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A Concept for Integrating Computer-Aided Drafting and Design With Cost Engineering and Specification Preparation

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2. Cost engineers/estimators will be freed from most of the laborious analysis of labor, equipment, and material, allowing them more time to evaluate cost estimates on the basis of local market conditions.

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FOREWORD

This research was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 62784AT41, "Military Facilities Engineering Technology"; Task SA; Work Unit AM9, "Integrated Final Design Cost Estimating." The Technical Monitor was Mr. John Reimcr (CEMP-ES).

This research was performed by the Facilities Engineering Management Team of the Facility Systems Division (FS) of the U.S. Army Construction Engineering Research Laboratory (USACERL). The concept was proposed by Mr. John Williamson and Mr. Robert Blackmon and was further developed by Mr. Donald Hicks, Principal Investigator, who was assisted by Mr. Michael Shamsie. Mr. Robert Neathammer assisted with the development and supervised its progress. Dr. Michael J. O'Connor is Chief, USACERL-FS. The USACERL Technical Editor was William J. Wolfe, Information Management Office.

LTC E.J. Grabert, Jr. is Commander of USACERL, and Dr. L.R. Shaffer is Director.

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A CONCEPT FOR INTEGRATING COMPUTER-AIDED DRAFTING AND DESIGN WITH COST ENGINEERING AND SPECIFICATION PREPARATION

1 INTRODUCTION

Background

There are many automated processes with sophisticated capabilities for design, specification, cost estimating, construction planning, and scheduling. However, since many of these systems have been independently developed for particular disciplines, they have never been integrated into a complete, coordinated design and construction management system.

The entire design process is accomplished by several groups, each of which uses computer-aided techniques to simplify its work and to ensure accuracy and completeness. Much needed information is presently transferred between groups on paper. Improved computer-aided design and drafting (CADD) systems will facilitate transfer of information between these design groups. This information, once entered as computer data, can be used as input to cost estimating and specifications systems.

Objective

The objective of this report is to outline approaches to integrate cost estimating and specification preparation processes into a CADD-based design system. This outline will provide a communication framework and will form a master plan for providing needed interfaces and supplementary software programs. The integrated system described is a tool to assist the cost engineer/estimator (CE/E) in the exercise of his or her professional judgment.

Approach

There were two steps in developing the research requirements for fully integrating the CADD environment with the environment of collecting data for generating cost estimates: first to study and define the functional requirements of such a system, and then to define approaches for several development solutions.

Functional requirements were defined through discussions and interviews with CE/Es and designers at Corps of Engineers District and Division offices. From these preliminary fact finding efforts, USACERL developed the concept of an integrated final design cost estimating system.

A workshop was conducted at USACERL during March 1988 to discuss the preliminary findings and to identify appropriate approaches to the development problems. Invitees included representatives from HQUSACE-CEMP-ES, the Corps of Engineers assigned responsible agency (ARA) for both CADD and the Computer-Aided Cost Engineering Support System (CACES), Savannah District (CESAS), CACES Steering Committee, the Control Estimate Generator (CEG) Subcommittee, and USACERL researchers. It was resolved that USACERL should develop the concept further and recommend alternatives for commercial and/or government development of the interface.

Scope

The scope of this investigation was limited to the development of functional requirements for the integration of CADD with cost estimating, the generation of materials specifications, and the creation of preliminary design estimates for future projects.

Mode of Technology Transfer

When the results of this research become available, the improved capacity to generate construction cost estimates should be delivered to the field through enhancements to existing Corps of Engineers' systems. These improvements will apply to CADD systems currently used by the Corps and Corps CACES. Additionally, because civil works construction cost estimating is similar to military construction cost estimating, this technology is equally applicable and should be made available to civil works projects through standard commercial channels.

2 SYSTEM CONCEPT

Existing Systems

There are a number of systems already in place or under development which have the potential for contributing to an integrated design/estimating/specification system.

Computer-Aided Drafting and Design (CADD)

Although initial CADD systems were used primarily as automated drafting systems, extending the current systems to include design parameter capabilities will add dramatic advantages. Structural, hydraulic, and other design considerations can already be considered along with the graphical representations of the components.

The latest generation of CADD systems can attach outside information to the graphical representation of a facility by use of associated relational data bases. For example, a construction component shown in a CADD system as two parallel lines, 2 in.* apart, can carry additional information: that the lines represent a certain quantity of 2 in. galvanized pipe, which will be used to transport a certain quantity of potable water, and which will require certain guide specifications and CACES estimating identifiers--all useful information for specification preparation, cost estimating, and construction scheduling.

