THE LIFE CYCLE OF A METAL BUILDING

by

Kevin J. Norton
Sari A. Khayyal
Moris M. Guvenis
Joseph F. Sacchetti
Sunil EVT
Kamarthi Vidyasagar

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

Technical Report No. 8

July 1989

CIC

COMPUTER INTEGRATED CONSTRUCTION

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

THE LIFE CYCLE OF A METAL BUILDING

by

Kevin J. Norton
Sari A. Khayyal
Moris M. Guvenis
Joseph F. Sacchetti
Sunil EVT
Kamarthi Vidyasagar

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

Technical Report No. 8

July 1989

CIC

COMPUTER INTEGRATED CONSTRUCTION

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

FOREWORD

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

In this report, Kevin Norton, the principal author has examined the life cycle of a pre engineered metal building. Metal buildings are economically engineered buildings, typically used as single story commercial facilities between 25,000 to 150,000 sq. ft. This report is a stand alone document focusing on the provision of these facilities. It describes the metal building supplier's role and the contractors involved in its supply. We believe that these facilities can be further driven by the suppliers based on improved front end service to the community. This front end service includes management of the provision of the facility by the owner or general contractor from planning, through design, construction and operations.

Building Technologies' sales depend on the contractor's ability to successfully recognize and plan the facility that meets the owner's needs. This is typically an

Architect's job. Hence new contractors need extensive training, while current contractors need frequent auditing by an independent third party to ensure repeat business from clients.

This report is an application of the IBPM developed in Technical Reports 1 to 7. A brief overview of the IBPM is provided in Appendix D., but the full model should be read to draw all the implications possible.

It is envisioned that this piece of applied research reported by Kevin and conducted by the CIC research team, will lead to many future applications in the areas of contracting strategy and methods, information systems, organizational design, software development and process integration for the metal building industry.

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

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

ABSTRACT

Metal buildings and the industry which produces them are a well defined and well organized segment of the overall construction industry. Building Technologies Corporation (BTC) is a leader and major producer of metal buildings. In the quest to integrate the facility provision process, much could be learned from a close investigation of firms such as BTC. This paper discusses the various activities undertaken by BTC in the production and provision of their products to their customers and compares these to the traditional approach taken by conventional construction. To close, areas of possible improvement on BTC's part are presented and discussed.

ACKNOWLEDGEMENTS

The authors would like to extend thanks to the many persons involved in the CIC project as well as the development and completion of this report. On the industry side, we would like to thank, foremost, Mr. Marty Densmore of Building Technologies Corporation for providing us with an excellent report subject. His tremendous and contagious enthusiasm aimed at the entire CIC project has been greatly appreciated. In addition, special thanks are given to the personnel of BTC who took time away from very busy schedules to give us two days for interviews. Thanks go to J. R. Hanawalt, W. W. Wilson, and F. L. Terrell at the Washington Courthouse plant and to R. C. Ruble, D. C. Horton, J. P. McGuine, and R. S. Napolitan in Cincinnati.

On the academic side, our gratitude goes the members of the CIC research team, Drs. V. E. Sanvido, D. J. Medeiros, and S. Kumara. Their continual support and guidance were instrumental in this project and in the development of this paper. In addition, we thank Dr. Paul Seaburg for his comments and insights which have gone into this report. We must also thank the force behind the whole project, the National Science Foundation. NSF has provided the resources (DMC-8717485) so that this project could be possible and our educations continued and enriched. Our final thanks goes to Penn State and those people and organizations we have overlooked. Thank you to all.

TABLE OF CONTENTS

FOREWORD i

ABSTRACT iii

ACKNOWLEDGEMENTS iv

1.0 INTRODUCTION 1

1.1 The Metal Building Industry 1

1.2 Scope of Work 4

1.3 Reader's Guide 4

2.0 MANAGE FACILITY 6

2.1 Management of Metal Buildings 6

2.2 BTC's Product Management Process 7

2.3 Comparison to the Integrated Facility Management Process Model 8

3.0 PLAN FACILITY 9

3.1 Planning of Metal Buildings 9

3.2 BTC's Planning Process 10

3.3 Comparison to the Integrated Facility Planning Process Model 11

4.0 DESIGN FACILITY 11

4.1 Design of Metal Buildings 12

4.2 BTC's Product Design Process 12

4.3 Comparison to the Integrated Facility Design Process Model .. 14

5.0 CONSTRUCT FACILITY 15

5.1 Construction of Metal Buildings 16

5.2 Comparison to the Integrated Facility Construction Process Model 17

6.0 **OPERATE FACILITY** 17

7.0 **AREAS FOR IMPROVEMENT** 18

7.1 Management 18

7.2 Planning 19

7.3 Design 19

7.4 Construction 19

7.5 Operation 20

8.0 **SUMMARY AND CONCLUSIONS** 20

Appendix A Minutes of NSF-CIC Meeting with Martin Densmore A-1

Appendix B Visit to Building Technologies Corporation B-1

Appendix C Case Study Data: Metal Building Contractor C-1

Appendix D Computer Integrated Construction D-1

BUILDING TECHNOLOGIES CORPORATION
CASE STUDY

by K. Norton, S. Khayyal, M. Guvenis,
J. Sacchetti, S. EVT, and K. Vidyasagar

1.0 - INTRODUCTION

Metal buildings represent a well defined, well organized segment of the construction industry. Metal building manufacturers, such as Building Technologies Corporation (BTC), rely on general contractors, who are licensed to market their product, for sales. The resulting image of metal buildings and BTC depends on the success of the general contractor in providing the building owner with a facility that meets his needs. This report will attempt to identify ways that BTC can better serve their general contractors over the life of the facility, resulting in higher profits for the company. This report will:

- Orient the reader to the metal building industry
- Compare the metal building industry to conventional construction methods via the IBPM
- Define areas for improvement in the life cycle of metal buildings (i.e., how can Building Technologies increase the quality of their service, support general contractors, and improve profits).

1.1 - The Metal Building Industry

Prior to any discussion on Building Technologies Corporation's activities in the development and provision of their products, a brief overview of the metal buildings industry may be beneficial. This industry emerged at the end of World

War II out of a new area of construction represented by the use of flexible and economic metal building systems. Today, this industry is characterized by their wide variety of systems and the manner of selling their products. Unlike more "traditional" construction methods, these building systems are marketed, sold, distributed, and erected by franchised contractors trained by the manufacturer. This management method places the responsibility for the structure on one party -- the builder, who deals with the end user directly for better project control. There are currently about 30 or so individual manufacturers in the industry and despite competition, there is a high degree of integration and coordination between the companies.

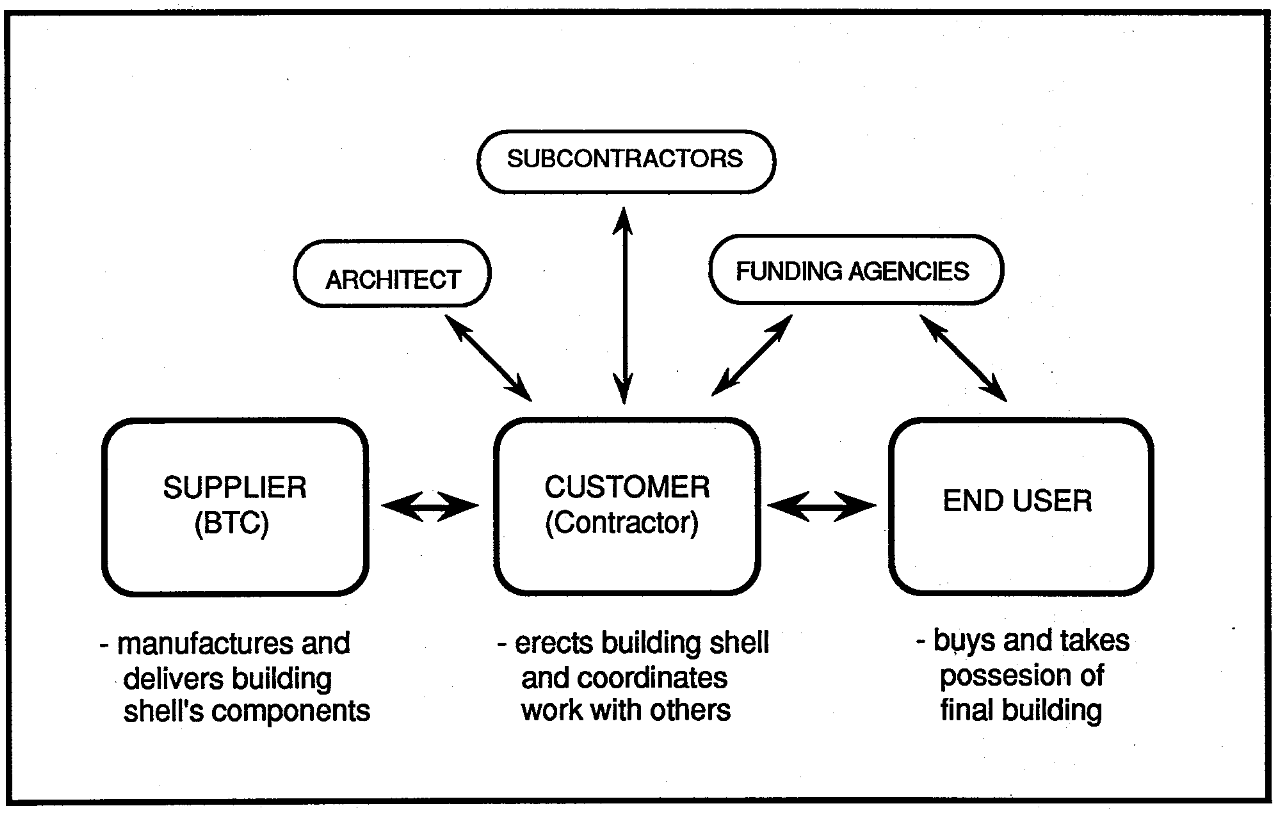


FIGURE 1: Principal Categories of Participants in the Metal Building Industry

As shown in Figure 1, there are three categories of participants in the metal building industry. The first is the supplier. This party (represented here by BTC) supplies the contractor with the building's structural frame and envelope. They are responsible for satisfying the codes specified by the general contractor. The second player is the customer (the general contractor) who must deal with the other involved parties such as the architect, the "supplier," any subcontractors, the final end user, etc. The customer is responsible for the erection of the building shell. The final category of participant is the end user. This party purchases and takes final custody of the completed building. This group deals only with the customer (contractor) and also defines the facility's functions based on the user's needs, wants, and abilities.

The stereotypical image of a metal building is probably a metal-clad, warehouse-type building. Though this structure was and still is an important part of the industry, it is by no means the only one. Appearances can be deceiving as the structure can be outfitted to handle almost any type of external material such as wood, masonry, and glass. At present, metal buildings make up about half of the low-rise, non-residential building market. These systems are in use today as offices, banks, shopping centers, showrooms, and other retail and service structures in addition to their industrial and institutional applications. The principal advantages of these systems are speed of construction and economy. Fast construction can reduce much of the financing and funding headaches which often accompany traditional construction methods. These buildings, typically, are very flexible and can be expanded quickly and simply catering better to tenant needs. Economies from predictable overhead costs, lower energy costs, and economical maintenance can contribute to cost savings by the users of these systems.

