AN INTEGRATED FACILITY CONSTRUCTION PROCESS MODEL

by

Michael S. Hetrick
Sari A. Khayyal

Report of Research Sponsored by
The National Science Foundation
Grant No. DMC-8717485

Technical Report No. 5
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February 1989

Computer Integrated Construction Research Program
Department of Architectural Engineering
The Pennsylvania State University
University Park, PA 16802
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FOREWORD

The Computer Integrated Construction (CIC) Research program at Penn State was started in 1987 with a large grant from the National Science Foundation. This grant enabled the research team to develop the fundamental process models defining the scope of the activities required to provide a facility. The research team comprised up to twenty researchers at various stages of its life. It included faculty and research assistants from Architectural and Industrial Engineering, an academic advisory board from five of the leading research schools in the country and a five member industrial advisory board representing experts in each of the phases of the facility life cycle.

In this report, Mike Hetrick, the principal author has defined the roles and essential functions required to construct a facility. This report is a stand alone document focusing on construction, but also complements the other six technical reports defining the remainder of the research undertaken by the team to provide the facility as a whole.

The four major Construction related activities, divided by similarity in process, are: acquire construction services (contracting), plan and control the work (estimating and management functions), provide resources (purchasing, personnel and support functions), and build the facility (field operations). It is envisioned that this cornerstone piece of basic research provided by Mike, assisted by Sari Khayyal, will lead to many future applications in the areas of contracting strategy and methods, information systems, organizational design, software development and process integration.

Other complimentary work resulting from this work will be detailed in subsequent technical reports issued by the CIC research program.

Victor Sanvido
Assistant Professor of Architectural Engineering
Director of CIC Research Program
ABSTRACT

This technical report presents a generic process model of the activities required to construct a facility. The model starts with the acquisition of construction services, namely the subcontracts, includes planning and controlling the work, providing the resources required (materials, labor, equipment etc.) to support the work and concludes with the actual building of the facility. In addition to the processes, specific information and other inputs, constraints and outputs associated with each function are identified.

An introduction to computer integrated construction (CIC) orients the reader to the model. The detailed methodology highlights the objectives of the model, its scope and defines the various research activities required to achieve this goal. Notable in this description is the use of two separate advisory boards, one including five industry members and a second comprising five leaders in research; and the extensive on-site data collection activities on six building sites.

The paucity of existing process models, explored in chapter three, illustrates the need for a comprehensive generic process model. An extensive explanation of the construction process model precedes the narrative descriptions used to validate and substantiate the model. Tables of information are included to facilitate future computerization efforts. In conclusion, five common field related problems resulting from the misuse or lack of information are identified. This model represents a contribution to basic research in the field of construction process modeling. It is intended to serve as the basis to develop many future applications in construction. Six of the potential uses for this model are identified.
ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of many individuals in completing this report. While many will go unthanked if we begin to mention names, we have chosen to identify the broad groups that have assisted in completion of this work. Thanks go to:

All the members of the CIC research team at Penn State for their cooperative research efforts; support and input,

The companies and employees who willingly participated in the case studies and showed an active interest in this research,

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Chapter 1

COMPUTER INTEGRATED CONSTRUCTION

1.1 INTRODUCTION TO THE CIC PROJECT

The National Science Foundation has funded a fourteen member interdisciplinary team together with ten advisors, to explore methods and means of enhancing the use of computers in all phases of the life of a constructed facility. The objective of this Computer Integrated Construction (CIC) project is to provide an open information architecture to support the provision of a facility. The team comprises Penn State Architectural and Industrial Engineering researchers together with McDonnell Douglas and selected industry professionals. The intent is to benefit from the pioneering work related to Computer Integrated Manufacturing (CIM) achieved at Penn State by applying similar advances to construction.

As the first major thrust of the project, we developed an Integrated Building Process Model (IBPM) that accurately represents the essential functions required to manage, plan, design, construct, operate and maintain a facility. The second half of the project, based on the IBPM, is to define the information and its attributes that are required to drive the system. The major benefit of this exercise is the development of a generic dynamic process and information model that can be applied to a specific project to develop and link the everyday models used to provide the facility. Examples of these models are: the architectural program, schematic drawings, CAD detailed drawings, contracts, CPM schedules, budgets, space planning models, energy management simulation, organizational charts and contracts.
IDEFO was selected as the most suitable process modeling tool. A schematic representation of the drawing format (Figure 1-1), and a graphical representation of how the model is decomposed (Figure 1-2) is included. A description of the model follows.

1.2 AN INTEGRATED BUILDING PROCESS MODEL

The Integrated Building Process Model (IBPM) is explained in two drawings. The first drawing (Figure 1-3) is an overview titled "Provide Facility" that defines the boundaries of the model in general terms. The second drawing (Figure 1-4) divides "Provide Facility" into five subprocesses. These drawings offer enhanced levels of details. Figure 1-3 has the least detail and is known as the level F model.

The model was developed from the perspective of an observer outside the whole process. It is an abstract representation taken from observations of many building projects by the project team, advisors and other reviewers. The actual mechanisms used in the execution of the functions will depend on the project delivery method. This generic model, when completed with the appropriate mechanisms, should account for all contract delivery options.
FUNCTION: An activity, process, operation, or transformation.

INPUT: Elements (resources or data) that are transformed through a process or an operation to form the outputs.

OUTPUT: Elements that result from the function being performed.

CONTROL: The elements that influence or determine the process of converting input to output. May limit the activity or allow the activity to occur without being affected.

MECHANISM: The elements used to perform a process or operation, such as a person or machine.

Figure 1-1: Schematic representation of the IDEF drawing format (adapted from ICAM Function Modeling Manual, June 1981).
Purpose: This model describes idealized owner's functions and their relationships in a construction process.

Viewpoint: The owner / User

Figure 1-3: F-0. Provide Facility
1.2.1 The Level F Model "Provide Facility"

The level F process flow model (Figure 1-3) consists of a single block showing the inputs (facility idea, resources), the controls (external, and project participants' constraints), the mechanism (free enterprise economic system and facility champion), and the outputs (operational facility, facility experience, and the impact on environment). Three elements will be tunnelled, shown as an arrow with parentheses on one end. In this case they are the free enterprise economic system, the external constraints, e.g., weather, and the impact on the environment. This tunneling of arrows means that they will not be shown at the next level of detail - they essentially add nothing to the model and clutter the drawing. These will reappear when their influence is specific to an activity.

1.2.2 Components of "Provide Facility"

The level F model breaks down the process of "Provide Facility" into the five subprocesses shown in Figure 1-4. These are: Manage Facility, Plan Facility, Design Facility, Construct Facility, and Operate Facility. Detailed definition of these subprocesses follow.

Manage Facility includes all the business functions and management processes required to support the provision of the facility from planning through operations. These activities focus on converting a facility idea, time and money into a facility team, facility management plans, documents and contracts, and resources to support the project. This function runs for the duration of the facility life. It is controlled by two
major factors - performance information about the facility as a whole and information to optimize subprocesses within the facility e.g., constructibility information.

**Plan Facility** encompasses all the functions required to define the owners needs and the methods to achieve these. These activities translate the facility idea into a program for design, a project execution plan (PEP), and a site for the facility. Major controls are constraints imposed by project participants (e.g., the owner or engineer), the facility plan, the contract and optimization information. Other outputs include facility planning knowledge and information on the performance of the team.

**Design Facility** comprises all the functions required to define and communicate the owner's needs to the builder. These activities translate the program and execution plan into bid and construction documents and operations and maintenance documents that allow the facility to meet the owner's needs. Controls or constraints include program and site information, the contract, facility planning knowledge transferred to the design team, the PEP and the design plan. Again, facility design knowledge and information on the performance of the design team is another output.

**Construct Facility** includes all functions required to assemble a facility so that it can be operated. These activities translate resources (e.g., materials) in accordance with the design into a completed facility. Typically appropriate facility operations and maintenance documents are generated. As a result, facility construction knowledge and information on the performance of the construction team is generated. Controls include bid and construction documents and criteria, the PEP, facility design knowledge transferred to the team, the contract and the construction plan.
Operate Facility comprises all of the activities which are required to provide the user with an operational facility. In addition, operating knowledge, and information on the performance of the team is generated. This process is controlled by the facility construction knowledge available to the team, the facility operating and maintenance documents, the PEP, the operating plans and the contract.

1.3 EVOLUTION OF THE MODEL

The IBPM has been developed through extensive interviews with experts and practitioners; sixteen site visits; and multiple reviews by each of a five member academic panel and a five member industry panel. Over 40 experts have reviewed this model for its completeness. The model has been extended four levels below the F level model. This has led to simplification and verification of the upper levels presented in this report.

While the drawings may seem obvious and simple, they differ radically from those first assembled by the project team. The first model included technical and management functions and was heavily influenced by who performed the function. A second model treated each of the four functions, viz. planning, design, construction and operations & maintenance as combined business and technical functions. The third revision, on the other hand, separated the management functions for each group and combined them into one generic management function called "management of the facility." The other four functions named above, focus on technical functions only. Finally, at lower levels, the model recognizes that there are planning and control, service acquisition and resource acquisition functions that are performed at both the facility level and the subfunction level. This report highlights the Construction portion of the model.
Chapter 2

INTRODUCTION TO THE
CONSTRUCTION PROCESS MODEL

2.1 OBJECTIVES - DEVELOP THE CONSTRUCTION PROCESS MODEL

The primary objective of this report is to develop a model of the construction process which will be coordinated and applied with the manage, plan, design, and operate process models. The construction model will represent the major functions performed and most importantly, identify the flow of information and knowledge that supports the execution of the work. Subsequently, applications and uses for the model will be proposed which can improve current construction practices concerning the handling and use of information.

2.2 SCOPE OF THE WORK

The focus of this report is on the identification of information elements which are transferred between the functions involved in the construction process. The developed model will represent the functions typically performed by a general contractor or construction management firm that is solely responsible for the construction of a facility, not including design. The work is assumed to be carried out in a free enterprise economic system, with the goal of the constructor being to optimize the use of time and physical resources to achieve the desired quality. The time frame for the study will start when the contractor has been
awarded the job and will end when the facility is turned over to the operations staff.

The model will represent the functions required to support an ideal project execution method. This was developed by combining the good qualities from the case studies with the recommendations of industry experts and existing technology identified during the literature search.

2.3 RESEARCH METHODS

In conducting this research the major tasks involved were: study the construction process and information concepts; review existing construction process models; conduct case studies to support the development of the model; develop the new construction process model; and analyze the case studies and propose uses for the model. Each of these tasks is discussed in the following sections.

