A SURVEY OF PROCESS MODELING TOOLS

by

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COMPUTER INTEGRATED CONSTRUCTION

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FOREWORD

Computer integration is being applied successfully in manufacturing to reduce the lead time required to bring a new product to market and to improve product quality. Techniques such as simultaneous engineering, group technology, and robotics and automation are advances brought about, in part, through the computerization and integration of design, manufacturing, and quality assurance functions.

The construction industry has made less progress in this area, due in part to the large number of firms and disciplines involved in a typical facility design and construction project. There is no generally agreed upon division of responsibilities among disciplines, nor is there a common structure and method of transfer of information. This has led to considerable regeneration and duplication of information, with attendant increases in errors. Such problems have severe impacts on schedule, budget, and quality of the resulting facility.

The purpose of the CIC Research program is to develop tools to enhance integration of the entire construction process, in part through technology transfer from the manufacturing sector. The first step in the program was to develop a model of the construction process, from the owner's viewpoint. This report describes previous models of construction, and applicable modeling methodologies. It presents an integrated model covering the entire scope of activities involved in providing a facility.

This work has served as the basis for development of a common information model to encompass the construction process. Development of the information model is currently in progress. It is anticipated that existing and future computer applications will fit within the framework of this information model, and communicate through it.

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ABSTRACT

Due to the lack of integration in the construction industry, the need for the development of a generic model of the construction industry was recognized. The objective of this study was to evaluate the different modeling approaches possible for developing the building construction model, and to propose the most appropriate model for this project.

This report reviews previous modeling efforts of the construction process, and identifies the need for a structured modeling methodology to aid in understanding and use of the models. Several structured methodologies capable of supporting a functional decomposition of the construction process are identified. Each methodology is illustrated through application to a simple process.

Selection criteria are established which reflect the needs of the construction industry. Based on these criteria, the IDEF0 modeling methodology was selected as the tool to be used in modeling the building construction process. A brief overview of the IDEF0 methodology is included in this report.

Using the IDEF0 methodology, the Integrated Building Process Model (IBPM) was developed. The first two levels of the model are presented, and their components are discussed. IDEF0 is shown to be an effective tool in developing a comprehensive process model. Finally, planned use and future extensions of the model are discussed.
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CHAPTER 1. INTRODUCTION

Since the beginning of history, man has been constructing facilities for human habitation. Early design and construction were founded on the principles of trial and error, and relied completely on experience to implement improved techniques. Changes in technology and specialization of services over time have gradually worked within the building industry to comprise a wide variety of disciplines, leading to new challenges in advancement of information transfer. The lack of integration has been widely recognized as a major problem in the construction industry [Sanvido 1987]. Due to the fragmented nature of the industry, the coordination among project members is ineffective and results in the loss and duplication of information. There is an evident need for the definition of the information flow required to support the building construction process, and for the clarification of tasks and responsibilities in information generation and transfer among the project participants.

The National Science Foundation has funded an interdisciplinary team to explore methods to enhance 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 [Sanvido 1987]. The team comprises Penn State Architectural and Industrial Engineering researchers, together with McDonnell Douglas and selected industry professionals. The intent is to benefit from pioneering work in Computer Integrated Manufacturing (CIM) by applying similar approaches to construction.
As the first step in the project, an integrated process model was to be developed which accurately represents the essential functions required to manage, plan, design, construct, operate and maintain a facility. To develop such a model, numerous modeling methodologies were surveyed and evaluated with respect to their suitability to model the construction process. In this report, previous work in modeling the construction process will be presented, and several modeling methodologies available in industry and academia will be discussed and evaluated. The most appropriate modeling methodology will be selected based on the selection criteria established by the members of this project, and its implementation will be discussed.

1.1 Lack of Integration in the Construction Industry

In the present construction industry, lack of integration has led to regeneration and duplication of information, as well as costly errors due to inaccurate documentation. Specific examples are cited by Al-Muallem [1988] such as discrepancies between design documents and other contract documents, discrepancies between construction documents and actual physical conditions, and design errors caused by lack of accurate information about existing conditions.

Two major factors are responsible for the lack of integration in the construction industry. First, no clear definition of tasks and responsibilities have been established. The members of the construction industry have not reached consensus on the definition of the tasks required, nor on the division of responsibilities among the disciplines. The
second factor is the lack of a common structure and method of transfer of the information required to support the construction process. Both factors have a significant impact on the construction industry's ability to function effectively and efficiently, and inhibit its ability to adapt to efforts in Computer Integrated Construction (CIC).

In the manufacturing industry, the advent of computers has led to profound changes in the basis of manufacturing concepts. The undertaking of automation in manufacturing has led to the recognition that the automation effort must be applied to the system as a whole, rather than in fragments, to acquire its full benefits. This has led to an ongoing attempt for the standardization of product and process definitions to enable the use of common data from design through production. Therefore, a major thrust of efforts in Computer Integrated Manufacturing (CIM) has been in the definition of a common data structure for the manufacturing process.

Similarly, a common data base must be defined for the construction process to enable the integration of the entire industry. Such an effort is even more difficult in the construction industry, as it involves the participation and coordination of members from widely dispersed disciplines and organizations, and is further prohibited by the sheer volume and complexity of the information required.

The building construction process requires the effort of a large number of participants from many disciplines including the architect, civil engineer, structural engineer, electrical engineer, vendors, owner, and facility manager. Members of each discipline follow different methods of
documenting project information, and different modes of information transfer. Sanvido [1987] attributes the difficulties in transfer of data in the construction industry to differences in data formats, lack of common data classification methods, and differing techniques for graphical representation of data.

The complexity and the amount of information required also lead to further confusion in the transfer of information in the construction process. The information supporting the construction process is generated from a wide variety of sources and may include "a collection of design documents..., verbal agreements, change orders, meeting notes, correspondence and contracts, government codes and regulations, inspection results, construction documents, and operating manuals [Sanvido 1987]." Standardization of such dynamic data which must be communicated to a large group of participants in a timely manner will be a major hurdle in the integration of the construction industry.

Before a common data format and mode of transfer can be established, however, the information which is generated and transferred during the construction process must be identified. Furthermore, the processes which generate, transform, and utilize the data must be identified to define the flow of information, and the building construction process. This report will consider the different approaches for modeling the essential processes in the provision of a facility, and will propose an appropriate modeling methodology.
1.2 Objective

This report proposes an appropriate modeling methodology which will enable the definition and representation of the building construction process. Alternate modeling approaches will be studied, and each modeling tool will be evaluated on its ability to model the processes and the supporting information flow which define the construction industry.

1.3 Purpose

The construction process is viewed as a system comprising many levels of subsystems, where inputs such as money and materials are transformed by the functions into outputs, such as building documents or a completed facility. Such a system may be represented by a generic model consisting of a set of functions, whose interrelationships are shown by the transfer of physical or informational entities among the functions. The processes and the information which support the construction process may then be represented and analyzed in a clear, concise manner and bring to light any discrepancy, incompleteness, or redundancy that may be present in the task definition of the project participants.

1.4 Methodology

The concept of modeling real-world systems was first considered, including the purpose of modeling, types of models, and the applications of modeling in engineering and in the construction industry. From literature research and discussions with project members, several previous modeling efforts
were discovered. Each piece of work was then evaluated in relation to the model's capability to model the processes and information/material flow in the construction process. A representative collection of these models is included in this report. The emphasis of evaluation was in the modeling methodology, rather than in the content of the models. From studying these construction models, much insight was gained in how the model should be developed and what the modeling tool should be capable of. In addition, the need for a structured modeling methodology capable of modeling a generic process was recognized.

The modeling efforts in other industries were considered, beginning with the manufacturing industry. The modeling methodology used to model the manufacturing process in 1978 was found to be based on a modeling tool developed in the system engineering discipline. Literature research in modeling efforts in system and software engineering led to a set of modeling methodologies which are capable of modeling the processes and/or flow of information/materials in a system. Each model was then studied and evaluated based on its ability to model a large, complex system such as the construction process. Based on the selection criteria outlined by the project members, the IDEF₀ modeling methodology was recommended for modeling the building construction process.

Since then, the Integrated Building Process Model has been in progress, and several levels of models have been developed to date. The modeling process will be reviewed and discussed, and future recommendations will be made in how the model may be applied in aiding the computer integration of the construction industry.
CHAPTER 2. MODELING CONCEPTS

A model is a representation of a real-world system. Models may be used for different purposes, depending on the user's objectives. In general, a model is a tool which is used to analyze an existent or a proposed system. DeMarco [1982] qualifies the definition of a model as one which must reflect the selected characteristics of the system it is meant to represent, and is only useful to the extent that it accurately portrays those characteristics.

2.1 Purpose of Modeling

Models are used for different purposes. Depending on the user's objectives, a model may be used to describe "what a system is (descriptive model), what it does (functional model) or what it works on (data model)" [Bond 1981, SofTech 1981]. Models come in various forms ranging from those which closely represent the concrete nature of a system, such as physical models, to very abstract representations of a system, such as mathematical representations [Wallace et al. 1987]. The level of abstraction depends on the application of the model in the analysis of the system, based on the essential properties the model is used to emphasize. Hence a single function may be represented by several models simultaneously.

For this project, the objective of modeling is to use models as aids in understanding the requirements of a system. The use of modeling as a problem solving tool is discussed by Kreutzer [1980]:
"Human beings can perceive and deal with the external world only relative to conceptual models of reality, which are analyzed and manipulated during problem solving processes."