Commercial architectural and engineering firms use advanced CADD capabilities in their offices. One interviewed firm develops complete piping networks, while simultaneously calculating the hydraulic capabilities of the components, producing plans, and computing bills of materials. Although such systems are common, no one has yet integrated them with other systems to ensure data compatibility and completeness.

These sophisticated capabilities make CADD an attractive candidate for Corps wide use. Such use would require coordinating the various disciplines in the facility delivery process (for example, cost engineering and specification preparation), whose systems are presently incompatible. The use of CADD to combine these tasks will require data integration.

Computer-Aided Cost Engineering Support System (CACES)

CACES is an automated cost estimating system which the Corps of Engineers uses primarily to prepare final construction cost estimates. This system is now available for microcomputer use. Although it can operate independently from other computer-based design systems, the cost item identifiers relate them to the Corps Guide Specifications.

The new micro-CACES produces complete direct cost estimates using various estimate generators. At the final design stage, the Final Estimate Generator (FEG) allows the CE/E to quickly produce a final cost estimate using the CACES *Unit Price Book.*** The *Unit Price Book* is updated annually by region to adjust cost data for regional material, labor, and equipment cost differences. The CE/E is then allowed to enter local prices when they are more accurate than regional estimates. Material estimates are

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*1 in. = 25.4 mm.

***Unit Price Book: Cost Engineering Support Data* (U.S. Army Engineer Division, Huntsville, AL, June 1988).

accompanied by associated labor and equipment costs. Labor is computed by using typical construction crew configurations and their productivity.

Construction Cost Management Analysis System (CCMAS)

Over the past 7 years, the Air Force has been developing a Construction Cost Management Analysis System (CCMAS) to provide an independent in-house capability to estimate and analyze construction costs. The CCMAS is modular, containing three major estimating subsystems and a data base. In the first major subsystem, the direct cost module, there are seven generic models: runways and taxiways, administrative facilities, medical facilities, supporting facilities, shielding, and systems. The second major subsystem estimates the life cycle cost of the facilities being investigated. The third subsystem contains a series of modifiers which adjusts the direct cost estimate by considering construction methods, site or area conditions, location of construction, escalation, construction management plans, design methods, and addition of indirect costs. Although the CCMAS currently operates on a Control Data Corporation (CDC) mainframe computer, the Air Force plans to reprogram the CCMAS to a Wang VS-100 minicomputer over the next 2 years. In this reprogramming, the system will be changed to use the CACES *Unit Price Book*, and much of the highly detailed data will be summarized to simplify data handling. It appears that much of the work contained in the CCMAS can be transferred into a CACES-based preliminary cost estimating system.

Cost Engineering System (CES)

CES is a two part, automated cost engineering system which the Naval Facilities Engineering Command (NAVFACENGCOM) uses to prepare conceptual and final construction cost estimates. The system is divided into the cost estimating portion and the historical database portion. The historical part of the system is resident on a mainframe and is used to maintain building construction cost data based on area, building type, construction cost, geographical area, and date of construction competition. This portion is used to project construction costs for planning and budgeting. The CES estimating part is a PC-based cost estimating system that can use either detailed quantity takeoffs or assemblies data to generate a final construction cost estimate. The database is updated several times annually to adjust the cost data for material, labor, and equipment cost differences. This system has been developed and is maintained by the United States Navy. The program is not commercially available; however, it is available to the private sector as public domain software. The CES system is very similar to the M-CACES program in terms of functionality, features, and reporting capability.

Construction Criteria Base (CCB)

The National Institute of Building Sciences (NIBS), in conjunction with the Corps of Engineers and the Navy, has developed and marketed the Construction Criteria Base (CCB), a CD-ROM containing a complete set of Corps of Engineers, Navy, National Aeronautics and Space Administration (NASA), and Veterans Administration (VA) guide specifications, part of the Bureau of Reclamation specifications, Navy Technical Manuals, the Navy cost estimating system, some Military and Federal specifications referenced in the text, and the SPECINTACT system for editing and preparing project specifications from the guides. SPECINTACT is an editing system designed to collect paragraphs selected from the guides to perform several of the repetitive functions in preparing project specifications.

Updates of the CD-ROM are published quarterly. With each update, new information is added to the CD-ROM for Beta testing. The CD-ROM will eventually contain all published references in the guide specification and new abridged guide specifications for minor construction and repair/maintenance contracts. It now appears that the American Society for Testing and Materials (ASTM) will publish its own CD-ROM to support the CCB.

USACERL Developments

In FY86 USACERL developed a new concept for estimating construction duration for use in planning mobilization construction programs.* The system uses CACES-generated labor hours and cost estimates in the process. The concept breaks the estimate into 20 construction components and uses the components in the scheduling process.