2.3.1 Study the Construction Process

A literature search was conducted to study current practices in construction to understand the steps in the process and to identify how projects are managed. Practical experiences learned while working on construction projects were used as input to this report.
2.3.2 Review Existing Construction Process Models

A literature search was conducted to identify existing construction models. These construction models were studied and the important aspects of each were incorporated into the construction process model developed in this report.

2.3.3 Conduct Case Studies to Support the Development of the Model

Companies and projects were selected for use as case studies. The criteria for the selection of these projects included the willingness of the company to cooperate and give permission for several staff members to be interviewed, the size of the project, and the size of the staff. Companies with two to six on-site managers or superintendents were desirable so that the investigation could be thorough and cross-checked whenever possible. Questions were developed to ask key personnel during the case studies to identify the specific tasks involved in the construction process, study the use of documents and other methods of information transfer, and identify the content of the information at different stages in the process. Project managers, construction managers, project engineers, assistant managers, superintendents, and foremen were interviewed.

In order to present a model of the building construction process which can be applied to many projects, this report considered six types of buildings. The case studies were a downtown commercial office building, a gymnasium, a single-family homes development, a convenience store, an apartment building, and a
university research building. When discussing or investigating the details of construction, masonry work was used as a typical example.

2.3.4 Develop the New Construction Process Model

The basic construction model was developed. This included node trees, definitions, function outlines, and diagrams, describing the processes and flows of information. It is based on the study of the construction processes found during the site visits. The model was progressively refined and improved using the results of each investigation. Valuable input to the model was obtained from the advisory board members, including leaders in the construction field from both academia and the industry.

2.3.5 Analyze the Case Studies and Propose Uses for the Model

An information labeling system was developed so that pieces of information could be efficiently labeled and entered into a spreadsheet program. These lists of examples of information, sorted by source, destination, model, arrow, or case study, were developed to support the model by showing examples of particular arrows in an organized list. Finally, the findings from the case studies were discussed and recommendations for the use of the model were presented.
LITERATURE SURVEY SUMMARY

3.1 PURPOSE OF MODELING

Models are created and used for a variety of purposes. Common uses for models include describing complicated processes, communicating ideas or concepts, analyzing systems, and answering questions about real systems (Lave and March 1975; Halpin and Woodhead 1976). Models can be used to make better decisions and to develop new and better models. In general, models should simplify a complex system and provide insight and understanding to users of the model.

3.2 EXISTING CONSTRUCTION MODELS

Models are widely utilized and applied, particularly in the construction industry. Several common examples are:

(1) Schedules - bar charts, CPM schedules
(2) Organization Charts
(3) Physical Models - scale mock-ups
(4) Budgets
(5) Drawings - building blueprints
(6) Specifications - material properties
This report presents a different type of model, a process model. The manufacturing industry uses process models extensively and has realized significant improvements in productivity through their application. Perhaps inappropriately, the construction industry does not extensively utilize process models. However, several previous attempts have been made to develop construction process models and four existing models are presented in the following sections.

3.2.1 Howell's Model of the Construction Process

Howell's model of the construction process identifies the resources which are required to support the work at the job site. These resources include a place to work, materials, tools, energy, people, and information (Howell and Casten in Sanvido 1984). The model also shows the importance of selecting suitable work methods and providing feedback to managers (see Figure 3-1).

This model accurately points out the key elements of the construction process in the field. It identifies information and feedback as critical elements, which indicates the need to model the information flow throughout the construction process. The model is generic to all construction processes at the crew level.

3.2.2 Wheeler's Project Life Cycle Model

Wheeler (1978) developed a model for managing architectural construction projects which separates the building process into nine sequential phases. These phases start with the organization of the building team and end with the occupancy of the facility by the user, with multiple design and construction
Figure 3.1 Howell's Model of the Construction Process
(Source: Howell and Casten in Sanvido 1984)
phases in between. The Wheeler model gradually exposes detail by subdividing each phase into sequential steps, and subsequently separating each step into activities. Definitions for each task in the process are provided to support and explain the model. The descriptions include an identifiable output or milestone for each activity. The model also identifies the major responsibilities of the client, project manager, design manager, and construction manager for each activity in the building process. This is graphically presented in a matrix format with the project participants on the vertical axis and the activities on the horizontal axis (see Figure 3-2).

The major shortcoming of the model is that the interrelationships between activities are not identified. It assumes a sequential assembly-line-type process to represent construction. In actuality, construction is an iterative and variable process which can more appropriately be described with a model which represents an ever-changing process with multiple interrelationships between activities. This is necessary because no two projects are the same.

3.2.3 Sanvido's Conceptual Construction Process Model

Sanvido (1984) presented a construction process model consisting of controlling functions which plan the work and control the resources based on the task definition and feedback information (see Figure 3-3). This model was designed with the goal of developing a management system to support the needs of the craftsman in the field (see Figure 3-4). On a broader scale the Sanvido model defined a hierarchy of management functions and coordinated these functions by identifying the interrelationships between them (see Figure 3-5). A portion of the model also identified the major influences on planning the
Figure 3.2 Wheeler's Project Life Cycle Model
(Source: Wheeler 1978)
Figure 3.3 A Dynamic System Model for Each Level in an Organization.
(Source: Sanvido 1984)
Figure 3.4 The Construction Process as the Craftsman Views It
(Source: Sanvido 1984)
Figure 3.5 Sanvido’s Consolidated Overview of the Construction Process
(Source: Sanvido 1984)
work and supplying resources. In turn, the influences of the project on participants and the environment were listed (see Figure 3-6).

The Sanvido model presents an effective strategy for controlling construction work. Three important basic rules are presented. These concepts are (1) a controller plans and controls to coordinate the functions of the controller directly below him and no lower; (2) resources are controlled one level above which they are shared; and (3) feedback information must be provided to the controller for their particular scope of work.

While establishing a basic work process and generic hierarchy of control, the Sanvido model has some limitations in this application. It is a conceptual model which does not define the detailed management functions, nor does it identify specific resources or pieces of information that flow between subprocesses.

3.2.4 Sanvido's Project Management Model

Sanvido (1986) presented an expanded construction model that defines inputs, processes, outputs, and control functions for the construction team, the design team, and the owner's project team (see Figure 3-7). The model is supplemented with detailed checklists covering functions to be performed by the parties involved in the construction process. Checklists were developed for the construction manager, the engineering (design) manager, and the project manager. The categories of the checklists for the construction manager are shown in Figure 3-8.
Figure 3.6 Influences on the Construction Process
(Source: Sanvido 1984)
Figure 3.7 Sanvido’s Project Management Model
(Source: Sanvido 1986)
Figure 3.8 Sanvido's Construction Function Outline
(Source: Sanvido 1986)
This model identifies the major functions which should be performed while constructing a facility, but does not define interrelationships between subfunctions. The detailed checklists accompanying the model were a primary source of documented information for the development of the construction model in this report.
Chapter 4

EXPLANATION OF THE
CONSTRUCTION PROCESS MODEL

The developed Construction Process Model is presented and explained in the first part of this chapter. This is followed by descriptions and analyses of the findings from the case studies.

4.1 THE CONSTRUCTION PROCESS MODEL

Providing a facility includes managing, planning, designing, constructing, and operating. The Construction Process Model describes the construction part of providing a facility as typically performed by a general contractor or construction manager responsible for building a facility.

The Construct Facility function represents the entire construction process (see Figure 4-1). In this function, a site and resources are converted into a facility. The resources include building materials, equipment, labor-hours, energy, time, and money. Time and money are important inputs to all the functions in the process, but they are only shown in the higher levels of the model in order to minimize redundancy. The work is executed based on the bid and construction documents and criteria, and the project execution plan which is provided by the owner. The external constraints (including the weather, government regulations, available technology, and the economy), directly impact the
Figure 4.1 Construct Facility Overview
construction process. The two main information outputs of the process are post-construction information and facility construction knowledge. Post-construction information includes as-built drawings and recommended operations and maintenance procedures. Facility construction knowledge is the information and knowledge that results from constructing the facility and the related experience that can be used in the future.

An overview of all the functions included in the construction model is shown in the function tree in Figure 4-2. The Construct Facility function is separated into the subfunctions of Acquire Construction Services, Plan and Control the Work, Provide Resources, and Build the Facility. All of the functions and subfunctions are explained in the following sections. Definitions of all the terms used in the model are provided in the glossary (see Appendix B).

4.2 CONSTRUCT FACILITY (C)

The Construct Facility function is broken down into four subfunctions (see Figure 4-3). Each is explained in the following sections.

C1. Acquire Construction Services: In this function, the construction team is selected and organized. This typically involves assigning in-house personnel to the project and hiring the needed subcontractors, consultants, and other additional staff. The appropriate contracts and agreements are coordinated.
Figure 4-2 Construct Function Tree
Figure 4.3 Construct Facility Model
C2. Plan and Control the Work: In this function, the construction work is directed and controlled. The primary output is the construction execution plan which establishes the strategies for organizing the construction team, providing resources, and building the facility. The execution plan is revised and updated based on feedback from performing the work. The execution plan is comprised of the staffing plan, resource acquisition plan, and the construction execution plan.

C3. Provide Resources: In this function, all of the resources needed to construct the facility are acquired and allocated. The mobilized site is an important output of this function.

C4. Build the Facility: In this function, the physical work of converting the available resources into the designed facility is performed. This function concludes with the start-up and turnover of the facility.

4.3 ACQUIRE CONSTRUCTION SERVICES (C1)

The Acquire Construction Services function is broken down into five subfunctions (see Figure 4-4). Each is explained in the following sections.

C11. Identify Qualified Parties: In this function, the parties qualified to perform aspects of the work as specified in the staffing plan are identified.
Figure 4.4 Acquire Construction Services Model
The output of this function might be several subcontractors who will be invited to bid on a work package.

C12. Provide Work Scope Information: In this function, work scope information is communicated to the qualified parties. Invitation-to-bid documents including the plans and specifications are supplied. Briefings or site visits might be conducted.

C13. Prepare and Submit Proposals: In this function, the qualified parties develop bid prices and plans based on the work scope information taking into account the economy and other external variables.

C14. Review Proposals and Select Constructor: In this function, the proposals are reviewed and checked against the intended work scope. A constructor is selected based on the criteria set by the staffing plan including contractor reputation, budget parameters, schedule objectives, and quality standards.

C15. Execute Contracts/Agreements: In this function, agreements are negotiated and the contracts between parties are formalized.
4.4 PLAN AND CONTROL THE WORK  (C2)

The Plan and Control the Work function is broken down into four subfunctions (see Figure 4-5). Each is explained in the following sections.

