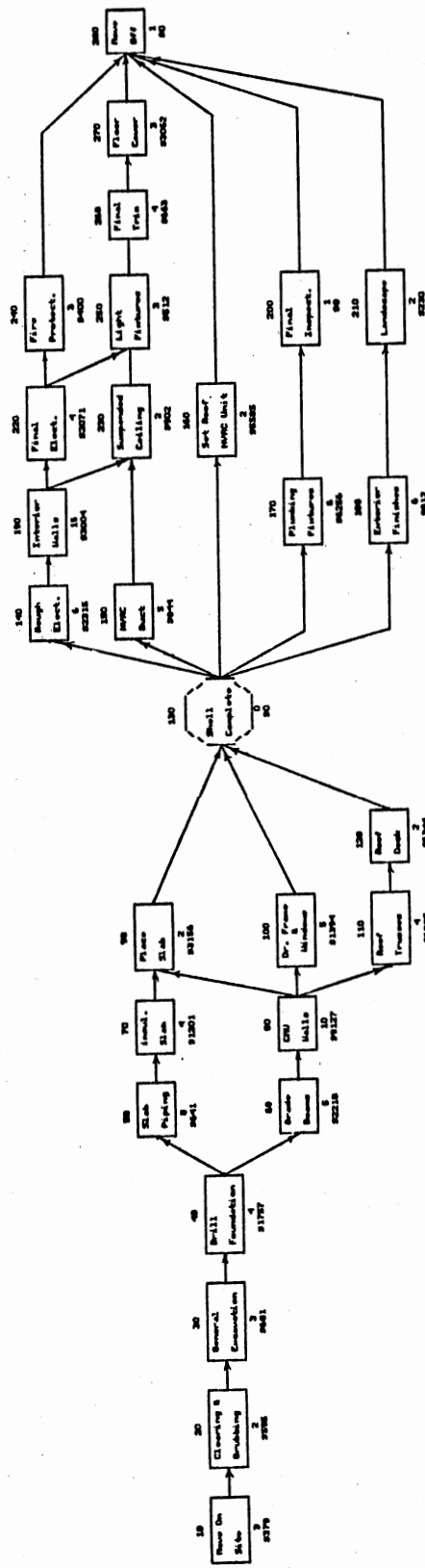


Figure 32. Example Problem CPM Precedence Network

Schedule Data Input Form

Job # : OSU101 Project : Fire Training Building, East Expansion__

Act. # : ____40 Act. Descrip. : Drill Foundation_____

Code	Description	Remaining	Total	%
_32112	Reinforcing Steel_____	_____1	_____1923	__0
_33055	Conc - Ready Mix, 3500 PSI_____	_____0	_____65	__0
_33401	Precast Roof TT Section_____	_____1	_____1	100
_33402	Precast Wall TT Section_____	_____1	_____1	100
_33627	Concrete Pumping for Slabs_____	_____33	_____33	100
_51602	Framing System Channels for Doors_____	_____5	_____5	100
_55308	Plate Steel 1/4"_____	_____254	_____254	100
_64201	Interior Framing_____	_____1128	_____1128	100

Interface Data

Order %	Description	Quantity	Unit	Cost	Product.	Duration
__1 100	Termite Control_____	_____1.00	LSum	___92.28	___1.00	1.00 Days
__2 100	Pier Excavation_____	_____9.00	EA__	___594.77	___4.50	2.00 Days
__2 _25	Reinforcing Steel_____	___485.76	LB__	___591.68	___250.00	1.94 Days
__3 _22	Conc - Read Mix, 3500 PS_____	___14.00	CY__	___478.05	___50.00	0.28 Days
__0 __0	_____	_____0.00		_____0.00	_____0.00	0.00 Days
__0 __0	_____	_____0.00		_____0.00	_____0.00	0.00 Days
	Total			___1756.78		3.28 Days

F1 : Help = Ctrl F10 : Schedule = Ctrl F9 : Interface = Shf-F1 : Exit

Figure 33. Example Problem Interface for Drill Foundation

Estimate Input and Edit Form

Job # : OSU101 Project : Fire Training Building, East Expansion__

Code : _22124 Item Description : Pier Excavation_____

Type	#	Description	Quantity	Unit	Price	Cost	Product.
Mat'l	---	-----	0.00	---	0.00	0.00	0.00
Labor	---	-----	0.00	---	0.00	0.00	0.00
Equip	---	-----	0.00	---	0.00	0.00	0.00
Sub	102	Power's Foundation & Dri	9.00	EA	55.00	495.00	4.50
Item Subtotal			9.00	EA	55.00	495.00	4.50