1.2 - Scope of Work

The authors of this paper are all involved in research of computer integrated construction. The drive of this research is to apply techniques and tools similar to those of computer integrated manufacturing to aid in the integration of the overall provision of the facility. The results of this research produced the Integrated Building Process Model (IBPM), which was developed to help understand the functions, activities, and physical and information flows involved in the complicated process of providing a facility. Figure 2 is a schematic tree showing the first three levels of the IBPM.

This research focuses on the management, planning, design, construction, and operation of a metal building. The information contained herein was obtained from interviews with Marty Densmore at Penn State University (Appendix A); site visits to BTC's home office in Cincinnati, Ohio and a fabrication facility in Washington Courthouse, Ohio (Appendix B); and site visits to Steel-Bilt Construction, a general contractor in Bridgeville, Pennsylvania (Appendix C). The IBPM is described in Appendix D.

1.3 - Reader's Guide

The remainder of this report discusses the various activities undertaken by BTC in the production and provision of their products to their customers. Each section corresponds to one of the five phases of a construction project as defined by the Integrated Building Process Model (IBPM). If the reader is unfamiliar with this model, please read Appendix D. Within each phase, the actual activities performed by BTC, if any, are described and compared with those of the IBPM. The final sections discuss areas of possible improvement on BTC's part and provide a summary of the paper.

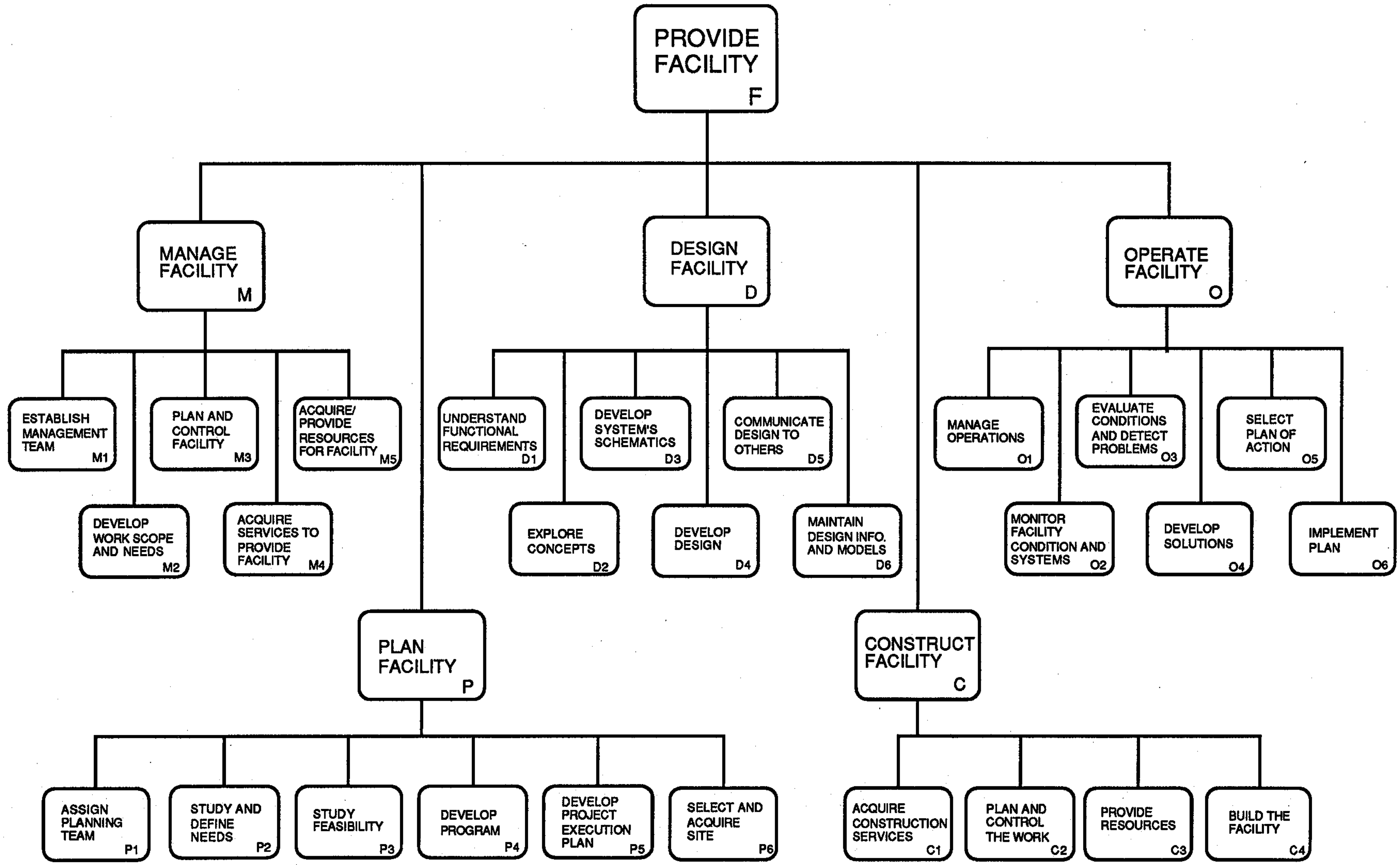


FIGURE 2: Schematic Tree of the Integrated Building Process Model

2.0 - MANAGE FACILITY

Manage Facility includes all the business functions and management processes required to support the provision of the facility, from its inception to its completion. It captures the generic ideas and the essential functions necessary for presenting an effective management process. It is separated into the following five subfunctions (M1 to M5):

Establish Management Team,
Develop Work Scope and Needs,
Plan / Control the Work,
Acquire Services to Provide Facility, and
Acquire / Provide Resources for Facility.

This function runs for the duration of the facility life and represents the activities required from the viewpoint of the facility end user.

2.1 - Management of Metal Buildings

Management and overall coordination of a project, from a life cycle viewpoint, begins and ends with the contractor. The general contractor manages the architectural aspects (taking the function and turning it into form) and with the overall provision of the facility (i.e. dealing with the codes applicable to a particular geographic area). BTC serves only as the producer of a highly defined product. The management activities performed by Building Technologies Corporation focus on their dealings with their customers, the 500-plus independent building contractors who deal exclusively with BTC and the Armco Building Systems. These activities are the company's internal management of the process and the production planning required to fabricate the metal building components. A description of how they manage the development and fabrication of a system is given below.

2.2 - BTC's Product Management Process

When Building Technologies receives an order, they first verify the description of the building, estimate the lead time it will take to deliver the components, and quote a price to the contractor based on the code requirements used. Once these activities are performed it becomes a matter of satisfying the design requirements set by the contractor's order and BTC's own design process. The outputs received from design are fabrication drawings and a bill of materials. The fabrication drawings identify each building item separately and in accordance to their manufacturing workcenter (i.e. grouping work items for manufacturing based on economic considerations). The bill of materials defines all the quantities used for a job, as well as the subassemblies that make up the various assemblies and components. Once the bill of materials is completed, the company uses interactive graphics / drafting to produce a set of erection drawings which show the layout of a building a piece at a time; this is done by coding numbers on parts for layout. This process is explained further in Appendix A.

Once the erection drawings are completed and checked, the manufacturing process (and the management of that process) begins for all the metal building parts. Normally, the company identifies similar manufacturing requirements to aid labor and process planning in saving set-up and manufacturing time (planning how the work will flow through work centers within the Building Technologies manufacturing facility). After fabricating, welding, finishing, and painting, the parts are packaged and shipped to their assigned destinations.

The general contractor assumes responsibility for the manufactured building items once they leave the plant. From this point on, it becomes a question of how quickly the general contractor or his subcontractors can erect the building. For details on what management activities are performed by the general contractor see Appendix C.

2.3 - Comparison to the Integrated Facility Management Process Model

BTC performs the activities of one node in our model of the management process. This is node M2: Develop Work Scope and Needs. Even this one node is not performed entirely by Building Technologies. They receive information from the general contractor and reinterpret it to fit their work modes and methods. Once the company gets the working drawings from the general contractor, the spans and dimensions of the building are taken off and analyzed to arrive at a structural framework / envelope for a building. Function M2.1, Understand Owner Needs, relates directly to the company's ability to understand and comprehend exactly the form and function that the owner intended. Function M2.2, Define Facility Work Scope and Needs, is accomplished by the company's fabrication drawings, the bill of materials, and the final erection drawings which are used by the general contractor. Function M2.3, Develop Strategy for Resource and Service Acquisition, relates to the companies own internal processing and labor plans for manufacturing the final product. The resources, in this case, pertain to the raw material supplies and the monetary funds which are obtained from the general contractor. BTC does not enter into contracts with its customers, instead it uses only purchase orders.

3.0 - PLAN FACILITY

The IBPM defines 'planning" as the development of the facility idea into a facility program, a project execution plan, and site information. These plans drive the remaining functions of Design Facility, Construct Facility, and Operate Facility by supplying them with some critical information. This phase is divided into the following six subfunctions (P1 to P6):

Assign Planning Team,
Study and Define Needs,
Study Feasibility,
Develop Program,
Develop Project Execution Plan, and
Select and Acquire Site.

Plan Facility clarifies the project requirements and the owner's constraints as well as provides the owner with the chance to influence the project through his decisions at this stage. It is typically performed by the owner, but may be performed by an external consultant depending on the nature of the facility and the owner's experience.

3.1 - Planning of Metal Buildings

Much of the planning of a metal building is performed by the end user and the general contractor prior to the building manufacturer being brought into the picture. In a general sense, planning a metal building is similar to planning almost any other type of facility. Once the facility needs have been determined, the end user may turn to a general contractor to assist him in the evaluation of a metal building as an option. The contractor assists the user in determining what physical characteristics of the structure (bay spacing, overall dimensions, exterior coverings, etc.) are needed or wanted. In some instances, the contractor may hire an architect to help with this. As a final step, an order is made to the manufacturer for the selected structure and shell.

3.2 - BTC's Planning Process

The term 'planning' within the Building Technologies Corporation context has the following two aspects:

- Strategic business planning
- Planning for plant expansion

Both of these aspects are oriented towards the manufacturing of metal building components, and neither of them implies the meaning of planning as understood within the life cycle of a project. Planning an end user's facility is not part of the work scope of the firm. This function is carried out by the end user and/or the general contractor. In other words, the planning process, as our model has defined it, takes place before the order is brought to the company. However, the planning is indirectly influenced in the following manner:

> Components for most of the commercial facilities are already designed, and are ready to be manufactured. On the other hand, facilities with predominantly architectural design may require additional component engineering and design, in order to meet the customer's requirements.

For that reason, catalogs on framing systems, covering systems and prices are prepared in order to give the customer an idea on what to expect and in which direction to plan (architecturally and structurally). These catalogs set industry standards for most of the metal buildings. Therefore, what the company has to offer to the market (or to the customer) can be an important consideration for the planning phase of a facility's life cycle.