C21. Develop the Construction Plan: In this function, the construction plan including work methods plans, estimates, and schedules, is formulated. During construction, the plan is revised based on the performance feedback.

C22. Implement the Plan: In this function, the construction plan is converted into the execution plan. Budgets and aggressive schedules are developed for use by the procurement and field labor teams. The execution plan is revised to reflect changes in the construction plan. Communications with the owner and designer in the form of submittals and shop drawings are handled as part of this function.

C23. Monitor Performance: In this function, the work is monitored and the performance feedback information is coordinated for use in developing performance reports which will be used to analyze job progress. Historical data is accumulated and stored for use on other projects.

C24. Analyze Performance: In this function, the status of the work is evaluated, problems are identified and investigated, and the sources of
Figure 4.5 Plan and Control the Work Model
problems are located. The need to make changes to the construction plan is determined and communicated as performance feedback. Adherence to the contract cost, schedule, and quality requirements is reviewed.

4.5 PROVIDE RESOURCES (C3)

The Provide Resources function is broken down into six subfunctions (see Figure 4-6). Each is explained in the following sections.

C31. Mobilize: In this function, the job trailers, laydown areas, parking areas, and other site facilities are set up. The temporary power, temporary phone, and other temporary services are acquired. The necessary permits, insurance policies, construction bonds, etc., are obtained.

C32. Acquire Resources: In this function, the needed resources as shown in the material takeoff are obtained in accordance with the schedule taking into account the delivery, inventory, and maintenance feedback information.

C33. Receive and Inspect the Resources: In this function, the acquired resources are checked as they are delivered to verify that the quantity and quality of the order is correct.
Figure 4.6  Provide Resources Model
C34. Store the Resources and Manage the Inventory: In this function, the resources are stockpiled and the on-hand inventory is tracked. The materials, supplies, and equipment are inspected and the needed repairs are identified.

C35. Repair and Maintain the Resources: In this function, the routine preventive maintenance is performed as specified in the maintenance program and the items in need of repair are fixed.

C36. Allocate the Resources: In this function, the distribution priorities for the on-hand resources are determined based on the construction schedule, available inventory, and the need for resources. The control of resources is allocated as the resources arrive on site.

4.6 BUILD THE FACILITY (C4)

The Build the Facility function is broken down into five subfunctions (see Figure 4-7). Each is explained in the following sections.

C41. Plan the Daily Work: In this function, people utilize field experience to give instructions for conducting the daily work based on the construction execution plan and feedback from performing the previous work. The environment and government regulations directly impact this plan.
Figure 4.7 Build the Facility Model
C42. Distribute the Resources: In this function, the needed resources are physically transported to the appropriate work areas as specified by the daily distribution plan and distribution priorities.

C43. Do the Physical Work: In this function, the resources are converted into completed elements of the designed facility.

C44. Inspect and Approve the Work: In this function, the completed work is checked to assure that the quantity, quality, and location of the product is sufficient and that the contract requirements were fulfilled. The owner, designer, constructor, code inspectors, and other government officials approve the constructed facility.

C45. Turn Over the Completed Work: In this function, the building systems are tested and adjusted, the occupancy permit is obtained, and the facility is started up. Operation information is provided to the owner. Any legal claims are resolved as a part of this function.

4.7 DEVELOP THE CONSTRUCTION PLAN (C21)

The Develop the Construction Plan function is broken down into five subfunctions (see Figure 4-8). Each is explained in the following sections.
C211. Determine the Scope of Work and Coordinate the Planning: In this function, the scope of work is defined as required by the contract requirements or requested by the owner or designer. The planning guidelines and goals are established. Decisions made concerning methods, cost, and schedule are communicated as part of the planning parameters.

C212. Select Work Methods: In this function, the techniques which could be used to construct the facility are identified, based on methods knowledge, project information, safety standards, resource availability, and the planning parameters.

C213. Estimate the Work: In this function, the resource needs and the anticipated costs associated with these needed resources are forecast, based on historical data, project information, alternative work methods, and the planning parameters.

C214. Schedule the Work Activities: In this function, the durations of activities are estimated, the interrelationships between tasks are identified, and activity starts and finishes are planned, based on productivity data, project information, alternative work methods, and the planning parameters.
C215. Analyze and Select the Plan: In this function, alternative plans are reviewed, portions of plans are approved, the need for replanning is determined, scope changes are proposed, and the construction plan is formalized.

4.8 DO THE PHYSICAL WORK (C43)

The Do the Physical Work function is broken down into five subfunctions (see Figure 4-9). Each is explained in the following sections.

C431. Identify the Location for the Work: In this function, the physical location on the site where a component of the facility will be constructed is pinpointed, based on the plans and specifications.

C432. Set Up the Work Area: In this function, the work space is established and organized (e.g., constructing scaffolding).

C433. Prepare the Resources: In this function, the resources needed to conduct the work are mobilized and coordinated (e.g., mixing the mortar).

C434. Perform the Work: This function is the core of the construction model. All of the other functions exist to support this process of converting resources into completed elements of the facility.
Figure 4.9 Do the Physical Work Model
C435. Clean Up the Work Area: In this function, the waste products are separated and removed from the improved site. Partially consumed resources, such as equipment and scaffolding, are salvaged for future use.

The above definitions of the functions in the Construction Process Model briefly describe the basic tasks. The findings from specific case studies, which support the validity of the Construction Process Model, are presented in the next chapter.
Chapter 5

VALIDATION OF THE MODEL

The findings from the case studies are summarized in three different formats: brief narrative descriptions, tables of arrow examples, and categorized discussions of the findings from the case studies. The detailed discussions are in Appendix D. The narrative descriptions and the tables of arrow examples are each provided in the following sections.

5.1 NARRATIVE DESCRIPTIONS

A brief narrative discussion of significant information problems and lessons learned related to information are presented for four of the case studies in the next sections. The projects investigated included an office building, a gymnasium, a luxury home development, and a convenience store.

5.1.1 Case Study "O" - Office Building

This case study involved the construction of two similar four-story medium-sized office buildings. The general contractor in charge of construction was studied.

The project was under budget, but behind schedule due to complications in obtaining permits during the clean-up of the existing conditions at the site. The buildings were being closed-in with the installation of the exterior glass. No major operational problems were observed.
Although not critical, several informational problems were identified. Since two similar buildings were being constructed, many small problems on the second building were accumulating and causing considerable delay and needless expense. Initially, it would appear that the work on the second building would progress more smoothly since the bugs would have been worked out during the construction of the first building. This may often be true, but on this job mistakes were being made due to laziness and not reading the drawings closely on the second building. Undetected differences between the building designs resulted in disruptive rework.

Another information problem involved the tracking of job progress and incurred costs. Even though the project manager knew it would be desirable to integrate the cost control and schedule systems, the two remained independent. The activities identified in the schedule could have been efficiently used as the categories for cost items in the cost control system, or vice versa. In several instances the same items were used in both, but each had to be entered separately resulting in the unnecessary duplication of effort.

The management staff had several useful suggestions and comments. One of these was that information highlighting potential mistakes should be provided to foremen so that they can effectively plan their work. For example, a drop ceiling subcontractor should be advised not to move the heat pump drain pipes because they depend on gravity for drainage.
The following quote from the project manager clearly emphasizes the importance of efficient communication with the field staff.

In order to effectively plan and control the work as a manager, you must know what’s out there in the field. You must learn the workers attitudes and their way of thinking. You can have the best management and computer system available, but if you can’t communicate effectively with the people who actually do the work, not much will be accomplished.

Another interesting point brought up during this case study involved deciding what should be documented. When deciding what information needs to be stored for future use, the possibility of the unexpected absence of important people on the project should be considered. The plans must provide for a short absence, as well as for an extended or even permanent absence due to an accident or termination of employment. How can work progress fairly smoothly in the absence of a person critical to the project? Also, how can the knowledge of experienced construction managers be captured for the benefit of the less-experienced people in the company?

5.1.2 Case Study "G" - Gymnasium

This case study involved the construction of a gymnasium with a large basketball court, indoor pool, locker rooms, and small office area. The general contractor in charge of construction was interviewed.

The project was not running smoothly. The work was considerably behind schedule. Since the quality of available labor was poor, constant supervision of
the workers was required. Employee theft of tools was cited as a major problem by the project manager and his assistant.

Several information problems existed. There was no evidence of plans for the allocation and distribution of tools and equipment. If certain items could not be located at the end of the day, management did not even know who had been using them. Since theft was a problem, some type of organized sign-in and sign-out system should have been established. Another information problem related to the planning of the work in general. Disruptive and cumbersome rework was necessary to upgrade several masonry walls to fire walls, since adequate instructions had not been communicated to the subcontractor.

The storage of information on this project was thorough. A full file of all project paperwork was kept in the job trailer. Duplicates of most documents were filed at the main office. A complete log of all phone calls was kept with comments as to who should follow up. This log was reviewed and taken care of routinely.

Two interesting techniques for the communication and storage of information were being used by the project manager. The first is simple but effective: write down everything on the drawings. If a missing dimension needs to be calculated, write it down on the drawings. It will probably be needed again. Secondly, when answering specific questions refer only to the updated set of drawings in the trailer. Never let the updated set leave the trailer, and do not rely on possibly old versions of drawings in the field.
5.1.3 Case Study "H" - Luxury Homes

This case study involved the construction of luxury single-family detached homes on half-acre lots. The construction manager in charge of the project was interviewed.

The work seemed to be progressing smoothly, except for one house which had an overcrowding and interference problem. The HVAC, electrical, window washing, painting, and finish carpentry subcontractors were all on site at the same time. This concurrent work was necessary because an open house was scheduled for the following day.

Several problems related to information were apparent. No schedules had been prepared, which probably led to the overcrowding situation. Major problems were caused by a representative of the developer who visited the site daily and gave instructions to the subcontractors, often in direct conflict with the requests of the construction manager. Another planning problem resulted in work tasks not falling under anyone's scope of work. The observed example involved the installation of a compressor unit on top of the refrigerator. Neither the appliance vendor nor the cabinetry subcontractor would install the unit. The construction manager installed the unit himself, but in the future the compressor installation will be included in the cabinetry contract.
5.1.4 Case Study "C" - Convenience Store

This case study involved the construction of a convenience store from fairly standardized plans. The general contractor in charge of construction was interviewed.

This project was in the final stages of construction. A major problem with the work was that budgets were not provided to the field staff. Since the job superintendent did not have access to any estimate information, he had no idea on the project profitability until a summary report was compiled after the work was completed.