To overcome the limitations in information processing capabilities, complex systems are represented in conceptual models by using a set of modeling techniques.

2.2 Applications of Modeling

Several uses of models are stated by DeMarco [1982]. First, a model may be used to establish a common view of the current system, and to gain insight into the entire system development process. Secondly, a model allows the quantification of the informational needs of the system, as well as the specification of the system requirements with minimal redundancy. In addition, a model may be used in defining a project as a set of tasks with well-defined products and intertask dependencies, and to indicate the allocation of resources within the system.

The modeling of a project in the construction industry will define the generic construction process as a set of essential functions, information flow, and material flow. The model will:

1) Establish a common language to define, analyze, and understand the construction process while deemphasizing differences in terminology among the project participants.

2) Identify the information and physical resources required to support the functions in the construction process.

3) Lead to an agreement on the boundaries of responsibilities of each project participant with respect to the activities performed and the generation and transfer of information and materials through the definition of outputs, mechanisms, and constraints.
4) Represent the interdependencies existent among the project participants and the need for consistent and accurate information communication methods.

Therefore, the modeling of the construction industry will aid in gaining understanding of the construction process, and improve the efficiency and effectiveness of the communication among the project participants. In addition, the identification of system requirements will enable the integration of data generation and communication within the industry, laying the foundation for computer integrated construction.

2.3 Types of Models

The types of models may be categorized by the level of abstraction used in the representation of the real-world system. The types of models are summarized as follows [Kerzner 1984, Fisher and Atkin 1985]:

- **Physical models:** Scaled replicas of the actual physical system.

- **Analog models:** Physical properties of modeled systems are represented by other physical properties, such as gauges.

- **Symbolic models:** Mathematical or symbolic representations of relationships among the variables in the model.

- **Schematic models:** Time independent models of relationships among variables and transformation of relationships which include:
  
  - **Static models:** Models showing set of relationships fixed in time such as organization charts and bar charts.

  - **Flow rate models:** Static models showing relationships between activities and their timing such as CPM, PERT, and precedence networks.
Dynamic models: Time independent models which show transformation of relationships rather than activities. Dynamic models are described by Kerzner (1984) as "the most effective in describing total systems".

Simulation models: Behavior models used for the prediction of the system performance and optimization of system design.

For the purpose of system definition, the schematic models and simulation models seem the most appropriate. However, the components of a system must first be defined before its performance can be evaluated. Therefore, the scope of this report will encompass the analysis and definition of the present system, which may serve as a basis for the optimization of the system performance.

2.4 Modeling Perspective

A system may be defined by three primary modeling perspectives: Functional, Informational, and Behavioral perspectives [Wallace et al. 1987]. The Functional modeling perspective defines the system's functions which transform data in order to achieve its purpose. The system is represented in terms of functions which transform inputs into outputs, and the flow of data which define the interrelationships among the functions of the system. The Information modeling perspective graphically illustrates the facts about the system, its definition of relevant information, and their relationships. It is used to determine the information flow and data requirements of a system, and is based on the Entity-Relationship-Attribute (ERA) approach to data modeling [Chen 1976]. The Behavioral modeling perspective defines the different behavioral states of a system.
and the events that cause the transition from one state to the next. Therefore, the dynamic characteristics of the systems are represented.

Much work has been accomplished in the Functional and Informational modeling perspectives. One modeling methodology, the ICAM Definition Method (IDEF), recognized the three modeling perspectives by partitioning the system definition into three models: IDEF0, IDEF1, and IDEF2, which define the functional, informational, and behavioral aspect of the system respectively [ICAM 1983]. The Functional definition of the system is first established, and serves as a basis for the Information and Behavior models. This is in accord with the scope of this report, which is to define the functions and the information flow to develop a functional model of the construction process. Future work will be in modeling the construction process from informational and behavioral perspectives.

2.5 Application of Models in Engineering

Many types of models have been used in various disciplines in science and engineering. Manufacturing systems have been analyzed by simulation models, physical models are used in aerodynamics, and graphical models are widely in use with the advent of CAD systems. Of special interest is the efforts in the Systems Engineering field to develop models of software systems. Much work has been accomplished in developing modeling methodologies which are capable of modeling a system's processes and/or data flow. Literature survey has led to the selection of several such modeling techniques which may be applicable in modeling the construction process.
Several models have been developed in the construction industry which represent the processes, information flow, or the decision making process in the building construction process. However, these models were developed to illustrate a specific viewpoint rather than the generic construction process, and their limited scope is not applicable in the development of an integrated, comprehensive model.

A similar modeling effort in the manufacturing industry has been accomplished through the Integrated Computer Aided Manufacturing (ICAM) project in 1978. The architecture of the manufacturing process was defined as a common framework which represents all functions of the discrete parts of manufacturing. The IDEF0 modeling methodology, adapted from the Structured Analysis and Design Technique (SADT™), was established and used to model the manufacturing process in its entirety. [ICAM 1978]

2.6 Modeling the Construction Process

The modeling methodologies developed in Systems Engineering and previous modeling efforts in construction and manufacturing will be considered in the selection and evaluation of the modeling methodology which will be used to model the construction process. The next chapter provides an overview of selected models which represent previous modeling efforts in the construction industry. It is by no means exhaustive, but it represents the various applications of modeling methodologies.
CHAPTER 3. PREVIOUS MODELS IN CONSTRUCTION

This chapter provides a selected overview of previous modeling efforts in the construction industry. Seven models which were developed to describe the processes in providing a constructed facilities are discussed.

3.1 Wheeler's Project Life Cycle Model

Wheeler [1978] developed a comprehensive model for managing the building construction process. The project life cycle is considered from the organization of the building team to the occupancy of the building. Wheeler divides the project life cycle into nine sequential phases as shown in Figure 3.1. Each phase is then divided into sub-phases called steps, each of which is then further divided into activities. The completion of a phase is identified as a primary milestone, and the completion of a step is called a secondary milestone.

The project participants are identified as the client (owner), project manager, design manager, construction manager, and contractor. For each activity, the responsible project participant is identified. Figure 3.2 shows these relationships in matrix format.

Wheeler's model is significant as it defines the entire project life cycle as a set of activities, and attempts to identify the project participant responsible for each activity. However, this model does not represent the interrelationships among the activities. The flow of information and the resulting interdependencies among the project participants is an integral
Figure 3.1 Phases and Steps of the Building Process
(Source: Wheeler 1978)
Figure 3.2 Responsibilities of the Building Project Participants
(Source: Wheeler 1978)
component of the building construction process, and must be addressed in developing an integrated model.

3.2 Project Initiation Model

Cumberpatch's Project Initiation Model [1983] depicts a generic model of the project generation process within a typical organization. The model traces the flow of "ideas" into projects, and represents the possible steps of review and approval which are required for the generation of a project proposal. As shown in Figure 3.3, the model begins with the generation of an idea by various sources, and traces its possible paths of review and approval, ending with authorization of proposals which have strong justification.

Cumberpatch limits the scope of his model to the project initiation process and represents the decision making processes involved in developing a project proposal. Although this model represents neither distinct processes nor the flow of information, the concept of modeling the flow of information of processes in parallel with this project's modeling efforts.

3.3 Project Definition Model

In the Project Definition Model, Salapatas [1983] models the project definition process in flow chart form (Figure 3.4). Beginning with "Establish objectives & schedule" and ending with "Execute project plan", the model provides an overview of the major decisions made in developing
Figure 3.3 A Project Initiation Model
(Source: Cumberpatch 1983)
Figure 3.4 Project Definition Model
(Source: Salapatas 1983)
the project plan. This model is not intended to define the activities, participants, nor the information in the construction process, and is not applicable in the process modeling efforts of the current project.

3.4 Walker's Model of Construction Process

Walker [1984] developed an input-process-output model of the project delivery process. The construction process is seen as a parallel function to the owner's process (Figure 3.5). Each process transforms input into outputs, and interacts with the environment, as well as each other. Walker also developed a hierarchical model of the construction process (Figure 3.6). The construction process is modeled as three sequential systems consisting of conception, inception, and realization. Each system is divided into subsystems, and key decision and operational decisions serve as the boundaries of systems and subsystems.

Walker's models offer two major contributions. First, the construction process is seen as a transformation process with inputs and outputs which interacts with the environment. Also, the processes involved are divided into tasks bounded by decision-making, which may be interpreted as a representation of information.

3.5 Sanvido's Conceptual Construction Process Model

Sanvido [1984] created a conceptual model of the construction process. He first defines the three major functions in the construction process, then identifies the major influences of each function. The second part of the
Figure 3.5  An Input-Process-Output Model of the Process of Providing a Project

(Source: Walker 1984)
Figure 3.6 Hierarchical Model of the Construction Project
(Source: Walker 1984)
model is a hierarchical description of the construction process. The model is a generic, time-independent representation of project site operations.

The three major functions are defined as Planning, Resource Acquisition, and Output Coordination (Figure 3.7). The Planning and Resource Acquisition functions are governed by Influences on Planning and Influences on Supply of Resources respectively. The Output Coordination function exerts Influences of Project on Participants and Environment. Each group of these influences is divided into influences from or on 1) the external environment; 2) the owner; 3) the contractor, and 4) the resource and service suppliers.

The hierarchical model identifies the hierarchy of management functions and the participants in the construction process (Figure 3.8). The interrelationships among the functions and their coordination are represented by the flow and feedback of resources and information. This model establishes the basic hierarchy of control in the construction process, and represents the coordination of planning and control, resource acquisition and allocation, and output coordination and synthesis in the construction industry.