3.3 - Comparison to the Integrated Facility Planning Process Model

Any comparisons which could be drawn between the IBPM and BTC's approach to planning would have to be considered hazardous. Due to the scope limitations of Building Technologies Corporation's planning process, no comparison will be drawn. As stated in section 3.1, it is typically the general contractor (BTC's customer) who performs the facility planning. These planning activities are defined and explained in Appendix C.

4.0 - DESIGN FACILITY

Design Facility, as identified by the IBPM, comprises all the functions required to define and communicate the owner's needs to the builder. It is broken into the following six subfunctions (D1 to D6):

Understand Functional Requirements,
Explore Concepts,
Develop System's Schematics,
Develop Design,
Communicate Design to Others, and
Maintain Design Information and Models.

Design is the method by which the needs, wishes, wants, and desires of the owner are defined, quantified, qualified, and communicated to other parties. Design must also take into account the demands society places on it. The activities of the IBPM translate the facility program and execution plan into bid and construction documents and operations documents which allow the facility to meet the owner's and society's needs.

4.1 - Design of Metal Buildings

As the summary of the visit indicates (see Appendix B), the overall approach in the metal buildings industry is shifting from supplying a stocked product to one of custom design and fabrication. Previously, a customer would review a catalog of available structures when a metal building was needed. The catalog represented the only options available to the customer. His needs had to be tailored to fit the available buildings. However, the trend today is toward more custom design and construction. Catalogs still are used but they provide only a base from which the design is begun. There are many options which can be added or deleted from any particular design. It is now the buildings which must be tailored to fit the needs. Coordination between the various designers on a project (i.e., the building manufacturer, HVAC designer, electrical designer, etc.) is usually the responsibility of the general contractor.

4.2 - BTC's Product Design Process

Presented below is a review of the discussion with J. P. McGuine, Manager, Front End Operations (November 18, 1988, BTC Headquarters, Cincinnati) about the design process used by Building Technologies. The headings represent the general 'phases' of design as applicable to and used by BTC's design staff.

Review of known information by the design engineers. Certain design parameters are readily available in-house such as available materials with their thicknesses, sizes, shapes, etc. Much of the information comes from the Order

Form filled out by the customer. The customer will often supply drawings or sketches of the desired building. The building description is also included (it may reference an earlier inquiry done by BTC). This step is analogous to function D.1, Understand Functional Requirements, of the Design Process Model.

Design of primary frame elements such as columns and beams. This step is the most time consuming; using 50 - 60% of the designer's time as well as 50 - 65% of the detailer's time. The design of these members is almost completely computer generated. First the nominal information is gathered and assembled from the previous step. Next, it is entered into the computer (a mainframe in this case) where the design is developed via an interactive, iterative program called Auto-Steel. This program designs within the constraints set by the designer, customer, and the applicable building codes. Special cases, such as craneway design, may be done in a PC environment.

Design of secondary frame elements such as purlins and girts. These are often taken straight off of design charts and are not usually computer aided. Wind and other loading checks, however, may done using personal computers, simply because done manually, they would be very time-consuming. The Front End Manager has 7 engineers working for him. A rough breakdown of their duties and workloads is given below:

Sales Service Engineer (1 person) is often the Head Designer who works with customers up front to help the customer determine what is wanted/needed.

The Estimators (1.25 people) review the customer's information and prepare the final detailed orders.

The Designers (4.75 people) perform the design of the ordered framing system.

Detailing of the design. The detailers get the design information from the designers to help in the production of fabrication drawings. These are most often done on the computer. Detailers will usually make the changes necessary for doors and windows or other customer changes. When the detailing is complete, the information is sent to the production plant and to Interactive Graphics (IG), a small computer graphics department within BTC. IG can produce detailed drawings if necessary. Fabrication drawings, the principal output of the design process, aren't necessarily to scale; they're only meant to be descriptive of the structural members and system. There is much less information on them than on typical shop drawings. There are 8 detailers on staff. The head detailer is often called the Schedule Coordinator. He/she maintains control on the designer's "production schedule" and is used at the front end.

4.3 - Comparison to the Integrated Facility Design Process Model

In attempting to compare this design process with the one in the Design Process Model of the IBPM, certain modifications to the latter will be necessary. These will take into account the inherent differences between design in the metal buildings industry and a "typical" design for an average construction project. A main point to note is that BTC does not perform coordination between the various discipline designers. This is the responsibility of the general contractor. As stated above, the first step in BTC's approach performs the activities of D.1 in the IBPM, Understand Functional Requirements. Here, the designers assemble any and all pertinent information about the proposed design before beginning the actual design. They establish the project objectives from the Order Form which gives them the customer's wants and needs. They also can determine the design parameters from the previously known parameters and constraints described above.

BTC performs functions D.2 and D.3, Explore Concepts and Develop System Schematics, respectively, at once. Many of the concepts and schematic designs are already completed through the customer's selection of a basic building arrangement from a catalog. It is generally only specific details or relatively minor changes that are required by the customer. Much of BTC's design activity takes place in function D.4 of the IBPM, Develop Design. This includes both the design and detailing of the proposed building. The detailers perform the activities of D.5, Communicate to Others, when they send the design to the manufacturing plant and to the constructor. The functions of D.6, Maintain Design Information and Models, are accomplished through the use of computer-based technology (i.e., design programs, pricing databases, etc.) in the design of the structure. The models of the various building arrangements, a variety of building codes, different loading configurations, and other similar data are stored in the computer system which assist in the design of the building.

5.0 - CONSTRUCT FACILITY

The IBPM describes the Construct Facility phase in terms of the following activities (C1 to C4):

Acquire Construction Services,
Plan and Control the Work,
Provide Resources, and

Build the Facility.

Building Technologies does not do any construction per se; all construction is performed by the general contractors. This appears to be the standard in the industry. Recently, the majority of the construction-type work performed by the company has been that of custom work, paralleling the trend in the industry's design process. In fact, approximately 80% of their orders are now custom building work showing that the industry is branching more towards the design-build method of construction. However, there are cases where BTC will do some construction related to the expressed warranties that go with their product line (typically replacements and/or repairs). These warranties cover such performance factors as corrosion resistance of roof panels, paint systems, and water tightness.

5.1 - Construction of Metal Buildings

The physical construction of metal buildings is rather straightforward. The general contractor will receive the structure and shell from the manufacturer with a set of erection drawings. These drawings show the relationships between the various elements of the structure and the part numbers. Typically, each component has a numbering or coding system on it which identifies the specific piece and its location in the structure. The contractor, or one of his subcontractors, then erects the shell according to the erection drawings. This usually occurs quickly and is one of the primary advantages of these systems over more traditional methods and systems of construction.

5.2 - Comparison to the Integrated Facility Construction Process Model

As stated above, BTC doesn't perform much construction at all. The little they do perform, would fall under node C.43, Do the Physical Work, of our model. Many of the preceding and following activities are "done" by default. Acquisition of services and resources as well as planning of the work is of negligible concern as BTC provides its own. Much of the work they do would be similar to replacing a faulty wall panel, repairing a leaking roof seal or seam, replacing an incorrect member, and the like. Overall, this work is outside of BTC's business scope and therefore was not considered to be a valid sample for investigation.

6.0 - OPERATE FACILITY

Operate Facility, as defined by the IBPM, includes the following (O1 to O6):

Manage Operations,
Monitor Facility Condition and Systems,
Evaluate Conditions and Detect Problems,
Develop Solutions,
Select Plan of Action, and
Implement Plan.

BTC plays no part in the operation of the structures they provide to their customers. To investigate the final workings of these buildings, the end users would need to be the focus of the study. However, since this is not the case, we have no information pertaining to this function and therefore no comparisons with the Integrated Facility Operation Process Model will be drawn.

7.0 - AREAS FOR IMPROVEMENT

This report is based upon our observations of the way the processes are actually performed when providing a metal building. Upon review of this report, it was brought to our attention that some of these suggested areas for improvement are covered by standard BTC procedures. In addition, BTC has made extensive investments in computerizing their design and manufacturing processes. Our report and suggestions are based on our findings as evidenced by the data collected. Below are possible areas within BTC's methodologies which may benefit from some improvement efforts on BTC's behalf. They are divided into the IBPM phases of the construction process. If solutions to these suggestions exist, we recommend that action be taken to ensure they are implemented.

7.1 - Management

We feel that there is something lacking in BTC's present approach to the management of the projects they supply. This is in the area of customer (contractor) support. At present, the project management is performed by the contractor in the field (covered in more detail in Appendix C). Building Technologies could improve their customer support by providing their expertise in the form of guidelines for the contractor included in BTC's training courses and programs. These guidelines could assist the contractor in the overall management of the process including the planning, design, construction, and operations of the facility. Specifically, these would help in the hiring and coordination of consultants, designers, subcontractors, and other parties.

7.2 - Planning

While BTC's sales engineers do call on potential customers to provide information which could influence the design and they do have a standard planning guide, we feel that BTC could provide contractors some guidance on the planning of a facility. This guidance should tell them how to achieve the functions in this part of the IBPM and when to get external assistance from architects, consultants, and engineers. This includes advice on defining user needs, site selection, feasibility, programming, etc. This guide will be useful if it informs the contractor of a need or a key function that must be performed and where to get help doing it.

7.3 - Design

BTC performs almost all of the activities of design as described by the IBPM with the modifications explained above in Section 4. Again, because of the way this industry operates, major changes in their design methodologies are not necessary. One main suggestion we have for the design phase is for BTC to take a leading role in the integration of the discipline designs. BTC could use its experience and knowledge in computerized design to coordinate the various designers on a project. One possible method may be a network of designers all using shared databases. These databases could be the basis for three-dimensional modeling of the structure.

7.4 - Construction

Building Technologies needs to look at branching into the role of construction manager. The company has the manpower, knowledge, and the efficiency to provide an excellent service on the projects in the field. In addition, BTC could establish guidelines to assist the contractor in the ordering, delivery, and erection procedures commonly used in the industry. The process of building metal buildings is fairly simple and the coordination involved in providing a facility is fairly straightforward. By moving in this direction, buildings will be built quicker, meaning sooner beneficial occupancy and, at the same time, costs will be reduced. Building Technologies would benefit because they will have a more integrated information flow and, simultaneously, it will refine their Just-In-Time processes. In addition, Building Technologies will also enhance their abilities to accommodate changes throughout the life cycle of metal building development.

7.5 - Operation

Metal building warrantees provide specific end use support. Certain structural features, such as interior frames for endwalls, are intended to facilitate future expansion. The manufacturer's files provide excellent documentation of structural load capacities that would be very helpful for any structural changes. BTC support of the end user via manuals and guidelines covering their product could be beneficial if the user decides to alter the structure after it is in operation.

8.0 - SUMMARY AND CONCLUSIONS

Geared toward the low-rise, non-residential building marketplace, metal building systems provide an owner with a variety of alternatives to meet their building shell requirements. The principal advantages of these systems over traditional construction approaches are rapid speed of construction and cost economies from known and/or lower costs. Building Technologies Corporation is a major company in this industry and, as such, the activities it performs as it provides its products are especially interesting to our continued research into computer integrated construction.