The foremen expressed several complaints related to information. The drawings were not sufficiently dimensioned. The laborers were forced to inefficiently calculate lengths in the field when the dimensions could have been included in the designer's drawings. Another inadequacy was that the dimensions shown were the angles of corners, not lengths. This is information in the wrong format because laborers use tape measures, not protractors. The foremen also wished that they had been provided with a complete set of specifications for use in the field.

5.2 TABLES OF ARROW EXAMPLES

Examples of arrows containing information found during the case studies were entered into a spreadsheet software to generate tables for each level in the model (see Tables 5-1 to 5-7 on pages 5-9 through 5-15). As can be seen,
several examples for almost every arrow are included in the tables. Redundancy was minimized by only including particular examples at the most appropriate level in the model and by not repeating examples if they were evident in more than one case study.

Examples of every arrow are not shown, usually due to one of the following three reasons:

1) Examples of a particular arrow might be shown at other more appropriate layers in the model. For instance, examples of Progress Information are not shown in model C, but are shown in model C4.
2) A particular arrow might not be included as part of the work that was being executed at the time of the case study investigation. For instance, the Acquire Construction function had been completed in most of the projects and therefore, there are few examples of arrows in this level of the model.
3) Portions of the work may not have been concentrated on during the interviews and particular examples simply may not have been discussed. For instance, the lower levels of the model were emphasized during the convenience store case study and the top level was only mentioned briefly.

Examples of arrows for each level of the model are included in the tables. A description of the arrow is in the arrow name column and the diagram code on which the arrow appears is in the model column. The source and destination functions of each arrow are given in the first two columns. A "0" in the source column indicates the arrow originates outside the diagram and a "0" in the
destination column means the arrow goes off the diagram. Zeros were added to the function box codes to label the arrows so the list could be easily sorted according to source and destination. The examples are given in the far right column with the case study code directly to the left of it.
Table 5.1  Construct Facility (C) - Examples of Information Arrows

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5-9
Table 5.2 Acquire Construction Services (C1)
- Examples of Information Arrows

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Table 5.4  Provide Resources (C3) - Examples of Information Arrows

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Table 5.5 Build the Facility (C4) - Examples of Information Arrows

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Chapter 6

DISCUSSIONS AND CONCLUSIONS

The primary sources of most information problems as discovered through the case studies and the literature review are described in this final chapter. Then, to attempt to solve some of these problems, potential uses for the developed Construction Model are proposed.

6.1 SOURCES OF MOST INFORMATION PROBLEMS

As discovered in the case study investigations and literature search, the problems relating to information are numerous and varied. In order to begin to solve these problems, the sources or causes must be identified. The likely sources of many of the problems are discussed in the following sections.

6.1.1 Inadequate Drawings and Specifications

The most common complaints heard while interviewing the construction people pertained to problems with the designer's drawings and specifications. The criticisms cover situations where the drawings are not up to code, the specifications are outdated, there are not enough sections or elevations, the dimensions are inadequate, and the drawings are simply incorrect.

These complaints may be valid since the trend in the construction industry is to minimize the architect's fees, and as a result the quality of their product may be suffering. This would put more of a burden on the constructor. However, it must
be remembered that the interviewees are likely to blame the other guy (designer) for problems on the project, rather than assume the responsibility themselves.

6.1.2 Inadequate Planning

A lack of proper planning, L.O.P.P. for short, appeared to be a major problem. The focus of the managers on jobs was to start moving resources and doing the physical work, often without analyzing alternatives or trying to coordinate the whole process. This leads to problems when resources are not stored properly and are either difficult to find, damaged, or lost. Aspects of the work are performed out of sequence and inefficiently. The importance and criticality of thorough planning needs to be appreciated and appropriate action must be taken. This can be accomplished by focusing on the functions in the C2, Plan and Control the Work, portion of the model and ensuring that the needs of the other functions are fulfilled.

Even when plans are made they are often not communicated to the most important people, the workers in the field. The instructions to the laborers are often unavailable or confusing. For example, when budget and schedule goals are not provided to the foremen, they have no measure against which to analyze their performance.

6.1.3 Failure to Learn from Mistakes

Another common problem which should not exist, or should at least be easy to solve, is that laborers and superintendents are not learning from their mistakes.
For example, a masonry crew constructed a block wall on two different days in subfreezing weather and in both instances the mortar in the walls crumbled the next day. This required considerable rework which slowed down the progress of the job and wasted expensive labor time. The obvious solution to the problem would be to take the temperature in the morning and check weather reports, and based on experience determine if the conditions are appropriate for laying block.

The managers are also guilty of not learning from their mistakes. For instance, when tools were commonly lost on one of the jobs the managers failed to take action to solve the problem. Instead, they just complained about the laborers stealing tools.

6.1.4 Poor Utilization of Existing Models

An obvious problem in each of the projects investigated was that the construction managers were not effectively utilizing their management tools. In particular, two of the most common modeling tools in construction, schedules and organization charts, were hardly being used. No schedules were developed on one job and on each of the other jobs a schedule was made, but was never updated. The schedules were like souvenirs from when the job was planned and bid. One project manager admitted that the work was scheduled not based on the schedule, but on walking around the site and seeing what can be done next with the available resources. Another manager said that variables and changes caused the CPM schedule for the job to be violated daily, and that keeping the schedule up-to-date would require hiring a full-time scheduler.
Organization charts were utilized even less than schedules. None of the jobs had a formal organization chart showing the appropriate lines of communication and areas of responsibility. Several of the managers had trouble describing the positions of the people in the company. Some of the staff members had no job title and many of the others said their titles did not represent the responsibilities of their positions. It appeared that the confusion in the structure of the organizations was causing communication problems.

Budgets were similarly underutilized on the projects investigated. However, one of the companies used budgets extensively to control the work. This happened to be the job which was running most smoothly and without major cost overruns. The Construction Model developed in this report is another management tool which could turn out to be underutilized. Some of the problems with this and other models are presented in the following section.

6.1.5 Difficulties in Implementing Models

Several obstacles exist which must be overcome in order to effectively implement and utilize the Construction Model developed in this report as well as other models. First, people resist change. It is easier and less stressful to do things the way they were done yesterday or in the past. Another potential problem with implementing the Construction Model is that the model appears to be fairly complicated at first glance and therefore causes negative initial feelings and opinions. The true value of the model is not immediately recognizable. To explain the usefulness of the model, several applications for the model are described in the following sections.
6.2 POTENTIAL USES FOR THE CONSTRUCTION MODEL

There are many potential applications for the use of the model developed in this report or other similar customized versions of this model. Several of these uses are presented and described in the following sections.

6.2.1 Analysis of Operations by the Constructor

The model can be used to either generally or carefully review the flow of information and resources between the various construction functions. Project personnel can be interviewed to analyze operations using the generic questions in Appendix C.

Another potential use of the model is to make it the basis for checklists which can be periodically reviewed to ensure that recommended procedures are being followed and that the needed information and resources are getting to the appropriate people at the proper time. By reviewing these checklists, improvements in procedures or changed information needs associated with a particular function can be identified. In comparing actual situations with the model, the effect of nonexistent or hindering arrows can be assessed.

6.2.2 Identification and Prevention of Problems

The model can be used to pinpoint the source of particular problems and the associated functions which were directly or indirectly impacted. In the future, a similar occurrence of a particular problem can be more easily recognized and hopefully avoided, or at least minimized in its severity. For example, when
laying block, if it is determined that the mortar freezes at 28F, then whenever the temperature drops below this level either the work should be halted or the appropriate precautions should be taken. If there was a poor estimate or no work methods plan, then high costs could result due to poor resource utilization.

6.2.3 Basis for the Development of Procedural Manuals

The Construction Process Model can be used to develop procedural manuals for construction companies. The functions and subfunctions in the model can be easily translated into specific instructions to be followed in carrying out the work. The functions defined in the model can be used as job descriptions for individuals or areas of responsibility for managers. The model can be a basis for the proper flow and use of both information and resources in the construction process. The needed resources and information can be clearly identified for each task in the process. Similarly, precautions can be taken to minimize the effects of bad controls or hindrances. Unlike schedules which are commonly developed simply to satisfy the requirements of the contract and then used as a wall decoration, this process model can be used and referred to throughout the project.

For example, if a newly hired assistant project engineer was given the responsibility to solicit bids from plumbing subcontractors to install a sprinkler system, he or she may not know exactly what this involves. One source of guidance would be this process model. By referring to the breakdown of the Acquire Construction Services function it can be seen that the basic procedure would be to identify qualified parties, provide them with information, and have
them submit proposals. The model can also give steps to be taken to accomplish each of these subtasks.

At a minimum the model would provide an unknowledgeable person with some intelligent questions to ask others concerning an aspect of the work. The arrows in the model identify the primary sources of information concerning particular functions.

A long-term goal in applying the model might be to provide each laborer with a card specifically describing the work to be done each day. This is currently being done by Japanese construction companies. This precise planning of the work would be formally done for large projects and companies, and informally developed in smaller ones such as home builders.

6.2.4 Integration of All Participants in the Construction Process

This Construction Model along with the models of the other aspects of the process, namely Managing, Planning, Designing, and Operating, can be used to get everyone working together toward the same objective. Well-defined, non-overlapping, coordinated tasks can be assigned to each of the participants in the construction process and incorporated into the contracts. This will help to integrate the work of the owners, designers, constructors, operators, material suppliers, inspectors, etc.
6.2.5 Basis for Further Research in Construction

Many other research projects can use this model as a basis for developing advanced computer applications for the construction industry. Some possibilities include the development of expert systems and integrated databases, as well as the use of artificial intelligence. Additional and more detailed models can be developed to improve procedures and coordinate the construction process.

6.2.6 Course Materials for Construction Students

This model can be an effective educational tool for use in introductory or advanced construction courses. Unlike schedules and budgets which only show the timing of activities and expected costs, the Construction Model is valuable since it shows the details of the construction process, and the flow of information and resources which support the process. Much can be learned through analyzing and developing construction process models.

6.3 CONCLUSION

The applications described in the preceding sections can be implemented to directly address the current sources of information problems discussed in the beginning of this chapter. By applying the model, communications between functions and parties in the construction process can be greatly improved, the effectiveness of planning can be increased, and the recurrence of problems can be minimized. The model can also be used to integrate the use of existing modeling tools in construction.
The use and further development of the construction process model will help to improve construction practices and techniques. Constructors can develop procedural manuals, design information systems, and thoroughly analyze operations with the model. The efforts of owners, designers, operators, material suppliers, inspectors, and constructors can be better coordinated. Probably most importantly, the model can be used as a basis for implementing currently available and ever-improving computer technology to upgrade the entire construction industry.
Appendix A

BIBLIOGRAPHY


Appendix B

GLOSSARY

Accepted Resources: resources which have been inspected and approved as meeting the specified quality and quantity (e.g., inspected for damage from transport). This is typically verified with a signed receipt of goods note.