This modeling effort is significant in its effort to identify the major functions in the construction process, as well as influences which govern, or are governed by, each function. In addition, the hierarchical decomposition represents the interdependencies and coordination required in the process. However, the scope of this model emphasizes the
Figure 3.7 Influences on the Construction Process
(Source: Sanvido 1984)
Figure 3.8  A Hierarchical Model of the Construction Process  
(Source: Sanvido 1984)
management and control aspect of the construction process, and the actual processes and information flow which occur are not identified.

3.6 Sanvido's Project Management Model

In the Project Management Model, Sanvido [1986] identifies three major functions in project management: the project function, the engineering functions, and the construction functions (Figure 3.9). The inputs, processes, outputs, and control factors are defined for the construction team, the design team, and the owner's project team. The three functions are shown to be interrelated, and coordinated by the project management team. Checklists which identify major activities to be performed are developed for the construction manager, engineering manager, and the project manager (Figure 3.10).

The model divides the entire construction process into three major functions which are interrelated, and each function is detailed further as a set of activities in the checklists. This step is an important extension to Sanvido's previous model and is a significant development in modeling the construction process. However, the model must be expanded in greater detail to represent the tasks and the flow of information required, as well as the interdependencies and overlap in functions among the project participants.
Figure 3.9, A Project Management Model
(Source: Sanvido 1985)
Figure 3.10 Owner/Project Management Function Outline
(Source: Sanvido 1985)
3.7 Vanegas' Early Design Model

As part of the Design-Construction Integration Research Project, Vanegas [1987] modeled the initial phases of the design process. The purpose of this modeling effort was to improve the constructibility of the design in the early design process. The model covers the project starting point to design freeze point, and defines the processes which are involved in the Predesign System and the Preliminary Design System (Figure 3.11). The relationships between the processes are also identified (Figure 3.12).

The model does not cover the entire life cycle, and does not identify the flow of information and materials among the processes. However, the model conveys the system as a set of processes which are interrelated and interdependent. Vanegas is successful in defining the major processes in the initial phases of design, and gives insight to the format required for modeling the construction system.

3.8 Summary of Previous Construction Models

The models discussed in this chapter were developed to illustrate a specific viewpoint rather than a generic construction process. Efforts include the definition of activities, job descriptions, decision making processes, and interactions among the functions. From these models, it is possible to envision a generic, comprehensive model which integrates the construction process from inception to demolition. To enhance communication and coordination among construction project participants, as well as acceptance by the construction industry, it was deemed
Figure 3.12 Vanegas’ Model - Partial (Level 2)
(Source: Vanegas 1987)
necessary to use an established modeling methodology for developing the integrated construction model. The next chapter presents the development of modeling methodologies.
CHAPTER 4. DEVELOPMENT OF MODELING METHODOLOGIES

The first step in selecting a modeling tool was to review previous modeling efforts in the construction industry, as discussed in the previous chapter. Finding a need for an established modeling methodology, the search continued outside the construction industry, starting with the manufacturing industry.

4.1 Modeling Efforts in the Manufacturing Industry

A major effort in modeling the manufacturing process by the Integrated Computer Aided Manufacturing (ICAM) project employed the IDEF0 modeling methodology, which was based on the Structured Analysis and Design Technique (SADT) [ICAM 1978]. SADT is one of several modeling tools developed in the software engineering discipline. This led to a review of modeling efforts in the information systems discipline. The major works in this area are by Aktas [1987] and Martin and McClure [1988], who summarize the development of structured techniques and the modeling tools generated. For further discussions of each modeling methodology, the reader is referred to various authors in the bibliography.

4.2 Development of Structured Techniques

In the mid-sixties, several costly failures in electronic data processing applications were attributed to poor or nonexistent system development techniques. Following these failures, information systems development methodologies began to emerge in the late sixties and early seventies.
Structured techniques evolved from the intention to make software generation into an engineering-like, structured discipline. Almost all of the information systems development methodologies were patterned after an engineering systems development process, such as construction and operation of buildings and machines [Aktas 1987]. Therefore, life cycles of information and engineering systems should share many similarities, and the general principles should be valid for either type of system.

4.3 Methodologies For Information Systems Development

The methodologies available for information systems development are divided into three groups by Aktas [1987]: (1) functional decomposition methodologies, (2) data-oriented methodologies, and (3) prescriptive methodologies. Each type of methodology is briefly discussed.

4.3.1 Functional Decomposition Methodologies

Functional decomposition methodologies emphasize the relevant dissection of a system into smaller subsystems so that the resulting elementary systems are not so complex to understand, design, and implement [Aktas 1987]. The system functions are of major concern. Two methodologies, HIPO and Structure Charts, will be discussed in this group.

4.3.2 Data Oriented Methodologies

Data oriented methodologies mainly emphasize the characteristics of the data to be processed, and are further divided into two groups: data flow and data structure methodologies.
4.3.2.1 Data Flow Oriented Methodologies

Data flow oriented methodologies are based on the decomposition of a system into modules by considering the type of data elements and their logical behavior within the system. The logical organization of the system is based on the data flow logic and functional relationships between the modules of the system [Aktas 1987]. Three models of this type are considered, including SADT, DFD, and SAMM.

4.3.2.2 Data Structure Oriented Methodologies

Data structure oriented methodologies emphasize the output/input data structures of the system. The functional relations between the modules or elements of the system and their decomposition are then realized in terms of the system structure [Aktas 1987]. Examples of the data structure oriented methodologies are Jackson's diagrams, and Warnier/Orr methodology.

4.3.3 Prescriptive Methodologies

Prescriptive methodologies are computerized procedures to help system development efforts, especially in software system development. The major objective is to provide a prescriptive approach to analyze the system specifications and to generate the needed software [Aktas 1987]. Some of these methodologies are in the form of commercially available information systems development packages.
Some prescriptive methodologies are Information System Design and Optimization System (ISDOS), the PLEXSYS Project, PRIDE, Systems Development Methodology/70 (SDM 70), SPECTRUM, and Software Requirement Engineering System (SRES) [Aktas 1987]. The major use of such software packages is to support, rather than develop, methodologies for systems requirement definition and software development activities. Therefore, these methodologies are beyond the scope of this report and will not be considered.

4.4 Information Systems vs. Engineering Systems

A system is defined as "an organized collection of people, machines, procedures, documents, data or any other entities such that they interact with each other as well as with the environment to reach a predefined goal" [Aktas 1987]. Furthermore, Marca and McGowan [1987] define system engineering as a "discipline for specifying subsystems, components, and how they interconnect; for identifying the constraints under which a system must operate; and for deciding upon an effective combination of people, machines, and software to realize a system." It is evident that information and engineering systems share common characteristics, and may be represented using the same modeling techniques. Therefore, the modeling methodologies which have been developed for information systems will be directly applicable to the construction process.

4.5 Summary of Modeling Methodology Development

To select an established modeling methodology, previous modeling efforts in industry were reviewed. The Integrated Computer Aided
Manufacturing project led to the discovery of developments in modeling methodologies in the information systems discipline. These models, which emerged in late sixties and early seventies, evolved from a need to structurize the software generation process, and were based on engineering systems development. Due to the similarities in their life cycles, the modeling methodologies developed in the information systems discipline should be applicable to the building construction process. In the following chapter, selected modeling methodologies are described and their modeling capabilities are demonstrated by modeling a common process.
CHAPTER 5. SURVEY OF MODELING METHODOLOGIES

In this chapter, seven modeling methodologies are discussed, and an example is given for each of the modeling techniques. The process "Build a Bookcase" is modeled using each of the seven modeling methodologies. Although a simple process was selected to introduce the reader to each modeling technique, the magnitude of complexity in the building construction system should be considered in evaluating each modeling method.

5.1 Hierarchy Plus Input-Process-Output (HIPO)

Hierarchy plus Input-Process-Output (HIPO) methodology, developed and supported by IBM, consists of a set of diagrams which graphically describe the input, output, and the functions of a system [Martin and McClure 1988]. It was first developed to document systems structure, and its uses have been extended to document the design and analysis of systems [Aktas 1987]. The HIPO methodology uses three diagram types [IBM 1975]:

1. Visual Table of Contents (VTOC): A tree diagram showing the hierarchical structure of the functions in the system. Contains names and identification numbers of the overview and detail HIPO diagrams in the package. A description section may be used to describe each function. (Figure 5.1)

2. Overview Diagrams: High level HIPO diagrams which describe the major functions in the VTOC. The inputs, processes, and the outputs of the functions are shown. An extended description area gives further explanation of the process in the diagram, and may be used to reference the lower level diagrams or non-HIPO documentation. (Figure 5.2)
Figure 5.1. Example of Visual Table Of Contents (HIPO)
Figure 5.2 Overview Diagram Example (HIPO)
3. Detail Diagrams: Lower level HIPO diagrams which contain the fundamental elements of the package. These diagrams describe specific functions, show specific input and output items, and refer to other detail diagrams. Extended description may also be used. (Figure 5.3)

The VTOC shows the overall system as a structure composed of functional components. The Overall and Detail diagrams describe the processes and the flow of data in increasing detail. Therefore, the HIPO methodology is capable of showing the processes and their hierarchical relationships. The HIPO diagrams also illustrate the input-process-output transformation for each process in the system.