The IBPM defines and describes the process of facility provision. This process is divided into five subprocesses covering the entire life cycle of the facility from initial conception through final demolition. The five subprocesses are manage, plan, design, construct, and operate the facility. Even though the IBPM was developed along the lines of a "traditional" approach to this process, only minor changes in the model are necessary to take into account the inherent differences between the traditional and the metal buildings approaches. As explained in the preceding sections, BTC performs at least some aspect of the first four functions to varying levels of detail. They presently have no role in the operation of the completed structure. The principal function into which BTC directs much of its time and effort is the design and manufacturing of their products. BTC's design process is also highly computerized and integrated, drawing heavily from such computer integrated manufacturing practices as group technology and numerically controlled equipment. In fact, their activities in the remaining functions (manage, plan, and construct) are all off-shoots of this approach.

The suggestions for improvements we have put forth are extensions of present BTC activities or expansion into possible new areas rather than changes to their present methodologies. Due mainly to the nature of their industry, BTC can't readily change their methods without major disruptions to their operations. The suggestions center about one basic idea; support of other parties. BTC can go for a broader service base through the support of IBPM phases. The facility management phase will benefit by better guidelines for the responsibilities in the remaining four phases (planning, design, construction, and operations) and ways to meet them (e.g., hiring architects, planners, consultants, subcontractors, etc.).

Planning the facility could be improved through support to those parties performing the project planning. Guidelines explaining the importance of site selection, how to conduct feasibility studies in the metal buildings context, and other similar activities would be useful in identifying a need or an activity which must be performed in this phase. Improvements in the design of the facility may be possible through better coordination of the designs and designers. BTC could be lead the effort in a shared database environment linking each discipline's design by applying their expertise in computerized design. Both construction and operations would benefit from guidelines aimed at the general contractor. Those for construction may focus on ordering and delivery of materials as well as erection procedures. Assistance in this phase could enhance one of the metal building's advantages; rapid construction of the structure. Operations guidelines would be geared to the end user and could be used in the startup of the facility and would prove valuable should an expansion of the facility be necessary. Each of the benefits from these phases will reflect back on the company as increased orders and additional services. BTC already has the know-how and experience in these areas and could benefit greatly from exploring these suggestions.

APPENDIX A

MINUTES OF NSF - CIC MEETING WITH MARTIN DENSMORE

by J. Sacchetti and K. Norton

Date:	Wednesday, October 12, 1988
Time:	10:30 A. M.
Present:	M. Densmore, V. Sanvido, S. Kumara, D. Medeiros, S. EVT, M. Guvenis, S. Khayyal, Kamarthi V., K. Norton, J. Sacchetti

Introduction

* Marty Densmore, Vice President, Building Technologies Corporation

* Each person present was introduced and commented on his participation in the project.

* Explained to Marty how functional teams were made up such that there is one I.E. and one A.E.

* Explained project summary; use technical report as a guide for questions in Part II of the project. Management, Planning, and Design all use fewer people (than Construction) but make key decisions. We must find out **how** and **why** they make these decisions.

Marty Densmore Introduces Building Technologies Corporation

There are three categories of participants in the metal industry:

(1) End User The group that purchases the building and takes custody of it. Deals only with the Customer (General Contractor). This group defines the function of the facility: his needs,

wants, and financial matters are all handled by the general contractor.

(2) Customer Is the general contractor and deals directly with the architect and other parties including Building Technologies. The general contractor deals with codes (i.e., Building, Zoning, etc.) and other geographically related data. There are approximately 1135 general contractors that deal with Building Technologies Corp.

(3) Supplier This group is Building Technologies Corp. They supply the Contractors or customers with the structure and envelop of the building (17% of "final cost"). Responsible for satisfying the codes specified by the general contractor. This is $135 million in annual values for Building Technologies.

About Building Technologies Corporation

* There are about 32 companies in this category (MBMA).

* Constitutes for about $1.5 billion in business.

* Most structures are one single story non-residential buildings which are about 25,000 sq. ft.

* This type of construction is faster than conventional types of construction.

* Material Costs are similar to typical costs of construction.

* Can supply for any order between a 4' x 4' x 8' facility to a facility with a 260' clear span.

* The price will depend upon the size, codes, and warranties.

* The quality depends on the end user's wants and choices.

* Lead time is usually between 4 and 10 weeks (The Life of an Order).

* The prices and the time to supply the structures is generic and is given to the general contractors periodically. The general contractor can then give time and price quotes to many end users from these general guidelines.

<u>The Life of an Order</u>

Week 1

* Get an order ==> verify order by quoting price, lead time, and description of building.

* Structural Size Function ==> take information and begin dealing with major frame components such as frames, rafters, and columns (codes govern intensities and combinations of loads). This may include cranes, etc.

THIS PROCESS TAKES ABOUT A WEEK OVERALL AND STRUCTURAL ENGINEERING IS RESPONSIBLE FOR THIS.

Week 2

* Must look at costs ==> Flange material - $400 / ton
  Web material - $550 / ton

* Once the frame is done ==> secondary systems such as purlins, longitudinal bracing, and covering panels must be taken care of. This system uses 2/3 of steel by conventional methods.

* There are five major computer tools used for this.

Detailing Function - Engineering requirements are turned into:

* Fabrication Drawings - defines each subassembly. Lengths, widths, weights; also goes to manufacturing plant (6 per member).

* Bill of Materials - defines all parts of building to contractor: listing of piece number; and also goes to manufacturing plant.

* Erection Drawings

THIS PROCESS TAKES ABOUT A WEEK OVERALL

Interactive Graphics/Drafting

* Use stick plan to show how and where individual pieces go together. This goes to the general contractor.

The remaining 4 weeks of the life cycle is in **MANUFACTURING.**

Week 3

Material and Process Planning:

* Planning how material will flow through workcenters in the facility.

* Look and concentrate on material utilization and labor efficiency.

* The workcenters are as follows:
    1. BAR-PREP (SHEARING)
    2. WELDING
    3. PUNCHING
    4. BRAKE FORMING
    5. ROLL FORMING
    6. PAINTING
    7. PACKAGING
    8. SHIPPING

Week 4

* Welding of subassemblies.

Week 5

* Welding and fitting to create assembly/finish welds.

*** Panels and purlins are done around weeks 5 and 6.

Week 6

* Painting, packaging, and shipment.

Additional Information

* An approval cycle (especially for larger projects) may occur between weeks 1 and 2.

* Generally, the contractor can begin site prep before having the building present but a permit is needed for above-ground work.

* With regards to interior of building; BTC provides some interfaces such as insulating systems. They don't go into HVAC, electrical, plumbing, etc. The general contractor deals with these disciplines.

* There are two types of Warranties that BTC offers:

  (1) Implied — Limited by definitions from codes. Issues of workmanship and design quality are dealt with.

  (2) Expressed — Guarantees for corrosion resistance of paint coatings/paint performance (color), water/weather tightness (roof especially).

* BTC holds educational seminars in:
    (1) DESIGN
    (2) CONSTRUCTION
    (3) MARKETING
    (4) MANAGEMENT

* BTC is evaluated against cost effectiveness, delivery of product, and structural services.

* BTC transports within a 500 mile sphere around each factory and only add 2% overage in parts (very small). Cube out before weight.

* New products in this industry will never be an overnight success. As an example, the standing seam roof which is just beginning to become popular was introduced at the 1934 WORLD'S FAIR. This took more than 50 years.

* Claims on BTC have been very small. The current statistics show that over the past three years, 0.49% of the company's income has gone to claims. This is about $650,000/year.

* Of the 6000 projects per year, there are about 21 active claim cases at present.

* There are three plants that have 110,000 tons of product/year.

* BTC buys materials 12 weeks ahead of scheduling.

*	Member cost	75% Material
		25% Labor
*	Envelope	96% Material
		4% Labor
*	Structural Sections	50% Material

50% Labor

Conclusion

BTC was an operating subsidiary of Armco. Ten years ago, 88% of materials came from the parent company. Now, only 17% comes from the parent company. Reason for this is because BTC is aiming at better materials and they want to broaden their product lines. The strength of BTC comes from the general contractor because they do not advertise a lot (less than 1% of the budget), so if the end user is satisfied, the general contractor is satisfied, therefore making BTC satisfied. BTC seldom deals with the end user unless it is a very big account.

APPENDIX B

VISIT TO BUILDING TECHNOLOGIES CORPORATION
(CINCINNATI, OHIO)

By : Sunil E.V.T.
Present: Joe Sacchetti
Kevin Norton
Moris Guvenis

Thursday (11/17/88) : Washington Courthouse Manufacturing Facility.

2:00 - 2:15 pm: Meeting with M. D. Densmore (V.P. Operations), J. R. Hanawalt (Plant Mgr.), W. W. Wilson (Superintendent).

2:15 - 4:00 pm : Tour of the facility with F. L. Terrell (Quality Control Supervisor).

Products Manufactured at the facility:

1. Steelox roof panels and wall panels -- 40%.
2. Rafters and Columns (Flanges, Plates, Webs & Clips) -- 25%.
3. Z's -- 18%.
4. Connectors (Gutters, Base Channels etc.) -- 10%.
5. Accessories (Doors, Windows etc.) -- 6%.
6. Pipes -- 1%.

Raw Materials used at the facility:

Aluminium sheets, Galvanized steel slabs and plates, steel cables, Aluminized steel, Zinc Aluminium alloys.

Processes employed:

Welding, Cutting, Burning, Bending, Drilling, Embossing, Assembly.

4:00 - 5:00 pm: Discussion with Wilson W. (Superintendent).

Company Operations and philosophy:

* Company operates in weekly time segments. Short term planning is done for the next week. Reports are processed at the end of the week.
* Goal of Manufacturing is to finish processing a particular order on the Friday prior to shipping week.
* Annual Objectives:

	Objectives	(Achieved in '87)
Yield (on raw material) :	95%	(96%)
Man-Hours / Ton :	9	(8.65)
Employee Safety :	(zero accidents)	
Cost / Ton of production	$272	($264)

  The cost per ton objective is estimated using expense account information, salaries, utility bills etc.
* Current objective is to reduce administrative costs.

Flow of Order :

* Designs from Engineering are rough and outline. The production control in Engineering schedules every bit and piece of an order. They consolidate like parts to take advantage of length of weld table and fill the schedule efficiently.
* Order Form contents include Order Number, Shipping Date, Customer Information, Pricing Summary (from manual), Structural Frames requirement.
* Detailer details bits and pieces on the order according to engineering guidelines. He produces manufacturing requirements of parts, associates an order number with each part of the order.
* An order is complete when all parts with the order numbers are ready.
* Example flow of Columns and Rafters through Manufacturing:
  1. Weldment
  2. Raw Material Inventory
  3. Shear Punch CNC
  4. Temporary Storage
  5. Automatic Weld
  6. Tack Weld

7. Finish Weld
8. Load Dock.

* One truck load is treated as one order number in Manufacturing an order.