During FY86 USACERL directed an Interdepartmental Independent Research (IDIR) study, "Development of Construction Contractor Resource Balancing Algorithms," to find ways to improve the accuracy of indirect cost estimates. The study showed that CE/Es normally make detailed estimates of indirect costs for each project rather than using a variable percentage of direct costs. An expert system was developed to prepare the estimate automatically, while considering a wide range of variables. A review of other systems revealed that the Air Force CCMAS already contains a series of algorithms for calculating indirect costs but using fewer variables. Both the USACERL and Air Force systems demonstrate the feasibility of automated calculation of quantity takeoffs to assist the CE/E in determining cost estimates. The CE/E will adjust the system output for local market factors such as labor costs and productivity and the prevalence of subcontracting.

During FY87 USACERL investigated techniques for designing the number and composition of work crews for trades involved in the construction process in the IDIR project "Evaluation of Construction Crew Design Procedures." In lieu of using the standard crews provided by CACES, the program tailors work crews to specific building design and project parameters. The technique was tested using a small sample of subcontractors with work representing all trades, and showed the successful application of the expert system approach to a construction design problem.

Integration Concept

One strategy for coordinating the disciplines involved in the automation of the design and estimating process is to investigate and identify the elements of the desired structure which already exist, and then to "close the gaps" by developing the missing components and interfaces.**

The proposed automated system would need to integrate three major activities. Figure 1 illustrates the relationship between the CADD design and the preparation of the cost estimates and project specifications. The key to integrating the three components is the ability to derive the project's bill of materials simultaneously with the project design. Some existing mechanical engineering CADD systems will produce a bill of materials as particular materials (piping, for example) are added to the drawings. As the designer selects materials or items of equipment and determines their quantity, the bill of material is generated for use in subsequent activities. The bill of materials inventory becomes a component of the total project data base. Since materials and equipment can be identified with CACES line item numbers,

*Robert B. Blackmon, *Mobilization Construction Scheduling System (MCSS), Vol 1-3*, Technical Report P-86/14/ADB107221/ADB107222/ADB107223 (USACERL, September 1986).

**Computer-Aided Cost Engineering Support System (CACES) Steering Committee; Control Estimate Generator (CEG) Subcommittee, USACERL, 29-30 March 1988, Champaign, IL.