The HIPO methodology shows several limitations. The HIPO diagrams do not show the interactions among the processes on a common level. The outputs of one process may serve as an input or a control to another process. Because distinctions are not made between data which is external to each level and data which is generated within the current level, it is difficult to trace the flow of data among the processes and levels. This also leads to difficulty in verification of consistency between levels. Therefore, it is difficult to update and verify HIPO diagrams, so that the HIPO methodology is not practical for modeling large systems.

5.2 Structure Charts

A structure chart is a hierarchical diagram which defines the overall architecture of a system by showing the modules and their interrelationships [Martin and McClure 1988]. A tree diagram is used to show the processes of the system and illustrate the relationships among
Figure 5.3  Detail Diagram Example (HIPO)
the modules. The interrelationships are indicated by the type of communication between two modules. The following symbols are used in this method [Aktas 1987]:

1. **Module**: A rectangle represents each module identified by a functional module name. The name consists of a descriptive verb followed by a singular object name.

2. **Connection**: Represented by a vector joining two modules, it indicates any reference from one module to another.

3. **Couple**: Shown by a short arrow with a circular tail, it is used to indicate either data communication (open circle), or control communication (solid circle) between two modules.

4. **Loop**: A semicircle shown on a connection indicates a major loop in the module.

5. **Decision**: A diamond shape shown inside the box indicates a major decision in the module.

An example of the structure chart methodology is shown in Figure 5.4. The data and control communication used in the structure chart are identified in Table 5.1. The structure chart represents the entire system in an efficient manner. The complete set of processes in the system is shown in one diagram, and the type of communication between the modules is also shown.

The structure chart is limited, however, in its ability to show detailed information about a system. It is difficult to represent a system where much interaction occurs among the functions. If more than two or three data types flow between two modules, further decomposition is recommended [Martin and McClure 1988]. In a complex system, this may lead to an enormous single-level diagram which is very difficult to
Figure 5.4 Example of Structure Chart

BUILD A BOOKCASE

FINISH BOOKCASE

ASSEMBLE BOOKCASE

SAND PIECES

DRILL HOLES

CUT PIECES

MEASURE & MARK PIECES

ACQUIRE TOOLS & MATERIALS

PREPARE PIECES

DESIGN A BOOKCASE

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27

5-7
Table 5.1 Data and Control Communication of the Structure Chart

<table>
<thead>
<tr>
<th>ENTITY #</th>
<th>TYPE</th>
<th>ENTITY NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CTRL</td>
<td>USER'S NEEDS</td>
</tr>
<tr>
<td>2</td>
<td>CTRL</td>
<td>BUDGET</td>
</tr>
<tr>
<td>3</td>
<td>CTRL</td>
<td>KNOWLEDGE</td>
</tr>
<tr>
<td>4</td>
<td>DATA</td>
<td>IDEA</td>
</tr>
<tr>
<td>5</td>
<td>CTRL</td>
<td>DESIGN</td>
</tr>
<tr>
<td>6</td>
<td>CTRL</td>
<td>MATERIAL REQUIREMENTS</td>
</tr>
<tr>
<td>7</td>
<td>DATA</td>
<td>MONEY</td>
</tr>
<tr>
<td>8</td>
<td>CTRL</td>
<td>ACCESSIBILITY TO MIRLS.</td>
</tr>
<tr>
<td>9</td>
<td>DATA</td>
<td>SALVAGE MATERIALS</td>
</tr>
<tr>
<td>10</td>
<td>DATA</td>
<td>TOOLS</td>
</tr>
<tr>
<td>11</td>
<td>DATA</td>
<td>MATERIALS</td>
</tr>
<tr>
<td>12</td>
<td>CTRL</td>
<td>INSTRUCTIONS</td>
</tr>
<tr>
<td>13</td>
<td>CTRL</td>
<td>SKILL</td>
</tr>
<tr>
<td>14</td>
<td>DATA</td>
<td>WASTE</td>
</tr>
<tr>
<td>15</td>
<td>DATA</td>
<td>PREPARED PIECES</td>
</tr>
<tr>
<td>16</td>
<td>DATA</td>
<td>ASSEMBLED BOOKCASE</td>
</tr>
<tr>
<td>17</td>
<td>DATA</td>
<td>FINISHED BOOKCASE</td>
</tr>
<tr>
<td>20</td>
<td>CTRL</td>
<td>WOOD</td>
</tr>
<tr>
<td>21</td>
<td>DATA</td>
<td>MEASURING/MARKING TOOLS</td>
</tr>
<tr>
<td>22</td>
<td>DATA</td>
<td>MARKED PIECES</td>
</tr>
<tr>
<td>23</td>
<td>DATA</td>
<td>CUTTING MACHINE/TOOLS</td>
</tr>
<tr>
<td>24</td>
<td>DATA</td>
<td>CUT PIECES</td>
</tr>
<tr>
<td>25</td>
<td>CTRL</td>
<td>DRILLING MACHINE/TOOLS</td>
</tr>
<tr>
<td>26</td>
<td>DATA</td>
<td>DRILLED PIECES</td>
</tr>
<tr>
<td>27</td>
<td>DATA</td>
<td>SANDING MACHINE/TOOLS</td>
</tr>
</tbody>
</table>
understand and maintain. Therefore, the complexity and the amount of information for large systems will be prohibitive for the structure chart methodology.

5.3 Data Flow Diagrams (DFD)

The data flow diagram is a system analysis tool which is used to show the data flow through a system composed of basic procedural components [Martin and McClure 1988]. The model describes a system as a network of processes, data stores, and sources and sinks, which are interconnected by flow of data. A data flow diagram may be used to describe an existing or a proposed system in an hierarchical manner. The following symbols are used in the DFD methodology [Aktas 1987, Martin and McClure 1988]:

1. **Data Flow:** Traces the flow of data through a system of processes. The direction of flow is indicated by the arrow, which is identified by its name. The data flow shows how the processes are connected.

2. **Process:** A procedural component in the system which transforms data. A circle with a brief descriptive statement consisting of an active verb followed by an object is used to identify the process. A reference number is associated with each process.

3. **Source/Sink:** A square is used to represent data origination or termination. The name of the originator/terminator entity is written inside the box. A source/sink is an independent system that produces or receives the data flows either processed or produced by the process. A system may serve as both a source and a sink, but must be shown separately.

4. **Storage:** Storage is represented by an open ended rectangle. Storage is used to store information or objects, and identifies a time delay for its content. An unidirectional or a bidirectional arrow may be used to show the flow of data between storage and processes.
The data flow diagrams are arranged in a hierarchical manner, starting with the Context diagram. The Context diagram defines the boundaries of the system by showing the external source/sink entities. The Context diagram is followed by the Level 0 diagram, also known as the Overview diagram, which identifies the major processes and data flow of the system. Using the top-down approach, the processes are studied with increasing detail with each level. It is recommended that the number of processes on any level be limited to 7 ± 2 processes [Aktas 1987].

All names used for data flows, description of processes, source/sink, and storage must be defined in the Data Dictionary (DD). Duplicate external entities (source/sink) or data stores are identified by the use of lines or asterisks. The data flow diagramming methodology is used to model the process "Build a Bookcase" [Figure 5.5].

The DFD method may be embellished by the use of relational operators. The following notation is used to show the relationships among data in the system:

* Logical AND (A and B must be true.)
+ Exclusive OR (A or B must be true.)
O Inclusive OR (A and/or B must be true.)

The data flow diagrams partition the system into a series of subsystems in a top-down manner. In addition, data flows in the system are shown which represent the object and information communication in the system. By showing greater detail at each level of subdivision, much information is represented efficiently. However, the data flow diagrams are difficult to read, and this difficulty will increase with complexity of systems. Also, the hierarchical relationship among the levels is not immediately apparent.

5-10
Figure 5.5 Example of Data Flow Diagram
5.4 Structured Analysis and Design Technique

Structure Analysis and Design Technique (SADT™), developed by SofTech Inc., is a graphics language and a set of analysis procedures used to describe a system and its environment. Two types of diagrams, activity diagrams and data diagrams, are included in the SADT methodology. The activity diagrams explode the activities of the system, whereas the data diagrams depict the data decomposition in the system [Aktas, 1987]. Since the scope of this report is limited to process modeling, the decomposition of activities in the modeling process will be the focus of this discussion.

The SADT model is a series of diagrams arranged in a hierarchy. The diagrams consist of a set of boxes, each of which represents a transformation function. Each function box may be exploded into a set of functions in a detail diagram, resulting in a gradual exposition of detail. The functions are interrelated by arrows which represent objects or information, collectively referred to as "data." The data may be divided into four types: input, control, mechanism, and output [ICAM 1978]:

1. **Input:** Information or objects which undergo a transformation process. Inputs enter the left side of the function box.

2. **Output:** The results of the transformation process. Outputs are shown exiting the box on the right hand side.

3. **Control:** That which influences or determines the process of converting inputs to outputs. Controls may limit the activity or allow the activity to occur, but are not affected by the activity. Enters the top side of the box.

4. **Mechanism:** Anything which performs a process or operation, including people, machines, or software. Mechanisms enter the underside of the box.
The SADT modeling methodology is demonstrated in Figure 5.6. Textual information accompanies each diagram, in which the data and the processes at each level are defined.

The SADT methodology is similar to the DFD technique in that it is modular and hierarchical. The flow of data is represented in both modeling techniques, but the SADT method further differentiates among input, control, and mechanism entities. The result is a modeling methodology which is structured and easy to use and understand, and one which may be readily updated and verified.