Information Flow:

* Fabrication Drawings (from Detailer & Engineering to Manufacturing).
* Manufacturing Reports for each major product category (from Manufacturing to Management)
  Example:
  Panel Report (information on roof, sculptured, and nestable panels):
  - Quantity of each by color.
  - Order number.

Computer Applications:

* A database on monthly production by gross weights, lengths, raw material yield is maintained. Measures of performance currently used are (in actual order processing): CAP (capacity) using data from Engineering, Sales and Manufacturing, and MEA (measured). Any serious discrepancy indicates a need to change the capacity.
* COALS (Computer Order Analysis & Logging System) is used to generate reports and schedule manufacturing operations.
* ARW is used to solve cutting-stock problems. Optimal cuts are determined in order to obtain required paneling footage from the sheets of the raw material.
* SCULP is used to help in detecting trends in backlog of production by Purchasing, and hiring/layoff planning by personnel.
* BOM (Bill Of Materials programs)is used to determine freight, weight, description, parts, grade, color etc.
* ESP (Express Systems Pricing) used by Sales and Purchasing department to estimate order costs.

Friday (11/18/88) : Cincinnati Office, Ohio.

8:30 - 9:15 am : Discussion with M. D. Densmore.

* The MBMA (Metal Building Manufacturers Association) has 27 member companies. One important area of collaboration is in corrosion resistance study of roof and purlin.
* Insurance facts and quality of structures are of consideration from risk point of view. Metal buildings are Class 3 (Non-combustible construction) according to insurance ratings.
* Aluminium steels are very useful as roof material due to excellent corrosion resistance.

9:15 - 10:45 : Discussion with R. C. Ruble (Mgr., Product Eng.. & Dev.).

* New ideas for products come from customers, competitors, design codes (AISI codes), and within the company.
* Trend in metal building industry is moving from stocked approach to custom built.
* Checklists which include information on economic feasibility, scope, services needed, etc. are used for product development.
* Five-digit part numbers which can be significant or nonsignificant are used for products. The aim is to use all significant part numbers to avoid the need for fabrication drawings.
* Product subsystem programs are developed to aid in purlin design, coverings, girts/frames.
* Computer tools are provided for design and engineering.

10:45 - 11:30 am : Meeting with D. C. Horton (G.M., M.I.S.).

Subjects discussed:

* Computer systems used by company and interfacing problems.
* Hardware and software support.

1:00 - 3:00 pm : Meeting with J.P. McGuine (Mgr., Front End Operations).

* A typical metal building is non-residential and low-rise.
* Building inquiry (from contractor) and pricing takes 1-3 days. Finishing the processing of an order is about eight weeks. Overall lead time is 5 to 10 weeks.

* Price of metal building supplies (structural, roof+wall covering) to the contractor is typically 10-12% of total contract price.
* Design has to comply with uniform building codes (BOCA).

3:00 - 4:00 pm : R. S. Napolitan (Mgr. S.C.).

* Product pricing in Building Technologies Corporation is both manual and computerized.
* ESP is used extensively in product pricing. Coming up with estimates for each order takes about 10-30 minutes . It is also easy to update changes in the company pricing policy.

4:00 - 5:00 pm : Summary and wrap-up by M. D. Densmore.

APPENDIX C

CASE STUDY DATA

METAL BUILDING CONTRACTOR

Subject: Interview with Mr. Ray Tucker, President
Company: Steel-Bilt Construction
Date: December 2, 1988
Location: 10 Carol Avenue
P. O. Box 397
Bridgeville, PA, 15017

M1 Establish Management Team

This function establishes an initial project organization as a steering team / committee. They develop a detailed work plan. This function also assesses internal resource capabilities for possible incorporation in providing the facility. Additionally, a project brief is established so that a program for further action can be made (i.e. a determination of site ownership, boundaries, and rights of way). Essentially, this function serves to form the initial strategy by setting the initial objectives, and it also surveys internal resources available for possible incorporation / aid in providing a facility.

Input: Facility Idea

Steel Built recognizes the need for a facility through phone calls they receive from owners. In most cases the owners already have a clear concept on what they want in terms of a pre-engineered metal building, and when this is the case Steel-Bilt is capable of giving the owners an initial quote on cost (usually dollars per square foot). This initial contact is then followed by an initial preconference meeting to clearly define the purpose of the facility.

Input: Resources

Steel-Bilt's main resources are its people. They are a small organization, and this allows every team member to be fully familiar with the other team member's work responsibilities and functions. However, for every job there is only one person that is held accountable for its planning and control.

Control: External Constraints - Resource Availability

There are no major constraints which affect Steel-Bilt in establishing a management team.

Output: Internal Capabilities / Resources

In some cases Steel-Bilt is confronted with situations whereby owners request that they use their own subcontractors to perform parts of the work (in most cases this is due to a relative or friend of the family who requests to have part of the work).

Output: Facility Management Team

The management team is composed of four main categories of personnel. Steel-Bilt retains an estimator, a construction supervisor, a structural engineer, and a salesman.

Mechanism: Facility Champion

Mr. Ray Tucker was identified as being the facilitator that brings about solutions from people (both external and internal to the company). The key facility champion is the owner of the facility, he/she holds the ultimate responsibility for following the facility to its completion.

M2 Develop Work Scope and Needs

Involves defining the proposed work as completely as possible. The scope of work defines what is required of all parties in the project, the services that each will provide, and the type of support each can expect from the owner. In addition, the owner's needs are defined and classified based on their priority. Once there is a clear description of the work and people involved in providing the facility, a policy/strategy is developed for resource and service acquisition.

Input: Needs

The needs of owners are developed through the use of a standard planning guide created by Armco Building Systems. The main advantage the guide serves the owner is that it makes the process a little easier, and it also serves to get questions answered ahead of time (this always relates to the physical requirements of a facility as well as the site surroundings). Once the work scope of a facility is defined, the performance requirements of the owner are passed on to the subcontractors performing the work.

Input: Resources

As far as financial requirements are concerned, Steel-Bilt usually obtains a letter from the owner's bank stating that there is sufficient money available for building a project; for big companies this requirement is waived due to their financial stability. Steel-Bilt expends man-hours in their efforts to collect the information relating to the work scope of a facility, in addition to the process of developing a strategy for resource and service acquisition.

Control: Working Plans

Steel-Bilt does not have any set of written guidelines to follow. Mr Tucker was quoted as saying: "Everyone says we should [have working plans] but we have never done it, we are just too small. If you put it [guidelines for executing control plans and work coordination] down on paper and try to follow it, it will never work out."

Control: External Constraints - Codes and Economy

Codes and insurance were cited to be the two main constraints which kept the firm from following through with the initial facility work scope requirements. For special buildings with high insurance requirements (i.e. an airplane hangar where the value of the plane is greater than the value of the hangar) a check is performed to ensure that no items are left out which the owner's insurance carrier may want. For codes, all drawings have to be submitted to the Department of Labor and Industry in Harrisburg.for approval. The firm does not do local building permits, they prefer that the owner handle them due to the large number of communities and the many different requirements each imposes.

Control: Performance Information - Project Execution Plan and Program

In the case where the job is small, Steel-Bilt performs their own in-house design (they do everything except for plumbing, heating and electrical), but in the case of large complex jobs an architect is hired. The architect's responsibility is to provide working specifications and working drawings. For jobs where an owner has concept drawings in hand, the drawings are given to local architects who then redesign the concept of a particular facility to meet the local codes (i.e. the proper traffic flow, proper parking, proper sprinklers, etc.). Once Steel-Bilt receives the working drawings and specifications they are then sent out to the subcontractors and Armco Building Systems to get firm bids. There are no set milestones that come with the execution plan and program, instead they are dependent on Building Technologies' delivery schedule (approximately six weeks). Once the building components arrive at the site, a milestone schedule is made for completing the facility (i.e. dates are set for building frame erection, and the building envelope, etc.).

Output: Facility Planning Information

The main information used by Steel-Bilt for further execution of their work is the erection drawings furnished by Building Technologies (subsidiary of Armco Building Systems). The drawings show the erector the exact locations of each part number furnished by Building Technologies, as well as how each part fits together. For bigger jobs with more complex systems, mechanical and electrical engineers are hired to furnish the respective drawings required for building a facility. In the case of small jobs, the mechanical and electrical drawings are made by the subcontractors hired. Steel-Bilt tells the subcontractors what is needed and where everything should go (i.e. a duplex outlet on each column) only.

Mechanism: Facility Management Team

The team members hold no titles, they all work as a team for everything. Each person on the team is familiar with the other team members' duties. The firm is so small that there is an overlap of responsibilities. They employ three people to do their in-house work and two people to control the field operations.

M3 Plan / Control Facility

The planning process includes: developing plans for resource acquisition, plan execution, and controlling of the facility; setting the methods, sequences, schedules, budgets, and quality of output from each of the technical phases. The control function continually monitors the actual performance, compares it to the planned performance, and plans and implements any changes found necessary.

Input: Resources

The initial resource element used to evaluate how Steel-Bilt is going to plan and control their work is the delivery date of the metal building items, which is given to them by Building Technologies. With this date, Steel-Bilt has to have the drawings finished, the foundations and floor poured, along with site level alterations (usually it is a 6-8 week period). For large jobs a schedule is made up to coordinate all the subcontractor activities, but for small jobs no schedule is used and the subcontractors are kept abreast of development based on their own site inspections.

Control: Facility Planning Information

The type of data that Steel-Bilt uses for monitoring and evaluating their work is their "break-out sheet" which is crafted from the drawings created. This essentially is a work breakdown sheet whereby every work item is broken down by cost. The break-out sheet serves both their accounting and plan / control needs. At the job meetings the company checks on the progress of the work items - the completed items are checked off and they are in turn billed to the owner. The owner receives the bill along with the cost breakdown of the completed work items.

Control: External Constraints - Resource Availability

Mis-fabrications, unions, price adjustments (by Armco Building Systems) and weather problems were cited as being the biggest constraints affecting their ability to plan and control the work. The president said. "When you have too many factors or variables, you can never control everything or plan for anything correctly, you are dealing with constant change."

Control: Performance Information

Steel-Bilt checks the progress of their management activities by: 1) comparing budget numbers from previous jobs, and 2) comparing the pricing sheet with Armco Building System's bill to see price differences. They check that their prices are at the market rate. The degree of detail of this feedback information is high, because each building piece is measured and priced individually (i.e. doors, windows, siding, roofing, columns, anchor bolts, etc.). The frequency for obtaining the performance information is related to the completion of each individual job. They take each job on its own merit - concurrent jobs are not compared. The president said, "All jobs are different and they are all too special." He backed this statement up by saying that 80% of all of Building Technologies work orders for buildings are special. At the same time the president said, "You don't want to price a custom building just by throwing a dart at the wall."