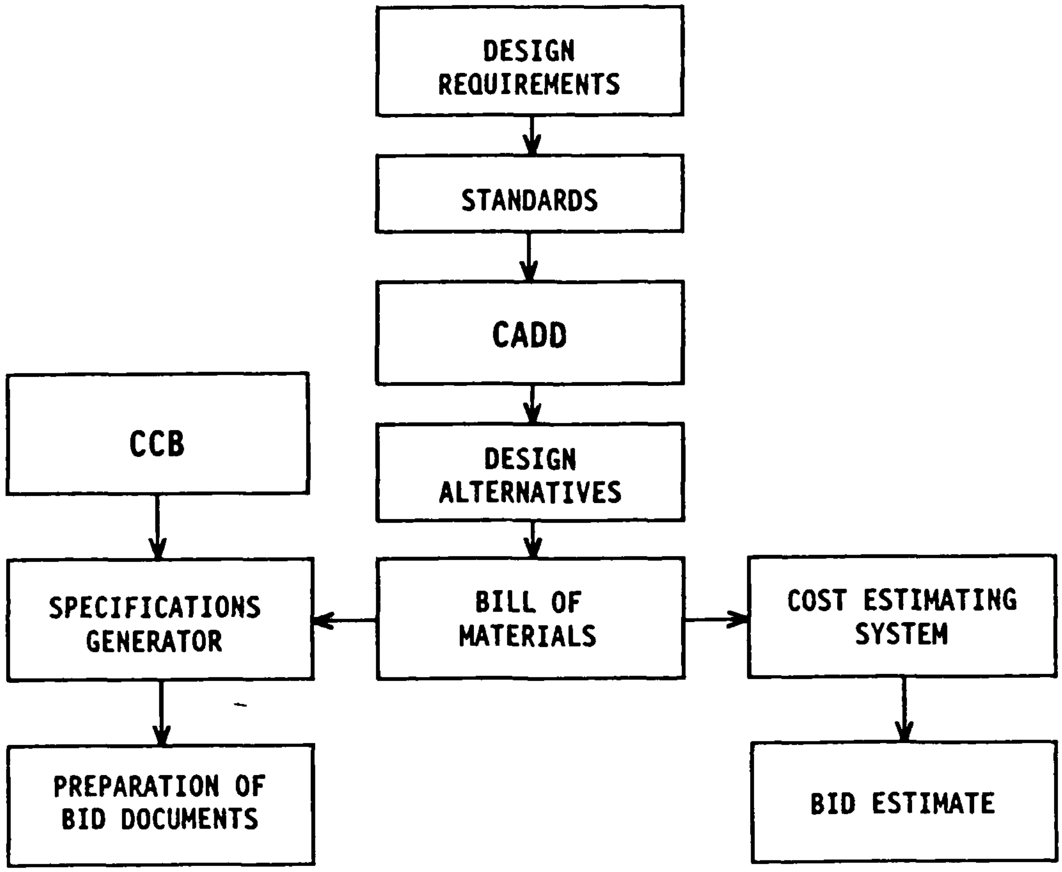

Figure 1. CADD - cost estimating/specifications relational diagram.

they can be included in a final cost estimate. The same numbers can also be related to specification paragraphs to provide data to an automated specification writing system.

Figure 2 presents the process for preparing the final cost estimate in greater detail. The first step of a project is to develop project criteria. These criteria are converted into the project design (CADD Activities); design decisions should be recorded for use by others in the facility delivery process. The design process generates a bill of materials for the project. CE/Es review the bill of materials (prepare the first pass cost estimate), and incorporate other cost items not included in the generated bill of materials.

The original project criteria may not show all relevant construction constraints and project parameters. Such information includes the season of start, coordination with other related projects, and the phasing of construction to meet other goals. This information is used after the first pass estimate to design the work crews required to accomplish the construction project. Construction duration can then be calculated based on the project cost and crew design. Different crew designs and project duration programs can be matched to determine an efficient combination. The indirect cost can then be calculated and the data summarized in the final pass through CACES. At this point the estimate is prepared for bid evaluation, the project data base is updated, and if necessary, the subsystem cost factors are updated to include the new data.