The SADT modeling methodology was adapted and standardized by the Integrated Computer Aided Manufacturing (ICAM) program of the U.S. Department of Defense [Marca and McGowan 1987]. The resulting technique, the ICAM Definition Method (IDEF0), was used to model the process "Manufacture A Product." The IDEF0 modeling methodology will be discussed further in Chapter 7.

5.5 Systematic Activity Modeling Method

The Boeing Computer Service Systematic Activity Modeling Method (BCS SAMM) is a functional modeling methodology. It is based on the decomposition of activities and data, and studies the flow of data through activities within a system. The SAMM methodology has been used to model the ICAM Architecture of Manufacturing Function Model based on the IDEF0 diagrams, and is very similar in nature to the IDEF0 modeling methodology. Several formats are used for viewing the data. These
formats are: Activity Flow Diagrams, Activity Description Lists, Data Description Lists, and Input-Output Control Charts [Leck and Lawrence 1978].

The Activity Flow Diagram contains a List of Data Identification Number (Figure 5.7) and an Activity Diagram (Figure 5.8). The List of Data Identification Number lists a descriptive name for each data item. The list contains trace information identifying how the data item is referred to at higher levels in the data hierarchy. The Activity Diagram displays the sequence of activities graphically. Input data enters top/bottom of the Activity Cell for forward/feedback data respectively. Similarly, the output data leaves the cell on the left/right for feedback/forward data respectively. The data is divided into the following categories [Leck and Lawrence 1978]:

- **External Data:** The data arrow crosses the model boundary. The label is shown outside the boundary. (EX)

- **Internal Data:** The data within the model boundary. It is labeled on the inside corner of the point where direction change occurs.

- **System Data:** The data which emanates from or terminates at the model boundary. System Data is labeled inside at the model boundary. (SYS)

The Activity Description List (Figure 5.9) consists of the Activity Identifier (ID), the Activity Name, and textual information. Data associated with each activity is called Related Data, and is shown as a Source or a Destination. The Data Description List (Figure 5.10) consists of the Identifier (ID), Data Name, its Source, and its Destination. The Source is the activity which produced the data, and the Destination is the activity for
## ACTIVITY DATA FLOW DIAGRAM  PART I

**NODE: A0**

**TITLE: Build A Bookcase**

<table>
<thead>
<tr>
<th>DATA DESIGNATION</th>
<th>DECOMPOSITION TRACE</th>
<th>DATA NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EX(1)</td>
<td>User's Needs</td>
</tr>
<tr>
<td>2</td>
<td>EX(2)</td>
<td>Budget</td>
</tr>
<tr>
<td>3</td>
<td>EX(3)</td>
<td>Knowledge</td>
</tr>
<tr>
<td>4</td>
<td>EX(4)</td>
<td>Idea</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Design</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Material Requirements</td>
</tr>
<tr>
<td>7</td>
<td>EX(5)</td>
<td>Money</td>
</tr>
<tr>
<td>8</td>
<td>EX(6)</td>
<td>Accessibility To Materials</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Salvage Materials</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Tools</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Materials</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Instructions</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Skill</td>
</tr>
<tr>
<td>14</td>
<td>EX(7)</td>
<td>Waste</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Prepared Pieces</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>Assembled Bookcase</td>
</tr>
<tr>
<td>17</td>
<td>EX(8)</td>
<td>Finished Bookcase</td>
</tr>
</tbody>
</table>

*Figure 5.7 List of Data Identification Example*
ACTIVITY DATA FLOW DIAGRAM PART II

NODE: A0

TITLE: Build A Bookcase

Figure 5.8 Example of SAMM Diagram
## ACTIVITY DESCRIPTIONS

**NODE: A0**  
**TITLE: Build A Bookcase**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>RELATED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ID</strong></td>
<td><strong>DESCRIPTION</strong></td>
</tr>
<tr>
<td>A1</td>
<td>DESIGN A BOOKCASE</td>
</tr>
<tr>
<td></td>
<td>Determine the dimensions,</td>
</tr>
<tr>
<td></td>
<td>materials, and design of the</td>
</tr>
<tr>
<td></td>
<td>bookcase. Select tools to be</td>
</tr>
<tr>
<td></td>
<td>used and plan the work methods.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>ACQUIRE TOOLS &amp; MATERIALS</td>
</tr>
<tr>
<td></td>
<td>Gather existing tools and materials.</td>
</tr>
<tr>
<td></td>
<td>Determine the purchase requirements and purchase the needed tools and materials.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>PREPARE PIECES</td>
</tr>
<tr>
<td></td>
<td>Measure and mark pieces.</td>
</tr>
<tr>
<td></td>
<td>Cut pieces to dimensions</td>
</tr>
<tr>
<td></td>
<td>per drawing. Drill holes as needed and sand pieces.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.9 Example of Activity Descriptions Diagram
**ACTIVITY DESCRIPTIONS**

**NODE: A0**

**TITLE: Build A Bookcase**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>RELATED DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESCRIPTION</strong></td>
<td><strong>ID</strong></td>
</tr>
<tr>
<td><strong>A4</strong> ASSEMBLE BOOKCASE</td>
<td>10</td>
</tr>
<tr>
<td>Position and align pieces.</td>
<td>11</td>
</tr>
<tr>
<td>Glue pieces in place. Fasten</td>
<td>12</td>
</tr>
<tr>
<td>with screws.</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td><strong>A5</strong> FINISH BOOKCASE</td>
<td>10</td>
</tr>
<tr>
<td>Sand and varnish surfaces.</td>
<td>11</td>
</tr>
<tr>
<td>Wait to dry. Move to the desired location.</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>

Figure 5.9 Example of Activity Descriptions Diagram  (Continued)
DATA DESCRIPTIONS

NODE: A0  
TITLE: Build A Bookcase

<table>
<thead>
<tr>
<th>ID</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>SOURCE</th>
<th>DEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FW</td>
<td>User's Needs - What the user wishes to use the bookcase for. How the user expects to use the bookcase.</td>
<td>EX</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>FW</td>
<td>Budget - How much the user is willing or able to expend to build this bookcase.</td>
<td>EX</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>FW</td>
<td>Knowledge - Knowledge and skills the user has gained through previous experiences with building bookcases.</td>
<td>EX</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>FW</td>
<td>Idea - The initial motivation to build a bookcase and some preconceived notions of what the bookcase should be like.</td>
<td>EX</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>FW</td>
<td>Design - The dimensions and specifications of the bookcase, as well as its material content.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>FW</td>
<td>Material Requirements - The type and amount of materials required to build the bookcase.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>FW</td>
<td>Money - Used to purchase the materials and tools the user needs but doesn’t already possess.</td>
<td>EX</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>FW</td>
<td>Accessibility to Materials - Availability of tools and materials to the user.</td>
<td>EX</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>FB</td>
<td>Salvage Materials - Materials left from building the bookcase which may be used to build another bookcase.</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 5.10 Example of Data Description Diagram
## DATA DESCRIPTIONS

**NODE: A0**  
**TITLE: Build A Bookcase**

<table>
<thead>
<tr>
<th>ID</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>SOURCE</th>
<th>DEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>FW</td>
<td>Tools - May include hammers, screwdrivers, drill, sander, level, saw, tape measure, etc.</td>
<td>2</td>
<td>3,4,5</td>
</tr>
<tr>
<td>11</td>
<td>FW</td>
<td>Materials - May include wood, screws, nails, glue, varnish, etc.</td>
<td>2</td>
<td>3,4,5</td>
</tr>
<tr>
<td>12</td>
<td>FW</td>
<td>Instructions - A list of steps which should be followed in building the bookcase.</td>
<td>1</td>
<td>3,4</td>
</tr>
<tr>
<td>13</td>
<td>FW</td>
<td>Skill - The ability of the user in handling the tools and materials gained from previous experiences.</td>
<td>EX</td>
<td>3,4,5</td>
</tr>
<tr>
<td>14</td>
<td>FW</td>
<td>Waste - Materials left over which are not salvageable for future uses and must be disposed.</td>
<td>3</td>
<td>EX</td>
</tr>
<tr>
<td>15</td>
<td>FW</td>
<td>Prepared Pieces - Pieces which have been cut to size, drilled, and sanded and are ready for assembly.</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>FW</td>
<td>Assembled Bookcase - The pieces have been fastened or joined together and are in the physical form of a bookcase.</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>FW</td>
<td>Finished Bookcase - The bookcase in its final form, which has been sanded, varnished, and moved to the desired location.</td>
<td>5</td>
<td>EX</td>
</tr>
</tbody>
</table>

Figure 5.10 Example of Data Description Diagram (Continued)
which the data is destined. Related Activities are activities which generate or use the data. The Output Conditions Descriptions Chart (Figure 5.11) identifies the activity, its outputs, required inputs, and any special conditions for its execution.

The SAMM methodology is similar to SADT in that the model represents the processes in a system in a top-down manner, and identifies the information and objects which flow through the system. However, the system is modeled in much greater detail by the SAMM methodology.

By using the four different formats to model each level in the hierarchy, the SAMM modeling method generates a comprehensive, detailed model. The SAMM technique is thorough in its coverage of each activity and data entity. Each activity and data entity is defined, and each related datum or activity is identified. These relationships are shown on both the diagram and the description lists. Furthermore, the input-output relationships are clearly defined, and the required inputs and conditions for each output are identified.