Control: Optimization Information

Optimization information is not used frequently by Steel-Bilt (metal building technology has not changed much), but there have been instances when it has occurred. As an example, they had field erection problems with a particular type of window manufactured by Building Technologies. The field crew was adapting a window to fit its allocated working space. This was remedied by having a Building Technologies representative inspect the site. The representative, after inspection, determined that the window was manufactured wrong and he then rectified the problem with their window supplier. In other situations, Building Technologies mails out flyers showing new products and new methods on improved construction techniques (i.e. a new clip, methods of fastening, or new bolts made from stronger materials, etc.). Generally though, the feedback is constant all the time. It's a two way street for all parties concerned in relation to optimization information transmittal.

Output: Facility Management Knowledge

All knowledge that the project personnel gain through job experiences is captured intuitively - there is no written information that is used for accumulating a knowledge database for future jobs. The exception to this would be similar jobs with cost information in the form of a work breakdown sheet.

Output: Facility Management Plan

Steel-Bilt's plan of action for coordinating the work is very flexible and informal. It's informal in the sense that they play everything "by ear," and it's flexible because they allow the subcontractors to do their work as they see fit - Steel-Bilt only gives them a start and finish date for each subcontractor activity. As far as directives or changes are concerned, they are taken care of at the weekly job site meetings. The meetings are attended by: the Steel-Bilt representative, the architect, the owner, and all the subcontractors currently working on the job. In the case of small jobs, the job site meetings are bypassed and are considered irrelevant.

Mechanism: Facility Management Team

See M2 Mechanism

M4 Acquire Services to Provide Facility

This is the process of soliciting the required services to provide the desired facility and assembling the facility team. These services include planners, designers, constructors, and facility management personnel. These services are not usually, but occasionally may be, acquired at the same time. For the management phase, this function includes all contracts and agreements, between owner and designer, contractor, operator, etc., (this does not include subcontracts between designer or contractor and subcontractors) that are made for providing a facility.

Input: Resources

The people resources that Steel-Bilt acquires for providing a facility to a client include any discipline or trade that the owner may want. All types of subcontractors are acquired. The services are acquired once initial drawings are completed by Steel-Bilt or by the Architect should it be a large job.

Control: Facility Management Plan - Contract Plan / Changes

The type of contract changes that are usually made on most jobs include: adding a room, dressing up a building, adding carpeting / vinyl tile, adding an extra garage door, etc. A cardinal change for a metal building would be stepping outside the set building size originally agreed upon with the owner. As an example of a change - adding a garage door addition - Steel-Bilt would have to price in a framed opening from Building Technologies, they would have to draw up the structural drawings for it, and the erector would have to give a price to install it. They would also have to get the price of a garage door from a door subcontractor. Once all the prices for the change are computed, the price is given to the owner for approval / disapproval. If the owner agrees to a change then an addendum would be written into the proposal and the owner would sign it or he / she would send a change order. Steel-Bilt would then contact Building Technologies to add a new door opening and the affected subcontractors would be sent a change order. Usually changes have no impact on Steel-Bilt's service acquisition efforts.

Control: Facility Planning Information

The specifications are the main information element used to determine which services are required for providing a facility.

Control: External Constraints - Resource Availability

Generally, Steel-Bilt has no problems acquiring any of the services they need. The key factors they check on prior to acquisition of a service is based on their own feelings of a particular service's past experience, as well as word of mouth on past performance of subcontractors.

Output: Documents and Contracts

Steel-Bilt only uses purchase orders as the mechanism for acquiring services. Normally, the subcontractors will send a proposal and if its lengthy then Steel-Bilt will issue a purchase order with a reference to the proposal sent, this way the scope of work is clearly defined in the purchase order.

Output: Facility Team

The type of outside services they do not wish to acquire are those involving landscape work and equipment selection. Steel-Bilt only likes to deal with those services which have known end results. In regard to equipment selection they prefer to have the owner choose the equipment he/she desires (used mostly for cranes), this way there is no room for dispute with the owner. Steel-Bilt helps make contact with the particular equipment manufacturer desired. Participants are brought on board based on the progress of a job. Steel-Bilt likes to send out all the purchase orders as soon as they know they have a job. This way all the parties concerned are made aware that they have been selected and the job can be discussed with greater ease, should any changes develop

Mechanism: Facility Management Team

See M2 Mechanism

M5 Acquire / Provide Resources for Facility

This is the process of acquisition, allocation, and the distribution of resources required to provide the facility. Resources include the necessary information, financing, funding, time, site, material, equipment, manpower, and operational support resources. This process also includes storage of the resources and management of the inventories (ensures delivery of services/resources - expedites, tracks, pays, and examines quality of items received).

Input: Resources

The main resource acquired is funding from the owner, and in some cases a loan is obtained from the bank for purchasing / leasing of equipment .

Control: Facility Management Plan - Resource Acquisition Plan

Steel-Bilt's plan for resource acquisition takes the form of a recapitulation sheet which lists all the building requirements and elements required for ordering items. The sheet is broken down by trade and discipline as they pertain to the subcontractor affected (i.e. Heating - John Smith Heating Company).

Control: Facility Planning Information

A standard form is used to keep control of all the resources acquired. The form will take into account all categories of work and all messages sent to and from the various subcontractors involved on a particular job. Steel-Bilt also maintains a file for each job so that all the paperwork is processed efficiently.

Control: External Constraints - Resource Availability

Steel-Bilt did not have any factors that would keep them from following through on their various resource acquisitions with the exception of forgetting something. The main assessments they make on selectiveness of their purchases relies solely on the recommendations of the subcontractors they have hired. Steel-Bilt does not use proprietary specifications, they prefer performance evaluations of systems from subcontractors instead.

Control: Documents and Contracts - Contract

In Steel-Bilt's case all agreements made involve purchase orders. For resources this involves the transmittal of catalog cuts between and among:

subcontractors, Steel-Bilt, and the owner. Once the decision by the owner is made as to the resources desired a purchase order is made out to the affected party.

Output: Resource Acquisition Information

In relation to information on inventory it is usually outdated. Steel-Bilt does not list resources that are left over from jobs. They only make a once in a year check on all items they have stored in their bins (open bins filled with Building Technologies standard parts that are stored in their warehouse) and this check is only conducted for insurance purposes.

Output: Available Resources

Material resources are distributed to subcontractors on an as needed basis for items that would pertain to warranties - this is done because Armco Building Systems backs up their products for leaks, rust, etc. These material resources include: flashing, curbs, stainless steel screws, caulking, etc. As far as funds are concerned, subcontractors are paid monthly based on progress and the owner is billed once a month for completed work.

Mechanism: Facility Management Team

See M2 Mechanism

APPENDIX D

COMPUTER INTEGRATED CONSTRUCTION

INTRODUCTION TO THE CIC PROJECT

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

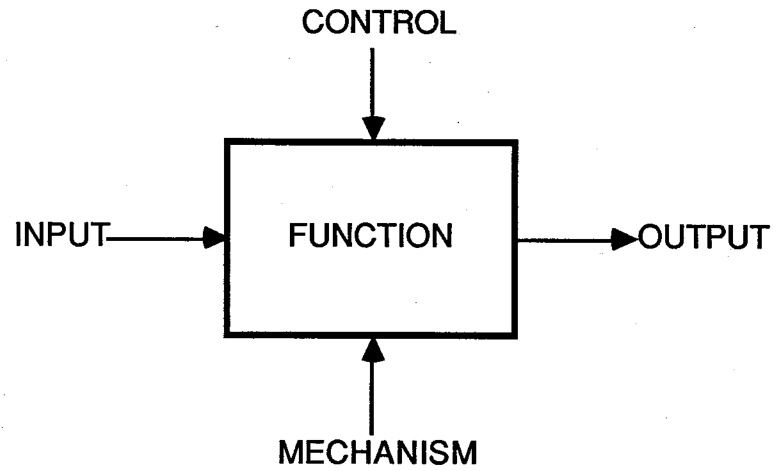
As the first major thrust of the project, we developed an Integrated Building Process Model (IBPM) that accurately represents the essential functions required to manage, plan, design, construct, operate and maintain a facility. The second half of the project, based on the IBPM, is to define the information and its attributes that are required to drive the system. The major benefit of this exercise is the development of a generic dynamic process and information model that can be applied to a specific project to develop and link the everyday models used to provide the facility. Examples of these models are: the architectural program, schematic drawings, CAD detailed drawings, contracts, CPM schedules, budgets, space planning models, energy management simulation, organizational charts and contracts.

$IDEF_0$ was selected as the most suitable process modeling tool. A schematic representation of the drawing format (Figure D-1), and a graphical representation of how the model is decomposed (Figure D-2) is included. A description of the model follows.

AN INTEGRATED BUILDING PROCESS MODEL

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

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



FUNCTION: An activity, process, operation, or transformation.

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

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

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

Figure D-1: Schematic representation of the IDEF drawing format (adapted from ICAM Function Modeling Manual, June 1981).