Acquired Resources: resources which have been delivered to the site, but have yet to be accepted.

Alternative Plans: several strategies (primarily concerning methods, estimate, and schedule information) which will be analyzed to select an optimum construction plan.

Alternative Work Methods: possible techniques or construction processes which could be implemented to build the facility (e.g., formwork designs, selected equipment, selected work techniques).

Approved Work: elements of systems in the facility which have been inspected and are deemed ready for start-up and turn over.

Available Resources: the personnel, computer technology, time, space, equipment, materials, energy, etc. available to the project.

Bid and Construction Documents and Criteria: the formal documents, drawings, specifications, instructions, limitations, procedures, and criteria for bidding and constructing the facility. These represent the best information available that conveys the nature of the facility and parts thereof to be built. They include bid documents, scope of work, working drawings, limitations of cost and schedule, and quality criteria as available.

Completed Work Unit: completed elements of the facility which have not been tested or started-up.

Construction Execution Plan: the selected construction plan which defines the way the construction will be performed. This plan includes budgets, schedule goals, approved shop drawings, work methods, quality objectives, safety plan, etc.

Construction Management Team: the subset of the construction team which is responsible for planning and controlling the construction of the facility (e.g., estimators, schedulers, methods planners).

Construction Plan: a working document including the methods plan, estimate, schedule, material take-off, etc. that defines the goals and means for the construction of the facility.
Construction Team: all parties who will participate in the construction of the facility.

Constructor Proposed Scope Changes: recommendations from the construction team which might improve the design of the facility or simplify the construction work (e.g., value engineering proposals).

Constructor Submittals: correspondence from the construction team to the owner and designer confirming the details of the design, material selection, equipment selection, etc. Examples include catalog cuts, color samples, shop drawings, and fabrication drawings.

Contract Requirements: the scope of work as described by the legal agreement between parties involved in the construction of the facility. Formal approved change orders become part of the contract requirements.

Daily Approval Plan: instructions defining the methods, order, and criteria for checking the physically completed items.

Daily Distribution Plan: instructions explaining the means and methods for transporting resources to the appropriate locations throughout the site (e.g., instructions to the crane operator).

Daily Plan: instructions explaining the methods and means for accomplishing the work. This includes the daily distribution plan, daily work plan, daily approval plan, and start-up plan.

Daily Progress Information: the feedback from the completion of the work which will be analyzed to aid in planning the next day’s work and also determine if changes to the daily plan or construction execution plan are needed.

Daily Work Plan: instructions describing the means, methods, and priorities for completing the physical work.

Delivery Information: feedback concerning the receipt of resources.

Delivery Schedule: projected timetable for the shipment and receipt on site of resources.

Distributed Resources: resources which have been transported to the appropriate work areas throughout the site.

Distribution Priorities: instructions defining the criticality of the need for resources in aspects of the work (e.g., priorities for the crane operator).

Distribution Progress Information: feedback (work status and problems) concerning the movement of resources around the site.
Economy: the current condition of the construction and financial markets which, in turn, determines the availability of constructors, resource suppliers, building permits, money, etc.

Environment: the physical conditions beyond the control of the project participants that affect the ability of the project team to provide the facility (e.g., weather, strikes, natural disasters).

Estimate Information: data describing the anticipated costs of alternative plans.

Expected Level of Performance: the standard against which the performance reports will be evaluated to determine if the progress is adequate and if the contract requirements are being fulfilled.

External Constraints: parameters and variables that impact the construction of the facility which are beyond the control of all project participants. These include the environment, economy, technology, government regulations, etc.

Facility Champion: The individual who initiates the idea, commits and mobilizes the funds and resources required to get the facility developed, and leads in establishing a project team.

Facility Construction Knowledge: the information and knowledge that results from constructing the facility and the related experience that can be used in the future (e.g., lessons learned and improved abilities for the next job).

Facility: the desired building and site, including all installed equipment.

Field Experience: the combined skills and knowledge of the field labor team.

Field Labor Team: the subset of the construction team which is responsible for constructing and turning over the facility.

Government Regulations: statutory requirements imposed by various governmental bodies (e.g., mandatory inspections, building codes, OSHA safety requirements, EPA requirements).

Historical Data: database of costs incurred and resources used in completing the work to construct the facility.

Identified Repair Needs: information describing the need for repair and maintenance of particular resources.

Identified Work Location: the exact physical location for a component of the facility (e.g., chalk lines defining the corner of a wall).

Inspection Records Information: feedback describing the performance of the testing and checking of the completed work (e.g., a failed inspection).
Inspections: formal determinations of the ability of the work to meet specifications and code requirements (e.g., reviews of the work by code officials).

Inventory Information: data concerning the quantity of resources available in stock.

Items in Need of Repair: resources for which a repair or maintenance need has been identified.

Maintained Resources: resources which have been repaired or maintained and are ready to become part of the available inventory.

Maintenance Info: feedback concerning the progress in maintaining and repairing the resources. This includes projections of when resources will be repaired and usable.

Maintenance Program: a subset of the resource acquisition plan which establishes standard procedures for the upkeep of resources, most importantly the construction equipment.

Material Takeoff: identified types and quantities of resources needed to execute the construction plan.

Methods Knowledge: expertise or experience in construction methods gained through constructing other facilities, attending seminars, reading industry literature, acquiring experienced people, etc.

Mobilized Site: a site that has the facilities to support construction work (e.g., tool storage, job trailer, access road, safety equipment).

On-hand Resources: resources which are in-stock or easily accessible and available to be allocated.

Owner/Designer Requests: informal change orders or directions from the designer and owner which may alter the plans or require the replanning of the work (e.g., a request to allow a potential client to tour the job site).

Partially Consumed Resources: materials and equipment that are leftover after performing a portion of the work (e.g., tools and supplies that can be reused).

Past Facility Construction Knowledge: expertise possessed by company personnel, consultant knowledge, etc.

Performance Feedback: an evaluation of the performance of the construction team in using the resources to achieve the goals, including identified sources of problems in performing the work, on-budget/over-budget data, on-schedule/behind-schedule data, problems with the plan, etc.
Performance Information Needs and Criteria: a subset of the construction execution plan that identifies the data which should be gathered in order to track the progress of the job or satisfy the requirements of the contract.

Performance Information: feedback about the actual progress of activities which, when compared to the plan, is interpreted to assess the status of the project and the appropriateness of the plan (e.g., time, money, quality, and other performance factors).

Performance Reports: organized and communicated data describing the performance of the work which will be analyzed to determine if the work is progressing according to plan or if replanning is necessary.

Planning Feedback: instructions to replan the work due to inadequate planning, poor performance, or unanticipated events. While the original plan is being formulated the planning feedback includes selected work methods, allowable costs, and schedule objectives.

Planning Parameters: a well-defined work scope and planning goals which set the strategy and guidelines for planning including the required level of detail and accuracy of the plan. The planning parameters also include decisions that have been made regarding methods, costs, and schedule which narrow the possibilities to be considered when planning.

Plans and Specifications: the formal media for communication of the design. These include the architectural, structural, mechanical, electrical, and plumbing drawings, and the accompanying narrative description of the specific details of the design and selected materials.

Post-Construction Information: vendor suggested maintenance procedures; documents prepared by the constructor which explain operations and maintenance procedures; edited construction drawings which represent exactly what was built (e.g., as-built).

Prepared Resources: distributed resources that have been processed or worked on to get them into their final form for use in performing the work (e.g., mortar).

Procurement Team: the subset of the construction team which is responsible for providing the resources required to build the facility.

Productivity Data: database of information gathered from past work which can be used to predict the duration of activities.

Progress Information: work performance information which may require revisions to the construction execution plan.
Project Execution Plan: owner's plan for procuring all resources and services that are required to provide and manage the facility. A PEP includes schedules, contracting strategy, milestones, and budgets.

Project Information: details concerning the designed facility which are discovered through sources other than the contract documents, such as: communications with the owner or designer, site investigations, consultant advice, etc.

Proposals: documents usually containing a bid price, scope of work, and definition of capabilities, prepared by qualified parties. These will be reviewed to select a constructor.

Qualified Parties: the contractors, consultants, company personnel, and other people who are identified as being capable of performing a portion of the work.

Quality Standards: criteria to be used to determine if resources should be accepted for use on the project.

Requests for Bidding Information: feedback from the parties preparing proposals asking for clarifications to the work scope or for additional project information.

Requests for Clarifications: questions to be answered by a bidding party concerning their submitted proposal.

Resource Acquisition Information: feedback concerning the current progress in obtaining resources, as well as the use of resources.

Resource Acquisition Plan: a subset of the execution plan including: site layout plan, material takeoff, quality standards, storage procedures, maintenance program, and schedule.

Resource Availability: the accessibility of resources as defined by the form, quantity, respective cost, and delivery time associated with obtaining particular resources.

Resources: includes all resources provided by all participants for the construction of the facility (e.g., man-hours, materials, equipment, energy, information, tools, etc.).

Safety Standards: the accepted practices designed to preserve human life and prevent injury of the project participants and the general public. These are specified through methods and performance standards.

Schedule Information: data defining the anticipated duration of activities.
Schedule: identified planned starts, finishes, float times, interrelationships, and associated resource needs for activities in the construction plan.

Selected Constructor: the constructor chosen from the qualified parties with whom an agreement will be made to perform the defined scope of the work as a member of the construction team.

Site Layout Plan: the strategy for operating the mobilized site throughout the project including identified locations for the temporary facilities and utilities, laydown areas, parking areas, trash bins, etc.

Site: the physical location of the land on which the facility is to be constructed.

Staffing Plan: strategies for acquiring the services of in-house staff, subcontractors, consultants, etc.

Start-up Plan: instructions consisting primarily of procedures, events, and schedules which identify how and when the facility’s systems will be tested and approved.

Storage Procedures: a plan for stock-piling resources, inspecting resources, and tracking the inventory.

Submittal Feedback: responses to the construction team from the owner and designer concerning material selection, equipment selection, design details, etc. (e.g., catalog cut and shop drawing approvals).

Turnover Information: feedback concerning the current progress in starting-up and handing over the facility.

Waste: residue from materials and resources used in the building process which need to be discarded (e.g., trash).

Work Progress Information: feedback defining the status of portions of the physical work.

Work Scope Information: all of the information which is supplied to the parties preparing proposals including the invitation to bid documents, plans, specifications, site visit data, etc.

Work Space: an area designated to the craftsmen for performing a portion of the work (e.g., assembled scaffolding, a cleared floor area).
Appendix C

QUESTIONNAIRE

QUESTIONS FOR FIELD PERSONNEL

Please explain your job to me.
   What are your areas of responsibility?