The thoroughness of the model also leads to redundancy. Much overlap of information exists as the same information is cross-referenced in several formats. The diagrams do not readily offer information about the overall system. To get a comprehensive view of the entire system, the user must refer to five diagrams for each module. To explode the functions in Figure 5.8 by one level, 25 additional diagrams are required. The generation of SAMM diagrams is tedious and time consuming, as the SAMM models are lengthy and cumbersome. The SAMM methodology has
## OUTPUT-CONDITIONS DESCRIPTIONS

**NODE: A0**

**TITLE: Build A Bookcase**

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>OUTPUT</th>
<th>INPUT</th>
<th>CC</th>
<th>CONDITION CODE DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>5</td>
<td>1,2,3,4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1,2,3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>1,3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>10</td>
<td>5,6,7,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>5,6,7,8,9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>9</td>
<td>11,12,13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>11,12,13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>16</td>
<td>10,11,12,13,15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A5</td>
<td>17</td>
<td>10,11,12,13,16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.11 Example of Output-Conditions Descriptions Diagram
compromised conciseness and simplicity for a greater level of detail, and will require much more time and cost to generate, update, and maintain.

5.6 Warnier/Orr Diagrams

The Warnier/Orr (W/O) diagrams graphically represent the hierarchical structure of a system, and are used for either data or process representation [Martin and McClure 1988]. Rather than using symbols, brackets " { " are used to show the decomposition of the system. Elements are items which cannot be decomposed further, called data elements in data structures and elementary operations in process structures. The following relational operators may be used to depict the relationships among the data/processes [Aktas 1987]:

- Exclusive OR: (O)
- Inclusive OR: (+)
- Arithmetic operators: (/) (*) (-) (+)

The general form of structures using W/O diagrams is given below [Aktas 1987]:

1. Hierarchy:
   
   aaa { bb { c  aaa consists of bb, which consists of c.

2. Sequence:
   
   aa  
   aaa bb  aaa consists of aa, followed by bb, followed by cc.
   cc

3. Repetition:

   - (1,N) indicates that aaa may occur 1 to N times.
   - (0,N) or (N) indicates that aaa may occur zero to N times.

5-24
- (10) indicates that aaa occurs exactly 10 times.

4. Selection:
   
   \[
   \begin{align*}
   &\text{aaa} \\
   &\text{(0,1)}
   \end{align*}
   \]

   aaa
   
   bb
   
   (0,1)

   aaa will consist of either aa or bb but not both.

5. Concurrency:
   
   \[
   \begin{align*}
   &\text{bbb} \\
   &\text{aaa} + \\
   &\text{cc}
   \end{align*}
   \]

   aaa will consist of both bb and cc.

6. Recursion:
   
   \[
   \begin{align*}
   &\text{bbb} \\
   &\text{aaa}
   \end{align*}
   \]

   aaa calls itself, as shown by the broken brace.

In Figure 5.12, the Warnier/Orr diagram is used to represent the "Build a Bookcase" process.

The Warnier/Orr diagram is easy to learn and use. The Warnier/Orr diagrams simply list the decomposition of each process into its elementary operations. The W/O diagrams are able to show sequence, selection, and iteration, but are not capable of showing the data flow relationships among the processes. Therefore, the W/O diagram is limited in its capability to show interactions among the processes in the system, and gives limited information about the system modeled.

5.7 Jackson's Diagram

Jackson's notation is used to represent any program, data structure, or information system in terms of system hierarchy and its elementary and
Figure 5.12 Example of Warnier/Orr Diagram
composite components [Aktas 1987]. Elementary components are those which cannot be further decomposed and contain no parts. Composite components may be of three types: sequence, iteration, or selection.

**Sequence:** Two or more parts which occur once in order.

**Iteration:** Part which occurs zero or more times for each occurrence of the component. Indicated by an asterisk inside the box.

**Selection:** Two or more parts of which one, and only one, occurs once for each occurrence of the selection component. A small circle inside the box designates the occurrence of selection.

Two types of notation are used to represent the composite components. The first, a graphical notation, is usually referred to as Jackson's Diagram or Structure Diagram. The second method is a nongraphical notation called Structure Text or Schematic Logic which is similar to pseudocode. The Jackson's diagram consists of a tree diagram showing the functions in a hierarchical manner. It is similar to Structure Charts, but is not capable of showing data flow relationships. An example of Jackson's diagram is shown in Figure 5.13. The Structure Text is primarily for use in representing software and is not illustrated here.

### 5.8 Summary of Modeling Methodologies

In this chapter seven modeling methodologies were discussed, and the application of each method was illustrated using the "Build A Bookcase" process. All seven modeling techniques modeled the process successfully, but in varying degrees of detail. Some models represent only the processes involved, such as the Warnier/Orr diagram, whereas the SAMM
Figure 5.13 Example of Jackson's Diagram
diagrams illustrated the process-data relationships in several formats. The appropriateness of each model for modeling the construction process is contingent on the expected applications of the final model. Therefore, selection criteria were established based on the needs of this project, and each modeling methodology was evaluated accordingly.
CHAPTER 6. SELECTION OF MODELING METHODOLOGY

The modeling methodologies discussed in the previous chapter offer different advantages and limitations. The applicability of each model is contingent on the purpose for which the model is to be developed. To evaluate each model, it is thus necessary to first establish the selection criteria which reflect the needs of this project.

6.1 Selection Criteria

From discussions with the advisory committee members, the following selection criteria were established:

1) **Technical Merit** - The model must allow accurate representation of the industry. The model must be capable of representing the type of functions and interrelationships which are prevalent in the construction industry.

2) **Ease of Use and Understanding** - The model must be easy to use and understand. This is especially important in the construction industry whose members are from very diverse disciplines. To facilitate acceptance and applicability, the models must be easy to generate, maintain, and explain to new users.

3) **Availability** - The modeling tool must be accessible to all members of the project and the construction industry. Any modeling tools which are proprietary or in limited distribution will inhibit the implementation of the models.

4) **Compatibility** - The models should be compatible with the major efforts in this area. This will lead to an interchange of ideas and knowledge, as well as allow an increase in the information available on the topic. In addition, this will facilitate the acceptance of the model by members in the construction industry, and in other industries as well.
5) **Robustness** - The modeling tool must be robust and proven through use in industry. New modeling tools are typically fragile in new applications.

The selection criteria may be applied more specifically to the construction industry. The characteristics of the system to be modeled should be considered in selecting the modeling methodology. The following characteristics are of special significance:

1. The building construction process is very complex and comprises much detail. It is necessary to break the construction process in a controlled manner into smaller pieces to properly portray the details of the system. Otherwise, the user will be overwhelmed with the magnitude of detail and complexity in the model.

2. The present construction industry has no standardized structure. Lack of agreement on the division of responsibilities among the industry members has led to overlap in, and negligence of, some functions. There are no industry wide standardized procedures for performance of functions, nor for the transfer and maintenance of information and data. Thus the model should be capable of defining the large number of processes and subprocesses in sufficient detail.

3. The construction industry is composed of members from diverse disciplines who perform disparate functions, but must communicate with each other consistently to transfer information and material resources. Therefore, the model must be modular in order to represent each section of the construction process.

4. In the construction industry, the timely transfer of a vast amount of data is of critical importance. The interfaces which occur among the processes are crucial components of the construction industry and must be modeled accurately by the selected modeling methodology.

The main challenge in modeling the construction process is in the model's ability to represent the complexity of the construction system. The model must represent all the processes involved, as well as their interfaces which
define the interrelationships among the processes. The models discussed in Chapter 5 were able to meet this requirement in varying degrees.

6.2 Discussion of Model Utility

All seven models were able to represent the functions involved in the building construction process. However, the models vary in their abilities to portray the interfaces among the functions. The Warnier/Orr and Jackson diagrams simply decompose processes into subprocesses and do not represent interfaces between levels nor between processes. The Structure Chart is similar to the Jackson diagram, and all processes are shown in a tree diagram. The Structure Chart does allow representation of data and control communication from one level to the next, but does not allow the interfaces among processes on a common level to be shown. All three diagrams are easy to develop and maintain. However, no level-by-level decomposition is utilized so that a single diagram is used to represent the entire system. Given the amount of information which needs to be modeled, the diagrams will be very complex and difficult to work with.

The HIPO diagramming technique does use level-by-level exposition of detail so that a lower level diagram shows far more detail in a given sub module. The input-process-output transformations are shown for each function and the data interfaces between levels can be deduced from these diagrams. However, the HIPO methodology is not capable of modeling data interfaces between modules on a common level. Also, because the data interfaces are shown on individual detail diagrams but not in the hierarchy
diagram, it is difficult to verify consistency of the data interfaces from one level to the next.

The Data Flow Diagrams, SADT diagrams, and SAMM diagrams have several characteristics in common. Each shows the system in a hierarchical manner. Each process is decomposed into subprocesses, and each decomposition is detailed so that successive decomposition leads to a greater level of information about the system. All models are modular. Each decomposition fits completely inside the parent function, so that each model is a set of modules and their submodules which are interrelated to each other by data interfaces. The models are able to represent complex systems such as the construction industry, as their level-by-level decomposition allows much information to be represented without confusing the user.

Several differences also exist in the three modeling methodologies. The Data Flow Diagrams are difficult to read and understand, especially for complex systems where much interaction occurs among the processes. In addition, it is difficult to verify integrity among levels as data interfaces enter and exit the system at several sources and destinations in the diagram. Therefore, a more structured methodology is required.

The SAMM diagrams are by far the most comprehensive of the models discussed. Each data interface is identified, defined, and traced to related activities and its origin. This information is cross-referenced to the activities for which similar information has been generated. Each output is identified, as are the required inputs and conditions. The SAMM
methodology's major shortcoming is that by trying to represent too much information, much of it redundant, it has compromised the simplicity and conciseness for which modeling was intended.