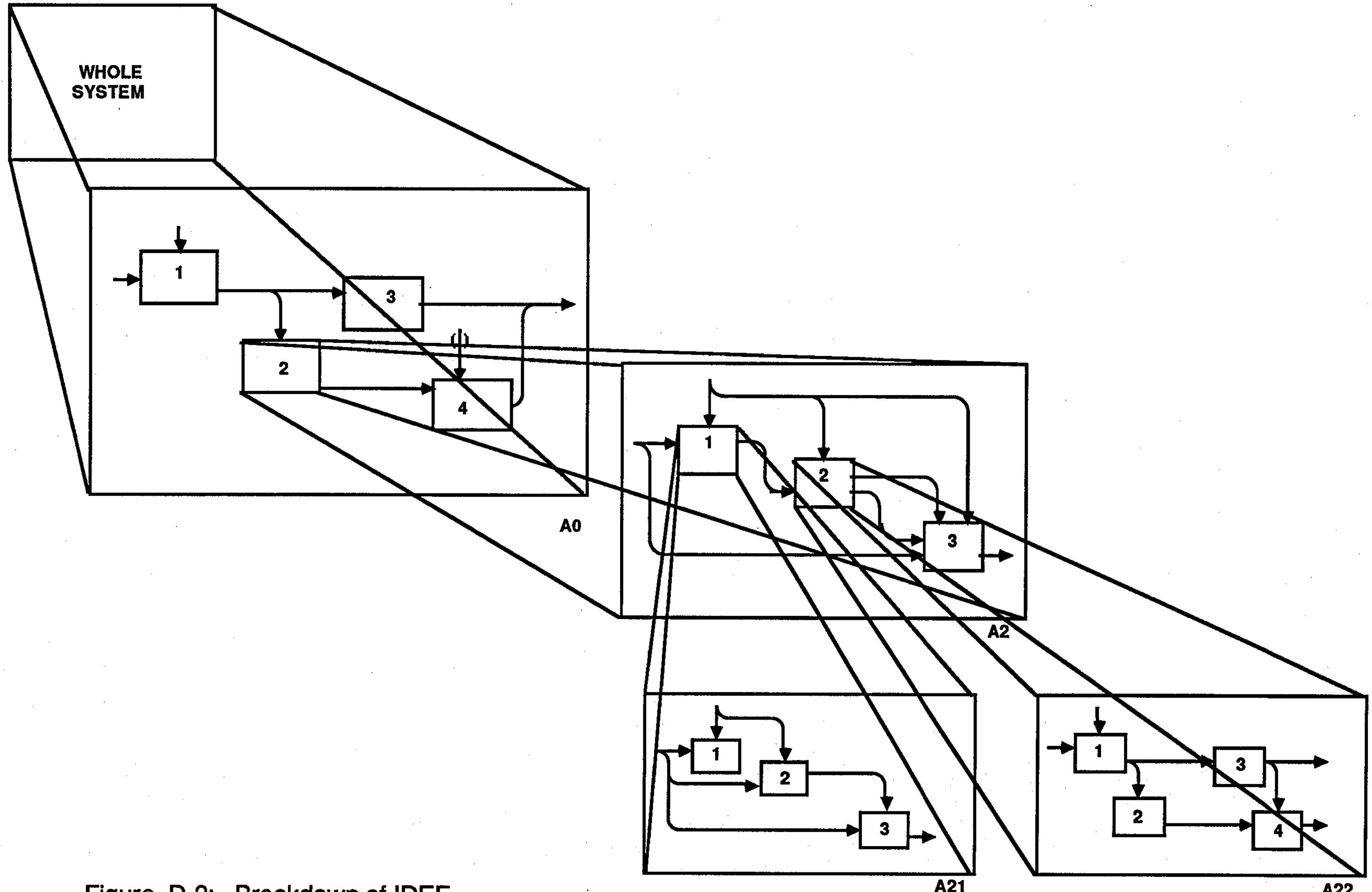
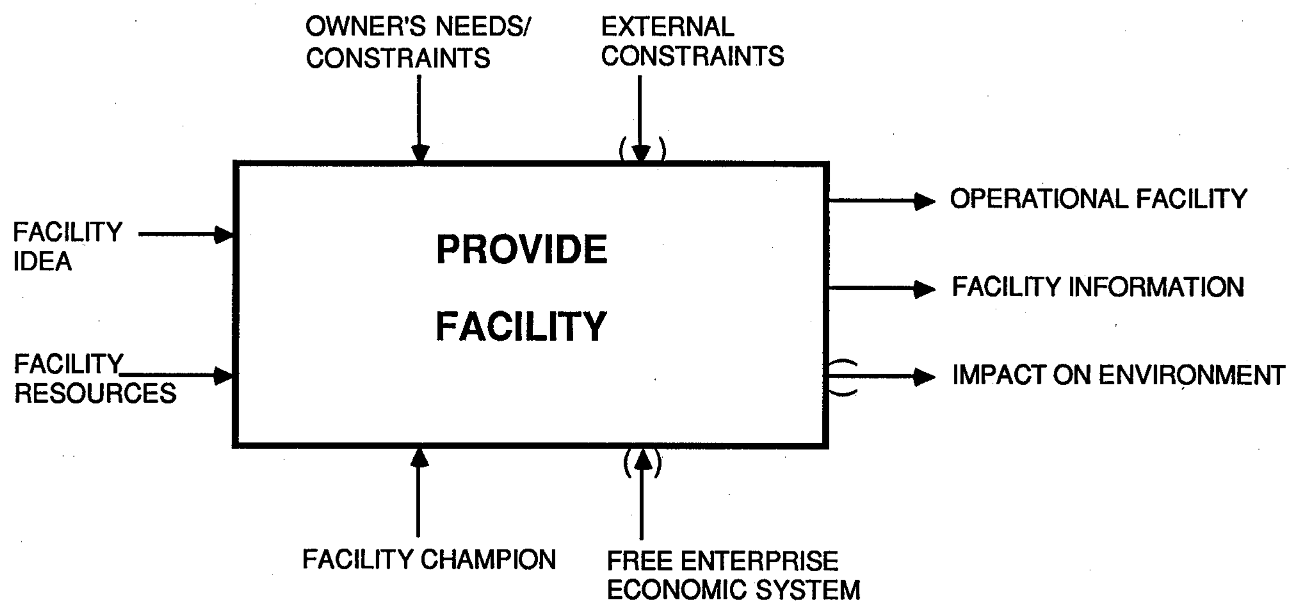


Figure D-2: Breakdown of $IDEF_0$

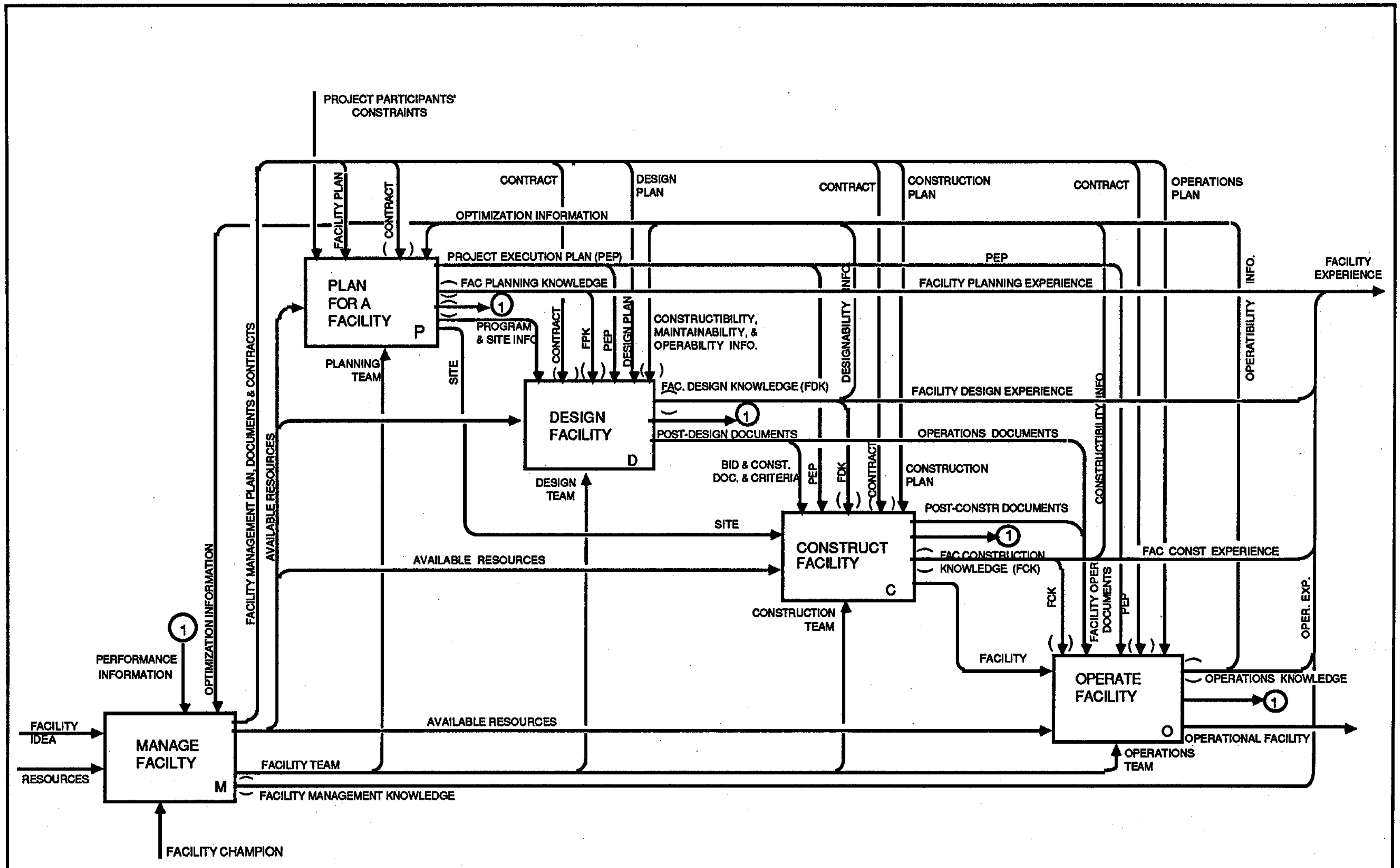


Purpose : This model describes idealized owner's functions and their relationships in a construction process.

Viewpoint : The Owner / User

NODE: F-0	TITLE: PROVIDE FACILITY	BY:	CHECKED BY:

Figure D-3: F-0. Provide Facility



NODE: F.	TITLE: PROVIDE FACILITY	BY:	CHECKED BY:

FIGURE D-4: PROVIDE FACILITY (NODE F)

THE LEVEL F MODEL "PROVIDE FACILITY"

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

COMPONENTS OF "PROVIDE FACILITY"

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

Manage Facility (Figure D-5) 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, documents and contracts, facility management plans, and resources to support the project. This function runs for the duration of the facility life. It is controlled by two major factors - performance information about the facility as a whole and information to optimize subprocesses within the facility e.g., constructibility information.

Plan Facility (Figure D-6) encompasses all the functions required to define the owners needs and the methods to achieve these. These activities translate the facility idea into a program for design, a project execution plan (PEP), and a site for the facility. Major controls are constraints imposed by project participants (e.g., the owner or engineer), the facility plan, the contract and optimization information. Other outputs include facility planning knowledge and information on the performance of the team.

Design Facility (Figure D-7) comprises all the functions required to define and communicate the owner's needs to the builder. These activities translate the program and execution plan into bid and construction documents and operations and maintenance documents that allow the facility to meet the owner's needs. Controls or constraints include program and site information, the contract, facility planning knowledge transferred to the design team, the PEP and the design plan. Again, facility design knowledge and information on the performance of the design team is another output.