How do you know what to do?
   How do you know when to do it?

What are you doing today? tomorrow? next week?

In what form do you receive instructions?
   Personal Conversations
   Telephone Conversations
   Hand Held Radios
   Meetings
   Drawings and Specifications
   Memos
   Reports

What resources do you need to do your work?

How do you know when resources are available?

What resources are usually difficult to get?

What (or who) slows you down while you are doing your work?

Please show me examples of documents that you use as a part of this work.

What daily or monthly reports must be filled out?
How often are you forced to do rework because of confusing or incorrect instructions?

What type of instructions does management give you?

What other instructions do you need?

How do you help to plan, schedule, estimate, and control the work?

How are you involved in developing quality and safety programs?
INFORMATION QUESTIONS RELATED TO EACH FUNCTION

What information is needed to do this work?

Where do you get the information?

Which of the following are involved with this work?

- Meetings
- Drawings
- Specifications
- Contract Documents
- Reports
- Job Tours
- Telephone Conversations
- Historical Data
- Personal Conversations
- Memos
- Computers

Please show me the documents which are related to this work.

What information do you wish were available for your use in completing this work?

How often do you receive incorrect information concerning this work? Please give examples.

What new information is created while completing this work?

What information should be stored for use in the future, both on this project and on others?
Appendix D

CASE STUDY DATA

Case Study "O" - Office Building

Contractor: Shoemaker Construction Company
Project: Riverview Executive Park
Location: Trenton, NJ

C. Control on Construct a Facility

Since an old US steel fabrication facility used to exist on this site, ensuring that the area was free of environmental hazards was of major importance. The Environmental Responsibility Cleanup Act (ERCA) and the New Jersey Department of Environmental Protection NJDEP were controls on the process. It was the responsibility of the previous owner to cleanup the site to the satisfaction of the DEP and an industrial hygienist. Even though the contractor received permits to proceed with the work, the project was halted for environmental reasons. Long delays (four months) are typical when trying to obtain government approval concerning environmental issues.

C. Control on Construct a Facility

The project manager expressed the opinion that the constructor should be brought on board with or before the architect in order to optimize value and constructibility.

C. Control on Construct a Facility

The project manager said that no drawing is perfect and mistakes should be expected.
C1. Function in Acquire Construction Services

Ten companies were invited to send marketing representatives to present proposals to the owner as part of the constructor selection process.

C1. Control on Acquire Construction Services

A 1/2% bond is often required to obtain the contract. This is an obstacle to many contractors. Liability insurance is another requirement.

C1. Control on Acquire Construction Services

In cost reimbursable contracts, the owner typically takes items out of the scope of work for activities late in the project, especially landscaping. This means it is desirable to wait until later in the job to sign the subcontract for landscaping so as to avoid complicated negotiations and changes.

C2. Output of Plan and Control the Work

The contractor developed a Health & Safety Plan which they monitored and enforced to ensure that the workers would not be exposed to hazardous conditions.

C2. Control on Plan and Control the Work

The contractor did not trust the information (numbers and prices) provided by the previous contractor on the job. Not trusting information provided to you by others can be a problem.

C2. Mechanism in Plan and Control the Work

The "Plantrac" software is used by the contractor on this job to schedule work, track costs, and follow change orders.
C2. Control on Plan and Control the Work

The time of year (weather) has a definite impact on costs. Pouring concrete in the winter costs more money because of more expensive methods such as covering the concrete with blankets, heating the mix ingredients, additives in the mix, and lower worker productivity rates.

C2. Output of Plan and Control the Work

Documents sent from the contractor to the architect include: shop drawings, color samples, and catalog cuts.

C2. Function in Plan and Control the Work

Negotiating with the owner and subcontractors is an important aspect of planning the work.

C2. Control on Plan and Control the Work

The Construction plan must be updated based on changes in scope, which are typically the result of the owner’s or architect’s requests. The performance must be analyzed based on the most current plans and the special circumstances affecting the work.

C2. Function in Plan and Control the Work

Meetings between the owner, architect, and contractor are held on a weekly or monthly basis to assess the progress of the work, approve payments, and plan the future work.

C2. Outputs of Plan and Control the Work

Transmittals, proposed changes, formal change orders, subcontractor changes, meeting minutes, schedules, safety reports, and photographs are all documents which flow through the planning process.
C2. Control on Plan and Control the Work

The specifications are often a good indicator of the degree of detail with which the owner and architect are concerned. Standard off-the-shelf specifications indicate that the work is fairly standard and that the architect is not overly concerned with the details. Original detailed specifications often highlight the special requirements of the job and indicate a meticulous attitude on the part of the architect.

C2. Control on Plan and Control the Work

Verbal instructions from the owner or architect carry very little weight. Everything should be documented so that there is a paper trail if there are any problems.

C2. Function in Plan and Control the Work

The project manager suggested that the following questions be considered when planning the work. "In deciding what needs to be documented and stored for future use, you must consider the possibility that important people on the project might not return to work the next day or ever, due to an accident or termination of employment. How could work progress fairly smoothly? Also, how can you begin to capture the knowledge of experienced construction managers for the benefit of the less-experienced people in the company?"

C21. Output of Develop the Construction Plan

Suggestions for breaking the project into phases are an output of planning. The contractor suggested that the owner not install all of the parking areas with the first two buildings. Instead, only the parking needed for the first two buildings should be constructed.
C21. Output of Develop the Construction Plan

Shop drawings are a form of planning the work. In millwork shop drawings the pieces are numbered so that during installation the field crew knows exactly where each piece goes.

C21. Function in Develop the Construction Plan

The preparation of shop drawings might appropriately be included as part of the planning of the work. The architect is not the appropriate person to create the shop drawings because he does not know the details of all of the components of the building. Instead, the subcontractors who work with detailed aspects of the project on a regular basis are more qualified to prepare the shop drawings. The subcontractors can draw from their experience while developing the shop drawings to hopefully design the details in an efficient, constructible, and cost effective manner.

C21. Function in Develop the Construction Plan

During the planning stage, the constructor enters into long hard sessions with the owner to discuss major changes such as structural or curtain wall systems.

C211. Control on Determine the Scope of Work and Coordinate the Planning

The required level of detail is an important consideration both in developing and communicating the plan. For example, to estimate the exact duration of the project it is important to include approval cycles and delivery times, but these should not necessarily be communicated to the laborers since what they need to know is when to start and finish.
C211. Control on **Determine the Scope of Work and Coordinate the Planning**

Changes in the drawings should be highlighted by the designer to bring the particular changes to the attention of the contractor. Sketching clouds around changes is one method used by designers to point out revisions. Notes can also be included to describe the change. Dishonest designers sometimes will not highlight changes, and instead will try to have the contractor sign off on major changes without him knowing. AIA phase numbers are commonly specified on the contract for reference.

C213. Controls on **Estimate the Work**

The bid price of another contractor including some cost breakdown was provided to the contractor. The owner supplied a maximum price above which the project is infeasible. Since another contractor which had been selected to develop a negotiated contract price failed to obtain the necessary construction bond, the new contractor took over the job after the other company had negotiated for over a year with the owner. The owner made the switch since negotiations were progressing so poorly. The owner wanted a contractor who could be trusted and who would provide accurate estimates of anticipated costs.

C213. **Output of Estimate the Work**

The items identified in the schedule could be efficiently used as the categories for cost items in the cost control system, or the cost control items could be input for the schedule. Either way, some consistency is desirable.

C214. Control on **Schedule the Work Activities**

Tasks can only be scheduled to start if the procurement function has obtained the subcontractor to do the work. Sometimes you can save money by scheduling a subcontractor's work earlier than usual because the subcontractor can offer you a better price since he is in need of work at that particular time.
C214. Function in **Schedule the Work Activities**

The Critical Path Method is an effective tool because it forces the scheduler to think through the work process in detail and identify all of the interrelationships and possible problems. One problem with the CPM is that it is difficult to keep it updated. (quote from the project manager "the CPM schedule is mutilated daily") A bar chart is a good communication tool because it makes it easier to visualize and communicate the schedule. A string can be hung from the top to the bottom of the chart at the current date so that you can quickly see where job progress should be.

C214. Control on **Schedule the Work Activities**

The contract may have penalties for late completion which are typically thousands of dollars a day.

C22. Control on **Implement the Plan**

The management should only communicate to the field information which is current and approved under the contract. Instructions to do work should only reach the field if the contractor has received authorization to proceed and confirmation that he will be paid for the work. Otherwise, the field crews might install proposed work which could later be changed and the contractor might not be compensated for the rework. In other words, if you have no contract, you cannot do the work. Similarly, the contractor cannot tell subcontractors to stop the current work because of a proposed change because this could result in a delay claim against the contractor.

C23. **Mechanism of Monitor Performance**

The workers in the field are responsible for tracking labor costs.
C23. Mechanism of Monitor Performance

An in-house developed Cost Event System (CES) is used to track costs. This system creates standard documents such as change orders to subcontractors, quotes to the owner, and cost reports. The system identifies and records every financial event and classifies them so that different costs can be tracked into categories such as:
- approved changes
- changes under review
- the owner's total current exposure
- the contractor's profit position
- the unfunded portion of change orders on which the contractor is working

C23. Function in Monitor Performance

The following information is tracked in the "Daily Manpower Report": contract number, date, contractors on the job, trades, number of men, visitors, deliveries, and accidents. For each company employee, a time card is kept on which time is charged against cost accounts according to what they worked on during the day.

C23. Function in Monitor Performance

Concrete order slips are saved and the areas where the concrete was poured is written on the order. Soil reports are also filed and kept on site.

C24. Function in Analyze Performance

The Accounting Department only tracks committed costs. Accounting must forecast profits so that tax obligations can be paid every three months. Accounting inputs their own cost numbers separately, when they would be more appropriately and more accurately obtained from the CES software. The contractor on this job calculates and reviews its profit position monthly.
C24. Control on Analyze Performance

The federal government requires that taxes must be paid quarterly based on projected profit. Larger companies can no longer use the completed contract accounting method. There are penalties for underestimating your taxes while at the same time you do not want to prepay additional taxes because of the time value of money. This means that costs and income must be accurately tracked.

C3. Output of Provide Resources

The contractor can often save money by ordering standard colors for items such as mortar mix. If a nonstandard color is selected, the contractor may be forced to order more material than needed due to minimum order sizes or the contractor may have to wait for the supplier's next manufacturing date for the special item. In order to improve the likelihood that a standard color is selected, contractors only send the architect selection catalogs for the standard items.