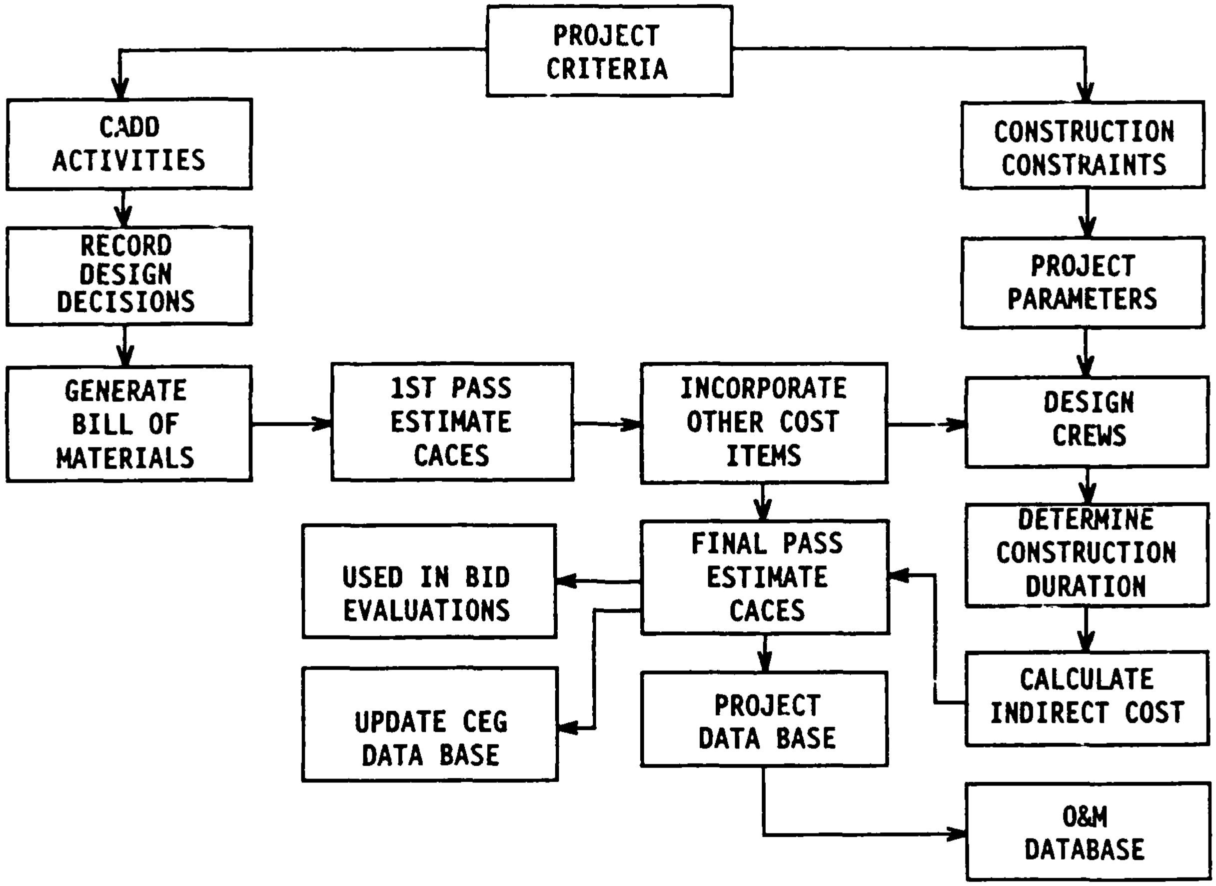

Figure 2. Final cost estimate logic diagram.

Systems To Be Developed

Certain components for the completely integrated system need to be developed, as do the interfaces that will link those parts which can be wholly consolidated into the new system.

Automated Specification Generator

Appropriate sections of the Corps of Engineers Guide Specifications could be assembled automatically with an Automated Specification Generator using the CACES material identifiers, converted into input to the SPECINTACT system. At the conceptual level, it appears that commands to SPECINTACT can be generated from a bill of materials based on a relationship between CACES line item numbers and specification paragraphs. The project specifications generated using this process will still require that a specification writer review the contents to add special or unique requirements to the final project specifications. The relationship between CACES line item numbers and specification paragraphs will vary. In some cases, the mention of a material (e.g., structural steel) would trigger an entire section being added to the project specifications. In other cases, the presence of a certain product might add a basic specification requirement or a specific requirement (e.g., reference to a lock set would add the hardware section, the lock set paragraph, and the specific requirement for the type of lock set mentioned).

Construction Scheduling System (CSS)

The Mobilization Construction Scheduling System (MCSS) automatically calculates durations of the typical construction subcontract activities for mobilization construction by using the data from the Mobilization Estimate Generator of CACES. Appropriate construction crew configurations were determined for each class of facility expected to be constructed during a mobilization effort. MCSS uses the crew configurations to determine the probable duration of construction subcontract activities and creates schedules. The MCSS can be generalized to the Construction Scheduling System (CSS) for scheduling the Military Construction, Army (MCA) and Military Construction Air Force (MCAF) construction using the CACES FEG. A current IDIR effort in USACERL's Facility Systems Division (FS) is developing algorithms for planning construction crew allocations using project parameters and construction constraints. CADD systems can automatically produce some of the parameters, such as floor area and number of floors. The scheduling system user must provide other parameters, such as availability of labor and expected weather conditions. CSS can then predict duration of subcontract activity and of the overall construction.

Indirect Cost Estimate Generator

Another USACERL IDIR research effort is developing an automated module for CACES to generate an estimate of indirect costs associated with a construction contract. Algorithms typically used by contractors to estimate indirect costs will be included in a system which will also use the duration calculations from CSS to estimate the time-driven indirect costs. The CACES Final Estimate Generator can then be run a second time to produce a complete estimate that will include indirect costs.

CACES Control Estimate Generator (CEG)

In addition to the Construction Specification Institute* (CSI) Master Format final cost estimate, the CACES FEG can also produce a building system estimate. This estimate can be used as the input data for the new micro-CEG to develop, budget, and plan future projects. Previous estimates from similar systems form a base from which the planner specifies the functional requirements for the new facility by category code. Micro-CEG will produce the new project requirements to use in developing (Department of Defense) DD Form 1391, the Project Design Brochure (PDB), Engineering Form (ENG FORM) 3086,** and other information. Once reviewed, this information forms the foundation for the CADD design for the new facility.

CACES Preliminary Cost Estimate Generator

Figure 3 illustrates the generation of preliminary cost estimates using CEG data and cost data from other sources. New projects begin with a set of requirements which develop new facilities criteria. The Subsystem Cost Data Base will create a summary level cost estimate and a project description. New project requirements will be updated and the cost estimate adjusted accordingly. This information will be input to an estimating model to complete the estimate. This system will use some of the algorithms and analytical processes developed by the Air Force in the Construction Cost Management Analysis System.

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*Construction Specification Institute, 601 Madison St., Alexandria, VA 22314.

**For a sample and explanation of ENG FORM 3086, see Engineering Regulation (ER) 415-345-42, *Construction Costs, Cost Estimating, and Reserves for Contingencies*, 1 March 1984.