The SADT modeling methodology successfully bridges the gap between showing enough information to be comprehensive, and yet limiting the detail to remain concise and clear. The SADT methodology is successful in meeting all elements of the selection criteria established by the members of this project.

The SADT models are capable of representing the construction industry accurately. The model is able to show the construction process as a set of subprocesses and data interfaces which define the interactions among them. The SADT models are easy to use and understand. The methodology is rigorously structured and documented, and it is relatively easy to train a new user. Its modular characteristic aids in the user's efforts to verify consistency between levels and modules, so that the task of updating and maintaining these models becomes more manageable.

The Integrated Computer-Aided Manufacturing project of the U.S. Department of Defense recognized the utility of SADT and developed IDEF0 based on this methodology. The ICAM project adapted and standardized the modeling tool and made public the IDEF0 methodology. The IDEF0 modeling method was used by the ICAM project to develop the architecture of the manufacturing process. The objectives of the manufacturing modeling effort are similar to the objectives of this project: to define the generic manufacturing process to generate a common vehicle
for exchange of information, as well as standardize the automation of subsets of the manufacturing process. The manufacturing model has been successfully completed, and may serve as a guide in modeling the construction process.

6.3 Selection of Modeling Methodology

To evaluate the applicability of each model discussed, selection criteria were established which reflect the objectives of this project. The key factors were deemed to be: technical merit, ease of use and understanding, availability, compatibility, and robustness. To meet the specific challenges of the construction industry, it was determined that the modeling methodology be hierarchical, modular, have standardized structure, and have the capability to represent the complexity of the processes and their interfaces. Based on these characteristics, the Integrated Computer Aided Manufacturing Definition model (IDEF0) was selected as the tool to be used in modeling the building construction process. In Chapter 7, the IDEF0 modeling methodology is described to familiarize the reader with the use of this modeling tool.
CHAPTER 7. IDEF0 MODELING METHODOLOGY

In this chapter, the ICAM Definition Method is described. The structure and schematic representation of the IDEF0 methodology is discussed, and the diagramming methodology is explained. The discussion is succinct and is intended to provide the reader with a brief overview of the IDEF0 modeling methodology. For a detailed discussion, the reader is referred to publications by the Integrated Computer Aided Manufacturing organization [ICAM 1978, 1981].

7.1 ICAM Definition Method (IDEF)

The Integrated Computer Aided Manufacturing (ICAM) Definition Method (IDEF) is a set of structured analysis techniques for performing system analysis. Its main purpose is to provide engineering methods for analyzing and designing complex systems, and is used to understand and manage such systems [Wallace et al. 1987]. IDEF supports multiple views of the system, and allows the system to be modeled from three different perspectives: Functional, Informational, and Dynamic.

The functional model, IDEF0, produces a structured representation of the functions of a system, and of the information and objects which interrelate the functions. IDEF1 is used to represent the structure of the information needed to support the functions of a system. Also referred to as the Information model, it is similar to Chen's Entity Relationship Attribute diagrams. The Dynamic model, IDEF2, represents the time varying interaction of the system with its environment. It shows the different
behavioral states and the events which cause the transition from one state to the next. [ICAM 1981, Wallace et al. 1987]

In this report, the scope of modeling is limited to process modeling techniques. Therefore, the discussion will be limited to the functional model IDEF0. The reader should keep in mind that functional modeling perspective is the first step in the IDEF modeling methodology, and informational and dynamic models may be developed in the future to create a comprehensive model of the construction process.

7.2 Functional Modeling Perspective (IDEF0)

IDEF0, based on the Structured Analysis and Design Technique, was adapted and standardized by the Integrated Computer Aided Manufacturing (ICAM) program of the U.S. Department of Defense [Marca and McGowan 1987, ICAM 1978]. In this program, IDEF0 was used to model the process "Manufacture A Product", which represented the architecture of manufacture for the generic manufacturing system, with specific applications to sheet metal processing in the aerospace industry [ICAM 1978]. Since then IDEF0 has been used in numerous applications in both private and public sectors. One such example is Harrington's model of the general manufacturing process "Conduct A Manufacturing Enterprise" [Harrington 1984, 1985].

7.3 Structure of IDEF0

IDEF0 represents a system by means of a model composed of diagrams, text, and glossary. The model is a series of diagrams with supportive
documentation that break a complex subject into its component parts [ICAM 1981]. The diagrams consist of boxes and arrows which express the functional activities, data, and function/data interfaces. Text accompanies each diagram which narrates the activities in the diagram. In the glossary, all terms used in the diagrams are defined.

7.3.1 Hierarchy of IDEF0 Diagrams

IDEF0 starts by representing the whole system as a simple unit, a single box with arrow interfaces to the environment external to the system. This box is decomposed into between three to six functions, each of which may be further decomposed into subprocesses. This top-down decomposition process may be continued, generating between three to six "child" or detail diagrams for each function on any given level. A hierarchy of diagrams results, as shown in Figure 7.1.

7.3.2 Gradual Exposition of Detail

The number of functions in each diagram is limited to a minimum of three and maximum of six. Thus the level of detail and complexity in any diagram is limited, and yet keeps the diagram from being trivial. The level of detail is also controlled by the position of the diagram in the hierarchy of diagrams. Each level of decomposition increases the amount of detail, resulting in a gradual exposition of detail. Decomposition along any given node is discontinued when the level of detail is sufficient for the application of the model.
7.3.3 Modularity of IDEF0 Diagrams

When a box is decomposed, the scope of the function and its interface arrows create a bounded context for the subfunctions. The scope of the detail diagram fits completely inside its parent function, and the interface arrows of the parent box match the external arrows of the detail diagram. Therefore, all arrows which enter or exit the detail diagram must be the same arrows which interact with the parent diagram.

7.3.4 Numbering the IDEF0 Diagrams

The highest level in the model which is the single box representation of the system is labeled A-0. The next level of decomposition shows the major functions of the system and is called the A0 level. Each box in this diagram is labeled from A1 up to A6 and is ordered in sequence. Decomposition of each box leads to diagrams A1 through A6. Further decomposition leads to additional digits placed after a decimal point, so that the diagram resulting from decomposing the first function on four successive levels is represented by A1.111. This numbering system allows the user to retrace the steps of decomposition through the parent function of each diagram.

7.4 Schematic Presentation

Each box in the diagram represents a function which is an activity, action, process, operation, or a transformation [ICAM 1981]. One or more inputs are transformed into one or more outputs using the mechanisms provided. The transformation process is controlled by one or more controls. Data is
defined as any information or physical object which is transformed, constrains the function, or results from the function. The data entities are represented schematically in the following manner:

![Diagram](image)

**Figure 7.2** Schematic Presentation of the Function Box

Five entity types are used in the IDEF0 modeling methodology: function, input, output, control, and mechanism. Each is briefly described below [ICAM 1978, 1981]:

**Function:** An activity, action, process, operation, or transformation which is described by an active verb and an object. The function is shown by the box in the diagram.

**Input:** An entity which undergoes a process or operation, and is typically transformed. Enters the left of the box, and may be any information or material resource.

**Output:** Shown exiting the right side of the box, outputs include entities which result from a process such as data or objects created by a function.

**Control:** Entities which influence or determine the process of converting input to outputs. Controls may limit the activity or allow the activity to occur but will not be
affected by it. On the diagram, controls are shown entering the top side of the box.

Mechanism: Shown on the bottom side of the box, mechanisms are entities which perform a process or an operation such as a person or a machine. It describes how a process is accomplished.

An example is shown in Figure 7.3 which demonstrates the use of each data entity type.

![Diagram of building a bookcase](image)

Figure 7.3 Example of a Function Box

7.5 Reading IDEF0 Diagrams

The IDEF0 model is a series of diagrams arranged in a hierarchic manner. The model is read top-down, and the following sequence should be followed in reading the model [ICAM 1981]:

1. Scan the boxes in the diagram to get a general impression of what is being described.
2. Refer back to the parent diagram and note the arrow connections to the diagram. Try to identify a "most important" input, control, and output.

3. Find the central theme of the current diagram. Try to determine if there is a main path linking the "most important" input or control and the "most important" output.

4. Mentally walk through the diagram from upper left to lower right, using the main path as a guide. Study the overall content of the diagram.

5. Read the text and the glossary provided to gain a further understanding of the author's intent.

7.6 Tunnelled Arrows

To maintain integrity of the model, the diagrams must remain consistent from one level to the next. All data entities which interface with a function box must appear on its detail diagram as arrows entering or leaving the boundaries of the detail diagram. Exceptions may be made, however, with arrows which are tunneled. Tunnelling indicates that the data conveyed by these arrows are not relevant to the particular level of detail. For example, all processes in the previous example in Chapter 5 require time as a control. However, no new information is gained by showing time at each function. In such cases, it would be appropriate to show the data entity tunneled at the highest level and not show it in the following levels.

Examples of tunneled arrows are shown in Figure 7.4. Tunnelling on the connected end (e.g. C3, O1) indicates that the data entity may not be shown in lower levels of detail. Tunnelling on the unconnected end (e.g. I1, C2)
represents data entities which may not be present in the higher level diagrams.

![Diagram](image)

Figure 7.4 Example of Tunnelling

It is possible for tunnelled data entities to not appear for several levels, then reappear as a tunnelled arrow. To reduce confusion, such data entities should be labeled by their origin.