Adjust. Factor : ___499.95 101.00%

Material Tax : ___0.00 __6.00% Item Installed : __/__/__

General Overhead : ___15.00 __3.00% Weather Cond. : _____

Job Overhead : ___25.75 __5.00% Job Cost : _____0.00

Profit : ___54.07 __10.00% Estimated by : _____

Total Item Cost : ___594.77

Unit Bid Price : ___66.09

Memo : _____

F1 : Help

Shf-F1 : Exit

Figure 34. Example Problem Pier Excavation

Estimate Input and Edit Form

Job # : OSU101 Project : Fire Training Building, East Expansion__

Code : _32112 Item Description : Reinforcing Steel_____

Type	#	Description	Quantity	Unit	Price	Cost	Product.
Mat'l	103	Roberson Steel_____	1922.56	LB__	0.50	961.28	250.00
Labor	101	Barry's Crew_____	186.00	Mhr_	5.00	930.00	0.00
Equip		_____	0.00		0.00	0.00	0.00
Sub		_____	0.00		0.00	0.00	0.00
Item Subtotal			1922.56	LB__	0.98	1891.28	250.00

Adjust. Factor : __1910.19 101.00%

Material Tax : ____58.25 __6.00% Item Installed : __/__/__

General Overhead : ____59.05 __3.00% Weather Cond. : _____

Job Overhead : ____101.37 __5.00% Job Cost : _____0.00

Profit : ____212.89 __10.00% Estimated by : _____

Total Item Cost : __2341.76

Unit Bid Price : ____1.22

Memo : _____

F1 : Help

Shf-F1 : Exit

Figure 35. Example Problem Reinforcing Steel

Estimate Input and Edit Form

Job # : OSU101 Project : Fire Training Building, East Expansion__

Code : _33055 Item Description : Conc - Ready Mix, 3500 PSI_____

Type	#	Description	Quantity	Unit	Price	Cost	Product.
Mat'l	101	Dolese Company_____	65.00	CY__	26.81	1742.28	50.00
Labor		_____	0.00		0.00	0.0	0.00
Equip		_____	0.00		0.00	0.0	0.00
Sub		_____	0.00		0.00	0.0	0.00
Item Subtotal			65.00		26.81	1742.65	50.00

Adjust. Factor : ___1760.08 101.00%

Material Tax : ___105.60 __6.00% Item Installed : __/__/__

General Overhead : _____55.97 __3.00% Weather Cond. : _____

Job Overhead : _____96.08 __5.00% Job Cost : _____0.00

Profit : ___201.77 _10.00% Estimated by : _____

Total Item Cost : ___2219.51

Unit Bid Price : _____34.15

Memo : _____

F1 : Help _____

Shf-F1 : Exit _____

Figure 36. Example Problem Conc - Ready Mix, 3500 PSI

the total duration from the estimate item with the largest duration. For example activity 40, that is shown in Figure 33, consists of 4 items from the estimate. The first item (Termite Control) is given an order number of 1, the second (Pier Excavation) and third (Reinforcing Steel) items are given an order number of 2, and the fourth (Conc - Ready Mix, 3500 PSI) item is given an order number of 3. Since the second and third items have a common order number, 2, this identifies these items as being performed simultaneously. Therefore the contribution of the duration from these two items is based upon the larger duration among them. The 2 day duration of the second item controls. Thus the activity duration is determined as the sum of the first, second, and fourth estimate items. $1 + 2 + 0.28 = 3.28$. Also it should be noted that the total cost is determined as the sum of the costs of all of the 4 items from the estimate.

The Schedule Data Input Form shows the percentage of the total of each estimate item to aid the user in making corrections. Negative quantities can be entered to remove any or all of an estimate item from a CPM schedule activity. If the user ends a session without distributing all the estimate items, ESTCPM will give the user the option of printing those items which have not been distributed. Undistributed items will also show a remaining quantity in the list of estimate items.

2
VITA

Gary Rock Spencer

Candidate for the Degree of

Doctor of Philosophy

Thesis: INTEGRATION OF COST ESTIMATING WITH CRITICAL PATH SCHEDULING

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