CACES Conceptual Cost Estimate Generator

Decisions made during the conceptual development process have more impact on final project cost than at any other time. Designers and concept developers need to know the cost implications of their decisions before completing their plans. Costs at the conceptual planning stage will appear higher than those of the preliminary cost generator because they will consider more specific facility features. The conceptual cost estimate generator will be capable of calculating quantities and applying cost factors. Analytical procedures will determine probable construction cost. Figure 4 illustrates the structure of a conceptual cost estimating system, from the point where a planner first defines the new project's functional requirements to include the specific desired features of the new facility. The CACES conceptual Subsystem will select cost data for those features and present a simulation model for review by the planner. When the model satisfactorily reflects the planner's view of the new facility, the system will produce program documents necessary for submittal, review, and approval of the project.

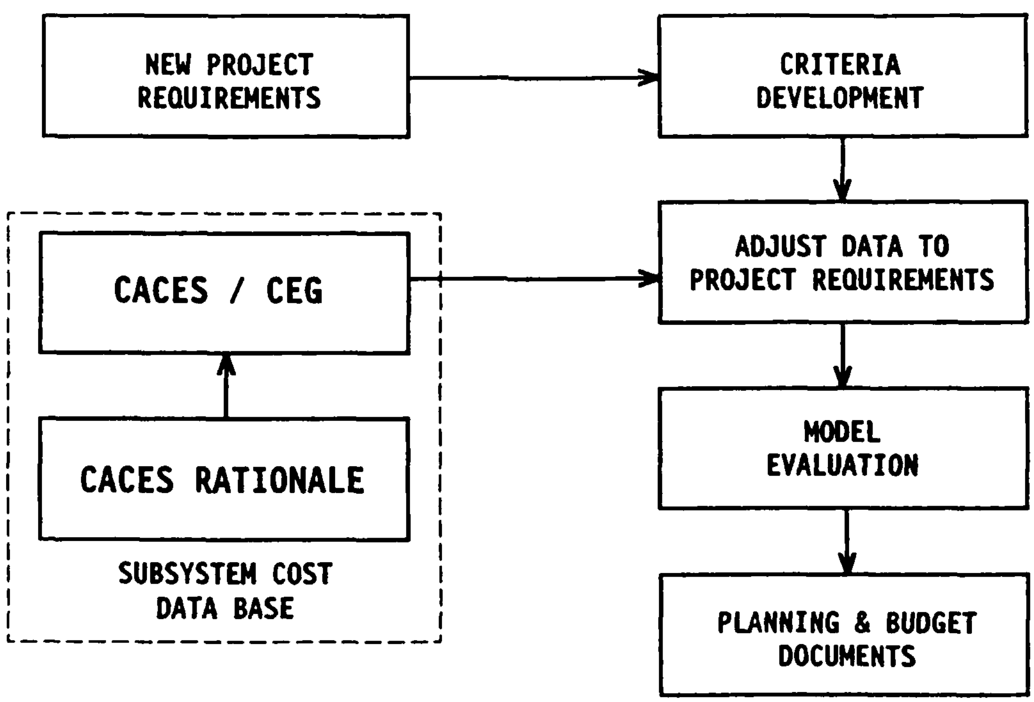

Figure 3. CEG - data base cost estimate diagram.

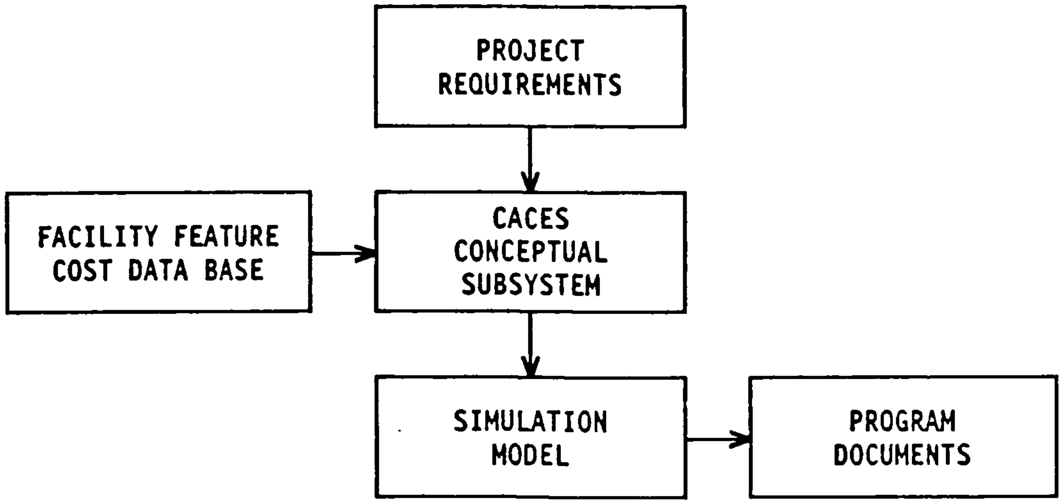

Figure 4. Conceptual design relationship diagram.