7.7 Summary of IDEF0 Modeling Methodology

The structure and the diagramming technique of the IDEF0 methodology was briefly described. The IDEF0 model is the first step in the IDEF model building process, and may be followed by information and dynamic models. The IDEF0 model is hierarchical, and uses top-down decomposition of processes. It represents functions and their interfaces which are divided into four categories: inputs, controls, mechanisms, and outputs. The IDEF0 modeling methodology was selected for the application of functional modeling of the construction process, the results of which will be discussed in the next chapter.

7-9
CHAPTER 8. INTEGRATED BUILDING PROCESS MODEL

Using the IDEF0 modeling methodology described in the previous chapter, the Integrated Building Process Model (IBPM) was developed. The IBPM is a hierarchical model of the construction process from conception to demolition. In this chapter, the first two levels of the Integrated Building Process Model are presented.

8.1 Integrated Building Process Model Description

The IBPM was developed from the perspective of the owner of the facility. It is an abstraction from observation of many building projects by the project team, advisors, and other reviewers. The model was developed to serve as a generic representation of the building construction process. Therefore, the actual mechanisms used in the execution of the functions, which depend on the project delivery method, were omitted from this model.

The model begins with an overview diagram which defines the boundaries of the system which is modeled. The overall diagram, Level F-0, identifies the primary process, "Provide Facility", and the major input, control, mechanism and output elements associated with this process. The next level, Node F, is a decomposition of the overview diagram and shows the major processes which comprise the "Provide Facility" function. Five processes are defined, resulting in nodes M, P, D, C, and O, defining the initial structure of the hierarchy of the model. This labeling system was used as a mnemonic aid so that detailed diagrams could be more easily associated with higher level functions.
8.2 Overview Diagram: Provide Facility

The overview diagram consists of one box which defines the primary function of the system, identified as "Provide Facility" as shown in Figure 8.1. The inputs required are shown to be Facility Idea and Facility Resources, resulting in outputs Operational Facility, Facility Information, and Impact on Environment. The transformation process is controlled by the Owner's Needs/Constraints and External Constraints. Facility Champion and Free Enterprise Economic System are shown as the mechanisms involved in this process. The elements in this diagram are very abstract, reflecting the need to represent overall relationships at the highest level. The purpose of the model is stated to "...describe idealized owner's functions and their relationships in a construction process." The viewpoint is also identified as the owner/user. Therefore, the initial constraints of this model are established at this level.

8.3 Level F: Components of Provide Facility

The Level F node breaks down the process "Provide Facility" into five major functions as shown in Figure 8.2. The five functions are: Manage Facility, Plan for a Facility, Design Facility, Construct Facility, and Operate Facility.

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, contracts, facility management plans,
Figure 8.1 Level F-0: Overview Diagram
Figure 8.2 Level F: "Provide Facility"
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 from the other functions and optimization information such as constructibility which represents evaluation by some function of its inputs from a preceding function.

**Plan Facility** encompasses all the functions required to define the owner's 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, the facility plan, the contract, and optimization information. Other outputs include facility planning knowledge, i.e., experience gained from performing this function, 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, construction, and operation documents which 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 are additional outputs.

**Construct Facility** includes all functions required to assemble a facility to an operational level. These activities translate resources in accordance with the design into a completed facility. Typically appropriate facility
operations documents are generated, as well as facility construction knowledge and information on the performance of the construction team. 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 documents, the PEP, the operating plans and the contract.

8.4 Lower Levels of the IBPM

The five major processes identified in Level F each serve as a parent node to lower level diagrams. Each process is further decomposed into several subprocesses which in turn are exploded to show greater detail, resulting in a hierarchical breakdown of the process. This is continued until the system is defined as a set of basic process elements. To date, four levels of decomposition have been completed. The lower level diagrams are not included in this report, and the reader is referred to Technical Report Numbers 1 through 6, which describe the IBPM and each of the five nodes in detail.
CHAPTER 9. CONCLUSION

The need for the development of a generic model of the construction industry was recognized. The model was to define the processes required to provide a facility, and then define the required information elements. The first step in generating this model was to select a modeling methodology. The objective of this study was to evaluate the different modeling approaches possible for building the construction model, and propose the most appropriate model for this project.

9.1 Selecting the Modeling Methodology

First, the previous modeling efforts in the construction industry were reviewed. These models were reviewed for their modeling capabilities rather than for their content. From these models, it was possible to gain an understanding of the modeling process, and it was also deemed necessary to continue the search for a structured, generic modeling technique.

Several structured methodologies were considered. Each modeling methodology was evaluated for its process/information representation capability. The complexity and size of the construction process was also considered. Selection of the modeling tool was based on a set of criteria established by the project and advisory committee members. Based on this selection criteria, IDEF0 was selected as the modeling tool to be used in modeling the construction process.
9.2 Developing the Integrated Building Process Model

The Integrated Building Process Model is a model of the generic construction process using the IDEF0 Functional Modeling Methodology. The information for the model was gathered through extensive interviews with experts and practitioners in each area, resulting from numerous site visits and advisory board meetings. In addition, much literature search was conducted to generate the model. The model is able to accurately represent the essential functions of the construction process such as Manage, Plan, Design, Construct, Operate and Maintain. To date, the models have been used successfully on four projects [Sanvido 1988].

In developing the Integrated Building Process model, the IDEF0 modeling methodology was successful in modeling the first several levels of the building construction process. More specifically, the IDEF0 modeling tool enabled the following accomplishments:

1. The definition of terms used in construction is leading to the establishment of a common vocabulary which may be used in discussing the construction industry. In addition, careful consideration of each term has led to a deeper understanding of the specifics of the construction process.

2. The IDEF0 modeling methodology has been an effective tool in developing a comprehensive process model for defining the functions involved in the process "Provide A Facility" at the global level.

3. The IDEF0 model has enabled the identification of information requirements in the construction process. As these information elements are identified and defined, some of the "mysteries" of the construction process are being identified and structured.
Several difficulties were also encountered in working with this modeling methodology:

1. Some difficulties were encountered in defining a "generic" process. The construction industry is very dynamic by nature, and each building may be considered a "prototype." Therefore, the generation of a model which may be adapted for any building project was a difficult process.

2. Problems were encountered in specification of project knowledge which is generated during the course of the project. In creating a generic model of the construction process, the identification of specific knowledge, information, and documentation was a challenge.

3. It was difficult to differentiate between inputs, controls, and mechanisms. The differences between inputs and controls was especially unclear in some instances, and many entities were shown to have multiple roles depending on the characteristics of the specific project.

4. In the initial phases of the model development, it was discovered that there was a tendency to lose the focus and viewpoint of the model unless continuously monitored. This led to several major changes in the structure of the initial model.

9.3 Application of the Integrated Building Process Model

In the manufacturing industry, the Manufacturing Architecture model was used to aid in the automation of portions of the manufacturing process [ICAM 1978]. Much progress has been made, and work is continuing in both developing the automation of tasks and integrating manufacturing facilities. Recent efforts encompass areas such as flexible manufacturing systems, robotics, CAD/CAM, CNC, Computer Aided Process Planning, Group Technology, and Automatic Storage/Retrieval Systems. For further information, see Mitchell and Barkmeyer [1982], Simpson et al. [1982],
Merabet [1984], Jorgensen and Alting [1984], and Albus et al. [1984]. Integration of these systems has been a major challenge in the manufacturing industry [Shafi-Nid 1984, Wisnosky 1984, Gondert 1984, Ellis 1984, Kelley 1984, Gale 1984, Vollum 1984, and Young 1984].

To facilitate computer integration of manufacturing systems, the definition of the common data structure and data format for communication has been a major area of research. IGES was developed to allow communication between different CAD systems to enable transfer of part definition data. The reader is referred to Smith and Wellington [1984], Schroeder [1984], Wilson [1985], Pratt [1985], Bloor [1986], Ames and Fletcher [1985], Cotter et al. [1983], Myer [1987], Palmer [1987], Stauffer [1985], and Wilson et al. [1985]. Recent development in PDDI and PDES further enables the transfer of information about a part, such as tolerances, dimensions, and manufacturing information [Elgabry 1985 and Carringer 1985]. Similarly, the building construction process may be integrated by enabling the transfer of information about a building. The intentions of the designer should be documented, the knowledge generated during the building process should be captured, and the history of the information generated about the building should be made available.

In the near future, computer communication will dominate the transfer of information in the construction industry. The structure of the data base should be established to facilitate the documentation and transfer of information about the building in construction and in operation. Many developments made in the manufacturing industry may be applied in the construction industry. Group technology classification and coding systems
may be established to store information about building structures and their components. Flexible manufacturing theories may be applicable to some areas of the construction industry such as formwork and stonecutting. Advances made in CAD and Computer Aided Process Planning may be applied directly to the construction processes, and integration of the entire construction process will be made possible through establishing a common data model.

9.4 Future Efforts

The objective of this report was to evaluate the various modeling approaches available and to propose a modeling methodology which would be appropriate for modeling the generic building construction process. After reviewing several modeling tools, the IDEF0 modeling methodology was recommended based on the selection criteria established by the project members. Since then the IDEF0 model has been shown to be successful in modeling the construction process, and the functional modeling step in this project is nearing completion.

The next step is to define the information and its attributes which support the building construction process. A generic information model will be developed to identify and document the information which define the building and its construction process. Advances made in the application of expert systems concepts in manufacturing will be applied in this part of the project.
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