C31. Control on Mobilize

The availability of temporary services affects the positioning of the trailers. Visibility from the street and security should also be considered. Locating the job trailers out of the way, so that work can progress efficiently, is commonly done. For example, the trailers are far from the building so that all of the paving can be done at one time. Moving the trailers periodically is another viable alternative.

C32. Function in Acquire Resources

Expedite material deliveries and approvals are important parts of providing resources.

C32. Control on Acquire Resources

The approval of the architect is important to obtain formally in writing, sometimes based on his visual inspection. The architect's approval of paint
numbers from a catalog for some contracts does not mean that the architect cannot turn down the paint after seeing it in the field.

C32. Output of Acquire Resources

Detailed information describing exactly how, when, and where you want resources to be delivered to the site should be communicated to the suppliers. Failure to do so results in problems for all parties involved. An elevator system which was delivered four months early, in error by the supplier due to poor communication, serves as a good example. The supplier is responsible for damages to the equipment and will not be paid until the date the contractor arranged for delivery of the elevator. The contractor has to make room for the storage of the equipment in the field and if it gets damaged or vandalized he will have to wait for a new delivery which could delay the entire project.

C32. Function in Acquire Resources

Some items, concrete deliveries for example, are called-in immediately prior to when they are needed. Some arrangements are made in advance, but the materials are not released until the telephone call is made.

C32. Mechanism of Acquire Resources

Orders can be expedited by using FAX systems to speed accurate communication.

C32. Function in Acquire Resources

It is important to stay current with advancements in technology, especially concerning the development of new tools, equipment, or construction processes which could have a positive impact on productivity. An example of an innovative tool is an attachment for a drill which holds drywall screws in place while the drill screws them in. The screws are fed to the attachment in line on a plastic belt similar to the arrangement for a large machine gun. This leaves one hand of the craftsman free and eliminates the need to grab for screws from your pocket. Investing in advanced equipment can save money in the long run.
C41. Function in Plan the Daily Work

Quality Control and Quality Assurance is the responsibility of the field superintendents and labor crews.

C41. Control on Plan the Daily Work

In order to be eligible for a discount on insurance rates the insurance companies require the contractor to conduct safety meetings on a weekly or monthly basis. These meetings include craftsmen and managers in the form of tool box meetings. Minutes are usually kept to document the results of the discussions and to prove that the meetings took place.

C41. Control on Plan the Daily Work

The superintendent offered the following advice, "You should decide what has to get done or what you want to get done, and schedule it first so that you know it will get done, otherwise you might not have time. You should also consider scheduling hidden or less important portions of a repetitive task first so that the workers can practice and get it right for the more important visible areas."

C41. Control on Plan the Daily Work

Unanticipated items or conditions must be dealt with and compensated for in the daily detailed plans. For example, a ceramic tile subcontractor might need to compensate for a sagging floor in the actual layout of his tiles.

C41. Control on Plan the Daily Work

Initially you might think that understanding the scope of work would be easier if you were working on a project which is similar to another project. In many cases this is true, but you can often fall into the trap of complacency and make mistakes out of laziness. In building sets of townhouses for example, it is easy not to check items on the drawings and just do it like before, and afterwards realize that there actually were some differences.
C41. Control on Plan the Daily Work

Information highlighting potential mistakes should be provided to foremen so that they can effectively plan their work. For example, a drop ceiling subcontractor should be advised not to move the heat pump drain pipes because they depend on gravity for drainage.

C41. Function in Plan the Daily Work

The following quote was taken from the project manager. "In order to effectively plan and control the work as a manager, you must know what's out there in the field. You must learn the workers attitudes and their way of thinking. You can have the best management and computer system available, but if you can't communicate effectively with the people who actually do the work, not much will be accomplished."

C42. Function in Distribute the Resources

Just in time delivery is the best system, since it eliminates the storage function and it is obviously efficient to unload materials from the truck and put them directly in place.

C43. Control on Do The Physical Work

Breakage problems can cause major delays especially if spare materials are not available. For example, if the window glass is breaking either during delivery or installation, the closing in of the building could be delayed directly hindering the progress or start of other tasks.

C431. Function in Identify the Location for the Work

The layout engineer locates everything on the site that needs to be located by setting up control points. The subcontractors are then responsible for working from these locations.
C431. Output of **Identify the Location for the Work**

Some dimensions are required to be field measured so that an accurate fit is guaranteed. This information must be communicated to the Acquire Resources Function.

C432. Function in **Set Up the Work Area**

Several options which are available to provide a working space for areas above grade include: a window wash set-up in which a platform is hung from the roof of the building; the use of scaffolding (stationary or portable); temporary hoists (elevators) on the edge of the building.

C44. Function in **Inspect and Approve the Work**

The following people approve the work: inspectors (take concrete samples), fire marshal, soils engineer, and OSHA.

C45. Function of **Turn Over the Completed Work**

The constructor provides information recommending what materials should be used to operate and maintain the facility. For example, what should and should not be used to clean the windows and marble surfaces. Constructors try to avoid liability and accountability when possible. The constructor arranges for the operations staff to be present when major systems are started up. Meetings are held in which the constructor introduces the subcontractors to the facility operators so that they have direct lines of communication. The constructor is required, fairly clearly by the specifications, to provide operational and instructional books to the owner.
Case Study "G" - Gymnasium

Contractor: Bowers and Sons, Inc.
Project: Athletic/Academic Facility
Location: Newark, NJ
Owner: St. Benedict's Preparatory School
Architect: Gregory Robert Arner AIA (201) 464-2160

C2. Control on Plan and Control the Work

Union trade jurisdiction rules can cause disruptive conflicts. Union work rules also cause inconveniences. For example, each trade must use it's own scaffolding. This causes unnecessary duplication of effort.

C21. Output of Develop the Construction Plan

Constructor reviewed and approved shop drawings are an output of the planning function.

C21. Control on Develop the Construction Plan

Day-to-day changes in the critical path are noted so that revisions to the plans can be made. The progress of critical activities is tracked closely.

C215. Output of Analyze and Select the Plan

The contractor proposes change orders which are submitted to the designer and owner.

C23. Function in Monitor Performance

A full file of all project paperwork is kept on site. A duplicate is usually kept at the home office. An independent contractor is hired to take photographs of the site and progress of the work. This is to ensure that the pictures were not set up or arranged. A phone log is kept which documents every telephone call. The
key items written down are who called, what company they are from, and who should follow-up. Calculations of dimensions, volumes, etc. are written on the back of the drawing in question.

C23. Function in Monitor Performance

Expenditure information is summarized. Time cards are kept. Daily progress reports are filled out listing labor on site, materials used and delivered, job meetings held, visitors to the site, and general diary information.

C34. Control on Store the Resources and Manage the Inventory

The decision was made not to restock resources because it is too expensive to pay for the labor, trucks, storage areas, etc.

C34. Control on Store the Resources and Manage the Inventory

Incidents of employee theft are a common occurrence. Power tools are distributed for the day and they commonly do not return at the end of the day.

C4. Control on Build the Facility

The project manager had the following comments. "The labor is performing poorly in general. The learning curve is very slow and often worsens. There is a need for constant supervision. The subcontractors fairly commonly do not show up for work." The foremen and the construction managers discuss the work progress at the end of the day.

C4. Control on Build the Facility

There was a local requirement for a traffic cop on this job. This was in the form of a fee which had to be paid to the local police department.
C4. Control on Build the Facility

Each contract specifies safety procedures which must be taken, but this is a very difficult item to enforce.

C4. Control on Build the Facility

One of the important objectives of the safety plan is to minimize the distance of falls. (e.g. use of handrails, nets, etc.)

C4. Output of Build the Facility

It is important to gather current progress information so tomorrow's work can be planned.

C43. Control on Do the Physical Work

Out of date specifications cause problems to the construction workers and often lead to rework.

C44. Control on Inspect and Approve the Work

The architect can force the contractor to do rework based on the drawings. The contractor can be forced to change installed work if it is not up to code.

C44. Mechanism of Inspect and Approve the Work

OSHA inspected the site only once in over a year. The inspection took over three days.

C44. Function in Inspect and Approve the Work

Outside testing certification was performed on the soil, concrete, steel, and fireproofing.

D-16
C45. Function in Turn Over the Completed Work

As the work is completed, the as-buils are updated and the operation documents are coordinated.
Case Study "H" - Luxury Homes

Contractor: Bowers and Sons, Inc.
Project: Luxury Single Family Detached Houses
Location: Pennington, NJ
Cost: $600,000 per home
Developer: Princeton Properties

C. Control on Construct a Facility

The owner or home buyer fills out a selection sheet which becomes part of the contractual agreement with the construction manager.

C. Control on Construct a Facility

Insurance availability is a function of the economy and directly impacts the cost of the job.

C. Control on Construct a Facility

The construction manager said, "Designers should take the time to write up good specifications. This minimizes rework. The lack of a good set of specifications on this job is a source of problems."

C. Control on Construct a Facility

Disruptive requests, such as when the owner changes his mind in midstream, cause problems and delays.

C. Mechanism of Construct a Facility

The construction manager spends an average of 4 hours/day on the telephone, sometimes at night also, usually scheduling subcontractors and acquiring resources.
C1. Function in Acquire Construction Services

Some items did not fall under anyone's contract. One example was the assembly of the refrigerator. This involved assembling and connecting the compressor on top of the unit. The supplier simply dumps the unit in the kitchen and the cabinetry contractor will not assemble the refrigerator because if he drops it, he has to buy it. In the future the cabinetry subcontractor will be responsible for this work, but his price will be raised substantially, due to the need for additional insurance.

C1. Function in Acquire Construction Services

Three subcontractors bid on each portion of the work.

C11. Control on Identify Qualified Parties

The developer provided the contractor with a list of recommended subcontractors.

C2. Function in Plan and Control the Work

Some examples of documents include purchase orders, contracts, house prints, specifications, daily job report, and company forms.

C2. Control on Plan and Control the Work

The bid and construction documents and criteria were causing problems. The drawings were lacking in that there were no details of front steps or footers. There were also not enough elevations included.

C2. Control on Plan and Control the Work

Changes in the drawings are noted and signed by the designer and subsequently, the constructor.
C2. Control on Plan and Control the Work

The construction manager cannot use a computer because the trailer is too hot (no air conditioning).

C2. Control on Plan and Control the Work

The construction manager compared Open Shop to Union jobs in the following way: "Construction managers have less control on union jobs. Union jobs are very bureaucratic and the major concern of the workers is if they get their coffee breaks." (This job was open shop.)

C2. Control on Plan and Control the Work

For one house, the owner requested an open house for sales purposes.