The Integrated System

The final step in developing a fully integrated design/estimating/specification system is to interlock the subsystems in a coordinated structure. Figure 5 illustrates the interrelationships necessary to achieve the completely automated process from concept to final estimate, with a feedback for future conceptual estimates for new projects.

The system described in Figure 5 works from the "top down," and begins by setting up the information that feeds into CADD. First, the function requirements are determined by category code, and are entered into the micro-CEG. This information will be used to generate new project requirements, which along with any later modifications, exist in the CADD environment as the project is drawn. Simultaneous with the creation of project drawings, a bill of materials and a set of project parameters are formulated.

The bill of materials is fed to the automatic specification generator (prepared from the construction criteria base), which together with the design drawings, creates the necessary bid documents. The bill of materials is also input to the micro-CACES to generate the final cost estimates. These estimates, along with the CADD-produced project parameters yield the optimal crew design.

Once crew design has been determined, the Construction Scheduling System (CSS) can determine Construction Duration, the Indirect Costs, and a Final Cost Estimate for the entire project, in CSI format. This estimation is filtered back through the system, to the Micro-CEG, in circular fashion, for later use in the current project and to form a reference for subsequent projects.

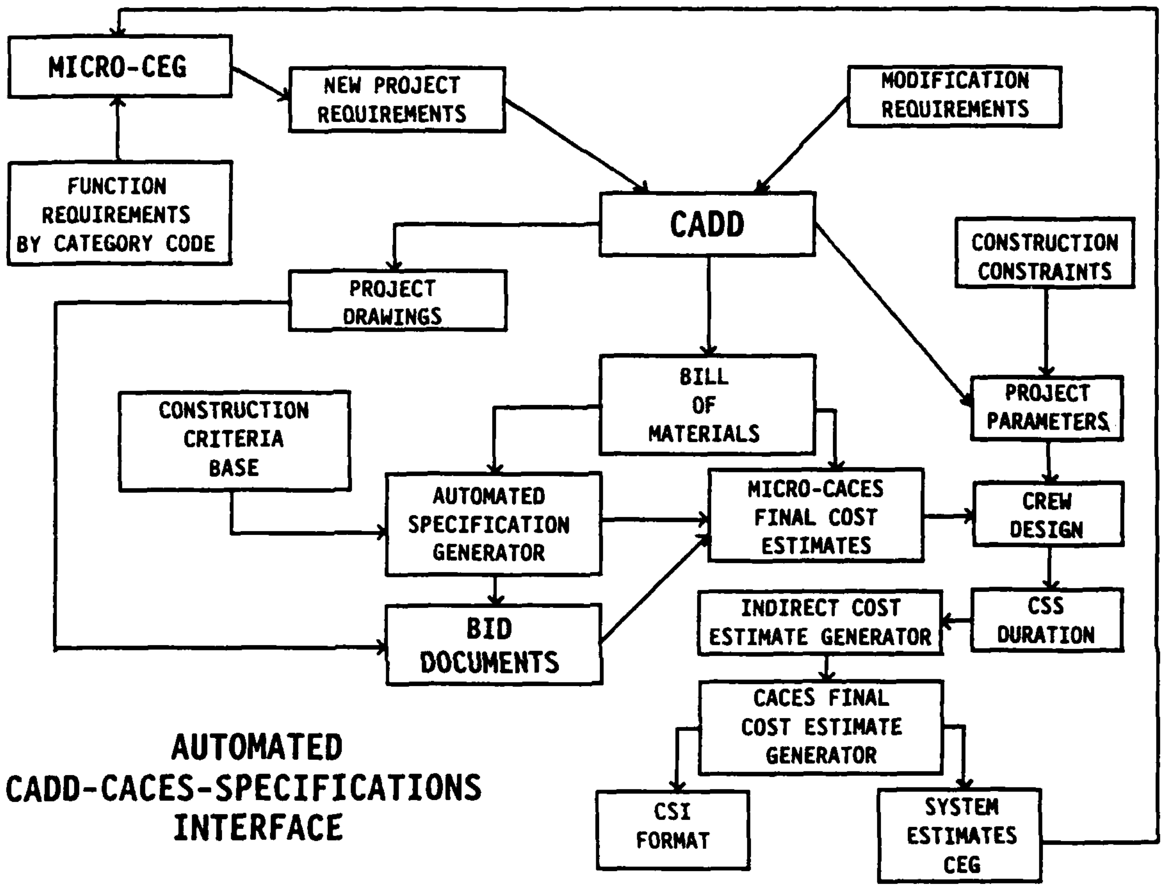

Figure 5. Consolidated CADD/CACES specifications interface diagram.

3 DEVELOPMENT ALTERNATIVES

There are several ways to develop the software that will integrate cost estimation and specification preparation in a CADD environment. The question to be resolved is one of authorship, whether the U.S. Army Corps of Engineers should leave the development entirely to the private sector, whether it should develop the software alone, or whether it should undertake a joint agreement with commercial developers to create the desired interface.

Private Sector Initiatives

Commercial software developers are presently developing the more sophisticated CADD software packages needed to supplement the CACES system, and the interfaces necessary to combine the two. The present software programs can generate bills of materials, cost estimates based on component packages, and construction schedules. However, the link between all of the different packages is virtually nonexistent. Simply waiting for commercial development of the desired software is inexpensive and requires no commitment, but carries the drawback that the new software will almost certainly not match Corps' requirements.

Corps of Engineers Research and Development

Through its laboratories, the Corps could solely fund the research and development of the systems and their interfaces with the CACES system and the specification generator. This direct alternative carries the burden of high cost of development coupled with a longterm commitment to support an ongoing development of enhanced versions that respond to rapidly changing technology.

Corps and Private Sector Cooperation

A Corps Cooperative Research and Development Agreement (CRDA) with a software vendor/developer will both facilitate development and enable the Corps to have an active role in the research program. In addition, the Corps may elect to mandate the interfacing of the new systems with CACES and the specification generator, thus obtaining the desired capabilities with an exact match to Corps' procedures. Preliminary discussions with some commercial vendors have disclosed considerable interest on their part.

4 CONCLUSIONS AND RECOMMENDATIONS

It would be possible, based on programs that already integrate CADD with expert systems, to develop a system that integrates CADD with cost engineering and specification preparation processes.

The proposed system should model itself after and should use as components presently available technology and software packages.

Such an integrated system would fill the expressed need of the Corps of Engineers CE/Es for continuous, real-time access to cost estimating information and to the implications of design decisions upon construction duration and cost. The system will reduce the time which CE/Es must now spend performing tedious analysis of labor, equipment, and material quantity, and thereby provide CE/Es with more time to evaluate cost estimating data on the basis of local market conditions.

It is recommended that the Corps undertake a Cooperative Research and Development Agreement with interested commercial software vendor/developer(s) to create such an interface, in order to ensure that such an interface satisfy Corps' requirements and procedures.

It is recommended that research begin to evaluate and acquire candidate software packages that may be integrated into the model. This research should also develop the capability for CACES to accept bar-coded input to simplify its interface with cost estimators.

It is also recommended that a multidisciplinary working task group be organized to monitor progress of the technology development, and to advise appropriate ARAs when to acquire and implement the product.

5 EPILOGUE

Since the writing of this report in June 1989, two advances have been made toward the goal of integration of the automation of design, cost engineering/estimating and specification preparation.

First, research is underway at the CADD Center, U.S. Army Waterways Experiment Station (USAWES), to develc p a neutral format as the necessary first step toward interfacing the Corps' CADD systems with cost esiimating software like CACES. This effort will also provide the basis for the inclusion of various specification generators based on the materials codes from the quantity takeoff systems. The ARAs for CADD and CACES, the appropriate Single Discipline Task Groups (SDTGs), and the Corps of Engineers National Automation Team (CENAT) are participants in this effort.

Second, USACERL is investigating the applicability of the SARA System project management software to provide scheduling and construction duration calculations for the facility delivery process which will aid in the estimation of construction overhead costs.

Any additional research in this area should be coordinated with CENAT, or their subcommittee, with direct input from USACERL and the ARAs for CADD and CACES.

LIST OF ACRONYMS

ARA	Assigned Responsible Agency
CACES	Computer-Aided Cost Engineering Support System
CADD	Computer-Aided Drafting and Design
CCB	Construction Criteria Base
CCMAS	Construction Cost Management Analysis System
CDC	Control Data Corporation
CD-ROM	Compact Disk - Read Only Memory
CE/E	Cost Engineer/Estimator
CEG	Control Estimate Generator
CENAT	Corps of Engineers National Automation Team
CRDA	Cooperative Research and Development Agreement
CSI	Construction Specification Institute
CSS	Construction Scheduling System
FEG	Final Estimate Generator
FY	Fiscal Year
HQUSACE	Headquarters, U.S. Army Corps of Engineers
MCA	Military Construction, Army
MCAF	Military Construction, Air Force
MCSS	Mobilization Construction Scheduling System
PDB	Project Design Brochure
SDTG	Single Discipline Task Group
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratory
USAWES	U.S. Army Waterways Experiment Station

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