C2. Control on Plan and Control the Work

Invoices from the carpenters and other subcontractors represent the progress made during the week.

C2. Mechanism of Plan and Control the Work

The contractor retains 10% of all payments to the subcontractors so that there is pressure on the subcontractors to complete the work and the punchlist items.

C2. Mechanism in Plan and Control the Work

There are weekly meetings between the construction manager and home office manager.

C214. Control on Schedule the Work Activities

The construction manager said "Always schedule what has to be done the next day (critical items), and plan for lead times on important items."
C214. Control on **Schedule the Work Activities**

Four to five months is a typical construction schedule, but a schedule is not drawn up for each house.

C23. Function in **Monitor Performance**

The construction manager documents all telephone calls, including information about the people involved and what needs to be done.

C23. Function in **Monitor Performance**

The cost codes indicate labor(L) and material(M).

C24. Mechanism of **Analyze Performance**

The construction manager approves bills. By doing this, he is inspecting and approving the work.

C3. Function in **Provide Resources**

The supplier takes the plans and tells the construction manager how much the wood will cost. Then the framer supplies a list of needed materials. The construction manager checks to make sure this amount is reasonable.

C32. Function in **Acquire Resources**

The construction manager must deal with salesmen who visit the job (e.g., a cedar cabinet salesman).

C32. Control on **Provide Resources**

Many items have long lead times associated with them. For example, windows require six weeks for delivery.
C32. Mechanism of Acquire the Resources

If needed, the supplier will deliver standard items daily. This convenience was commonly used on this job.

C4. Output of Build the Facility

Overcrowding and interference was a problem. The HVAC, electrical, window washing, painting, and finish carpentry subcontractors were all on site at the same time. This was planned however, due to an open house that was scheduled for the next day.

C4. Function in Build the Facility

You always miss something, which means back charges. The construction manager visits each of the subcontractors in the morning to get feedback to prevent and catch these mistakes before they become a major problem.

C4. Control on Build the Facility

Building permits are a form of government regulation which controls the start of construction work.

C431. Function in Identify the Location for the Work

The site plan from the engineer identifies the location of the house, well, and grades.

C44. Control on Inspect and Approve the Work

Varying local codes and varying interpretations of these codes by inspectors can cause problems. Refusing to do what the inspector says is usually not in your best interest. They can keep you from getting the occupancy permit while you try to have their opinion overturned.

D-22
C44. Control on Inspect and Approve the Work

The following inspections are performed: Electrical, Insulation, Plumbing, Well, and Septic.
Case Study "C" - Convenience Store

Contractor: UniCo Construction Co.
Project: Uni-Mart Convenience Store
Cost: $150,000
Schedule: 2 months
Location: State College, PA

C. Control on Construct a Facility

The job was halted and the contractor was fined because the Storm Water Management Board of Directors was not consulted and therefore did not have a chance to approve the design. This board only meets twice a month and submitted designs must be received one week in advance. This results in at least a three-week unnecessary delay in the project due to an overlooked step in the permit acquisition process.

C2. Control on Plan and Control the Work

People are a major variable when planning the work. The material take-off, schedule, etc. depend on the capabilities and work methods of the people who will do the work. This can vary greatly from area to area, or based on the experience level of particular employees.

C2. Control on Plan and Control the Work

A general complaint concerning the drawings was that they do not contain enough dimensions. The dimensions show exactly what the architect has designed and it is not appropriate (and often times illegal) for the contractor to scale items from drawings. It is also not efficient for laborers to be forced to calculate lengths in the field when they could be identified directly on the drawings. It is also not desirable to identify only angles of corners on the drawings because the laborers do not use protractors, they use tape measures. Another common problem with drawings is that they do not meet code. If the design is inadequate, adjustments must then be made by the constructor.
C214. Function in **Schedule the Work Activities**

A schedule should have some flexibility. Ideally, a good schedule would have alternative plans for situations when the originally scheduled work cannot take place.

C22. Output of **Implement the Plan**

A budget should be communicated to the Provide Resources and Build the Facility functions so that the people doing the work have a goal to strive to achieve. This was not the case for this job. The job superintendent did not know the estimated amount and had no idea on the project profitability until after all the numbers were totaled for the job after the work was completed.

C23. Function in **Monitor Performance**

In order to track and allocate the costs incurred from the operation of company owned equipment, many firms set up an in-house rental service, in which the different jobs are charged based on their usage of the equipment.

C23. Function in **Monitor Performance**

Methods of documenting telephone calls and conversations should be implemented so that the details concerning the correspondence can be referred to in the future, if needed.

C3. **Control on Provide Resources**

A plan should be communicated to the Provide Resources function describing the material storage system, especially during the beginning of a project when no areas of the facility can be securely locked.
C32. Mechanism of Acquire Resources

It is often desirable to have one person who can be sent to local vendors to purchase items which are needed immediately by the laborers. For critical resources, the expense of sending someone directly can be a cost effective alternative to the typically lengthy procurement cycle.

C34. Function in Store the Resources and Manage the Inventory

Materials should be stacked in the order in which you intend to use them with the items to be used first obviously on top. Blocks should be kept dry in storage to ensure a structurally strong wall. When the blocks are dry they absorb some of the mortar, thus resulting in a stronger bond. Wet blocks will not sufficiently absorb the mortar.

C4. Control on Build the Facility

Resources which are delivered late affect the planning of the work and the progress in the field. Information concerning the near-future availability of resources should be communicated from the Provide Resources function to the Build the Facility function so that the short term work plans may be adjusted appropriately.

C4. Control on Build the Facility

The specifications provide valuable information describing the detailed requirements concerning the work which can be useful to the field. Many times these specifications are not available to the field, and this is not desirable.

C4. Control on Build the Facility

A non-optimized design, as far as constructibility is concerned, results in cumbersome work for the laborers. For example, the installation of a masonry wall with a sloping roof at the top results in difficult and time consuming brick cuts at the top of the wall.
C41. Control on Plan the Daily Work

Changes after items have been installed (forced rework) are very disruptive.

C41. Function in Plan the Daily Work

Precautions which should be taken to protect masonry work from cold weather should be planned. Some options include: constructing tents, covering the walls with thermal blankets, adding anti-freeze to the mortar, and heating the ingredients of the mortar mix.

C41. Control on Plan the Daily Work

The temperature below which mortar typically freezes causing masonry work to stop is 28F. Wind and open exposure to the cold affect this temperature by making the mortar freeze more quickly. (When the mortar freezes it crumbles by the next day.) The use of anti-freeze should be considered.

C41. Function in Plan the Daily Work

On this job, safety measures are primarily planned at the site. Only very major safety topics are considered in the construction plan.

C43. Control on Do the Physical Work

Typically when a superintendent is not present on site, the laborers productivity declines. The project manager pointed out that this may be more of a result of goofing around and laziness than a lack of understanding what needs to be done.

C44. Function in Inspect and Approve the Work

The following groups must approve the work: highway, local, sewer, water, electrical (ten days notice), fire marshal (ten days notice), and the bureau of standard weights and measures (ensures scales and gauges are accurate).
Case Study "A" - Apartments

Contractor: Fahr Construction (Masonry Contractor)
Project: Fairmont Apartments
Location: State College, PA

C2. Control on Plan and Control the Work

The best way to construct a door in a masonry wall is to lay the block with the door frame already in place. This method ensures that the door frame will fit properly. On this job, probably due to lack of experience or material delivery problems, the openings for the doors were put in without the door frames. In order to install one of the door frames, the carpenters had to chip away at the masonry since the frame would not fit.

C21. Control on Develop the Construction Plan

Interference from other activities can severely impact the progress of the work. For masonry work, the installation of a precast concrete planking system can slow down progress. In order for the planks to be installed the supporting structural masonry walls must be constructed. Sometimes the partition masonry walls are completed only after all of the structural walls have been installed. In this case, care must be taken to store the block needed for the curtain walls on each floor before the planks are laid so that they can be moved more easily. Improper sequencing is the source of most interference problems. For this job, the masonry crew often had to move out of the way while some planks were being installed.

C21. Control on Develop the Construction Plan

Backfilling is an item which should be coordinated. Below grade walls must be waterproofed and have sufficient strength before backfilling. If the backfilling can be done early, less scaffolding will be needed for the exterior walls.

D-28
C212. Control on **Select Work Methods**

The variety of material movement methods for concrete should be considered. These include: crane, forklift, manual, conveyor, pump, pallet jacks, and wheelbarrow.

C41. Control on **Plan the Daily Work**

Some safety measures which should be considered to be applied while laying block include: fastening the scaffolding to the building; installing scaffolding rails; fully planking the scaffolding; strapping ladders to the structure; and wearing hard hats.

C41. Control on **Plan the Daily Work**

Common practices for masonry work should be known. Below grade masonry walls typically consist of 12" blocks which are grouted. For added strength, 8" 75% block are used. The 75% means that the holes through the block are smaller and only take up 25% of the block volume. Masonry block can be ordered with one side finished, with quarry tile for example, to provide a desirable appearance. The weather from the previous day also affects the work. Snow accumulation, rain puddles, and mud are examples.

C43. Control on **Do the Physical Work**

Information about extremely cold weather should prevent the work from starting. Several times on this job the masonry crew was sent home after the mortar froze, when they did not need to try it to find this out. At a minimum, the foreman should have learned from the first mistake.
Case Study "R" - Research Building

Project: Research Building
Contractor: Masonry Contractor
Owner: Penn State University
Location: University Park, PA

C41. Control on Plan the Daily Work

Areas should not be closed-in so that materials may be moved around more easily, possibly with large equipment. The need for people to carry materials should be minimized.

C41. Function in Plan the Daily Work

Pre-planning the use of the scaffolding is a necessary prerequisite for efficient masonry work.

C41. Function in Plan the Daily Work

The crew sizes must be selected and responsibilities must be assigned. These assignments should be fairly consistent from day to day so that the benefits from the learning curve concept can be realized.

C43. Control on Do the Physical Work

Grouting limits the number of courses which can be laid in one day.

C43. Control on Do the Physical Work

Welding work above (falling sparks) limits the areas in which the masons can work.
C43. Control on **Do the Physical Work**

Cutting blocks takes a lot of time. First, they must be custom measured in most cases. Then, the blocks must be cut at the power saw. And finally, they must be taken to the areas where they are being laid.

C43. Control on **Do the Physical Work**

Door frames are needed so that work can progress. These frames need to be supported while the mortar is setting.

C433. Function in **Prepare the Resources**

Mortar is mixed in a mixer and wheelbarrowed to the locations where block is being laid. The ingredients for the mix are not measured very carefully. Instead, the laborer uses his experience and judgement.