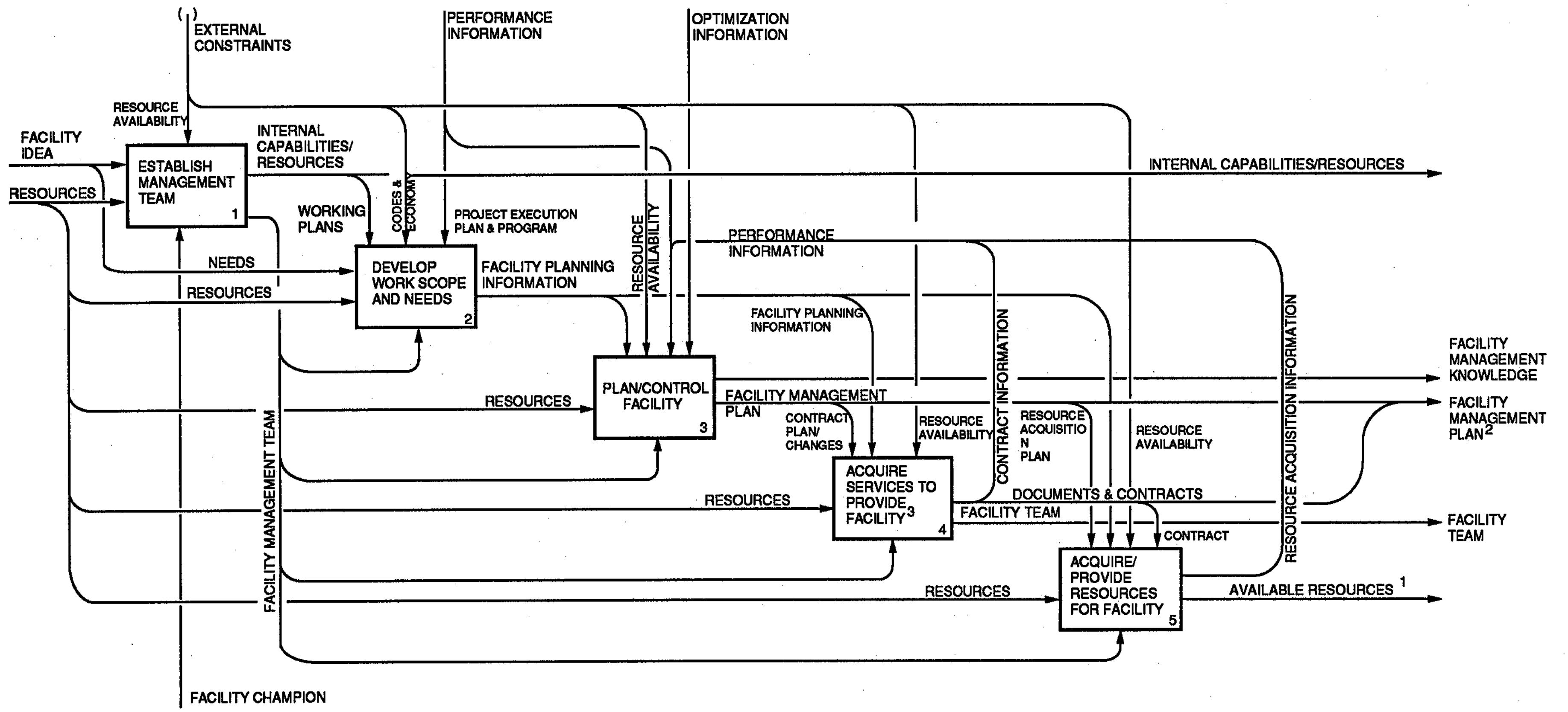
Construct Facility (Figure D-8) includes all functions required to assemble a facility so that it can be operated. These activities translate resources (e.g., materials) in accordance with the design into a completed facility. Typically appropriate facility operations and maintenance documents are generated. As a result, facility construction knowledge and information on the performance of the construction team is generated. Controls include bid and construction documents and criteria, the PEP, facility design knowledge transferred to the team, the contract and the construction plan.

Operate Facility (Figure D-9) comprises all of the activities which are required to provide the user with an operational facility. In addition, operating knowledge, and information on the performance of the team is generated. This process is controlled by the facility construction knowledge available to the team, the facility operating and maintenance documents, the PEP, the operating plans and the contract.

EVOLUTION OF THE MODEL

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

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



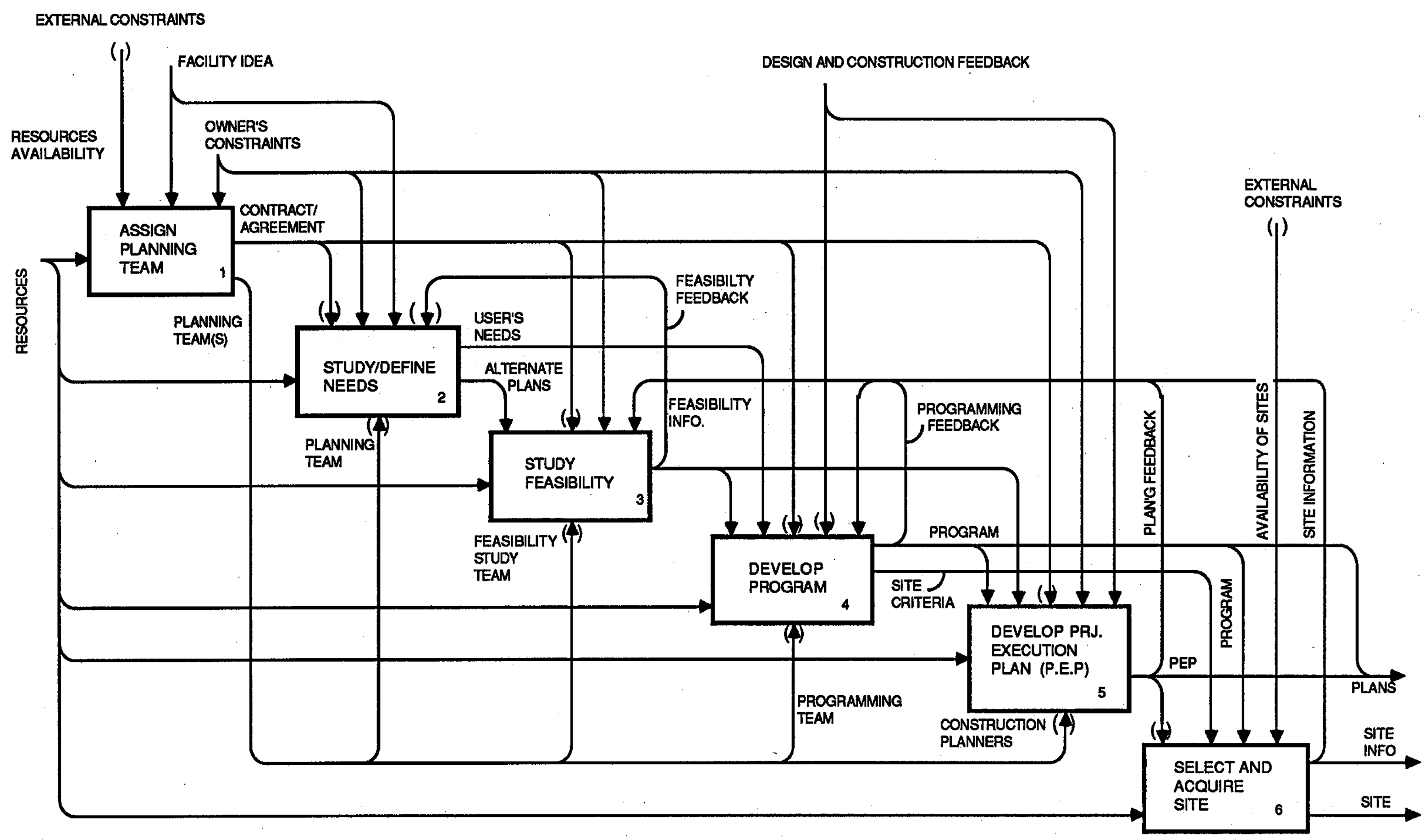
1 ONE SUCH RESOURCE IS FUNDS.

2 INCLUDES ALL CHANGES TO FACILITY MANAGEMENT PLANS AND DIRECTIVES.

3 THIS INCLUDES ALL CONTRACTS AND AGREEMENTS BETWEEN THE OWNER AND DESIGNER, CONTRACTOR, OPERATOR, ETC. IT DOES NOT INCLUDE SUBCONTRACTS AND AGREEMENTS BETWEEN AND AMONG DESIGNERS, CONTRACTORS, AND SUBCONTRACTORS.

NODE: M	TITLE: MANAGE FACILITY	BY:	CHECKED BY:

FIGURE D-5: MANAGE FACILITY (NODE M)



NODE: P	TITLE: PLAN FACILITY	BY:	CHECKED BY

FIGURE D-6: PLAN FACILITY (NODE P)

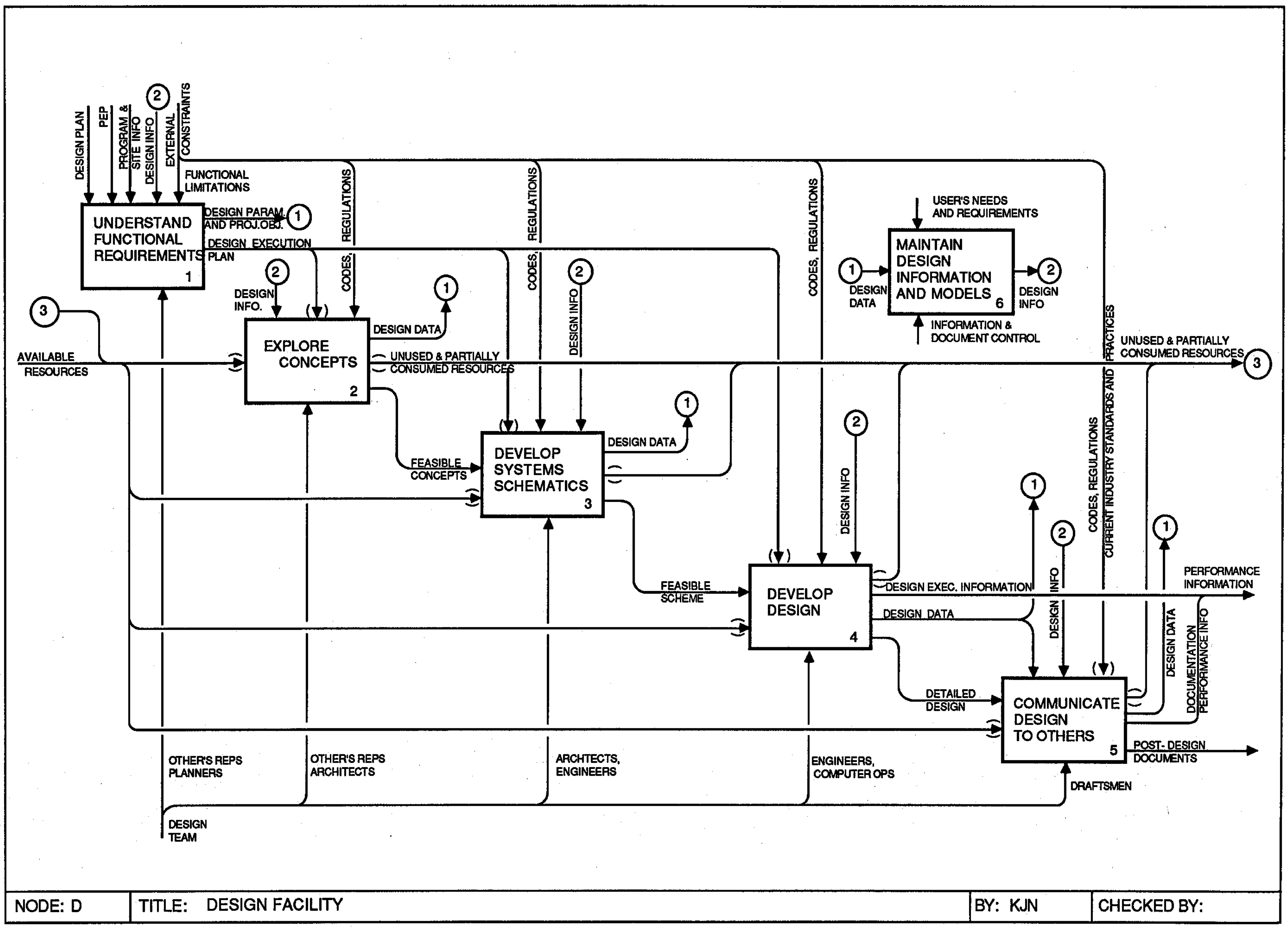
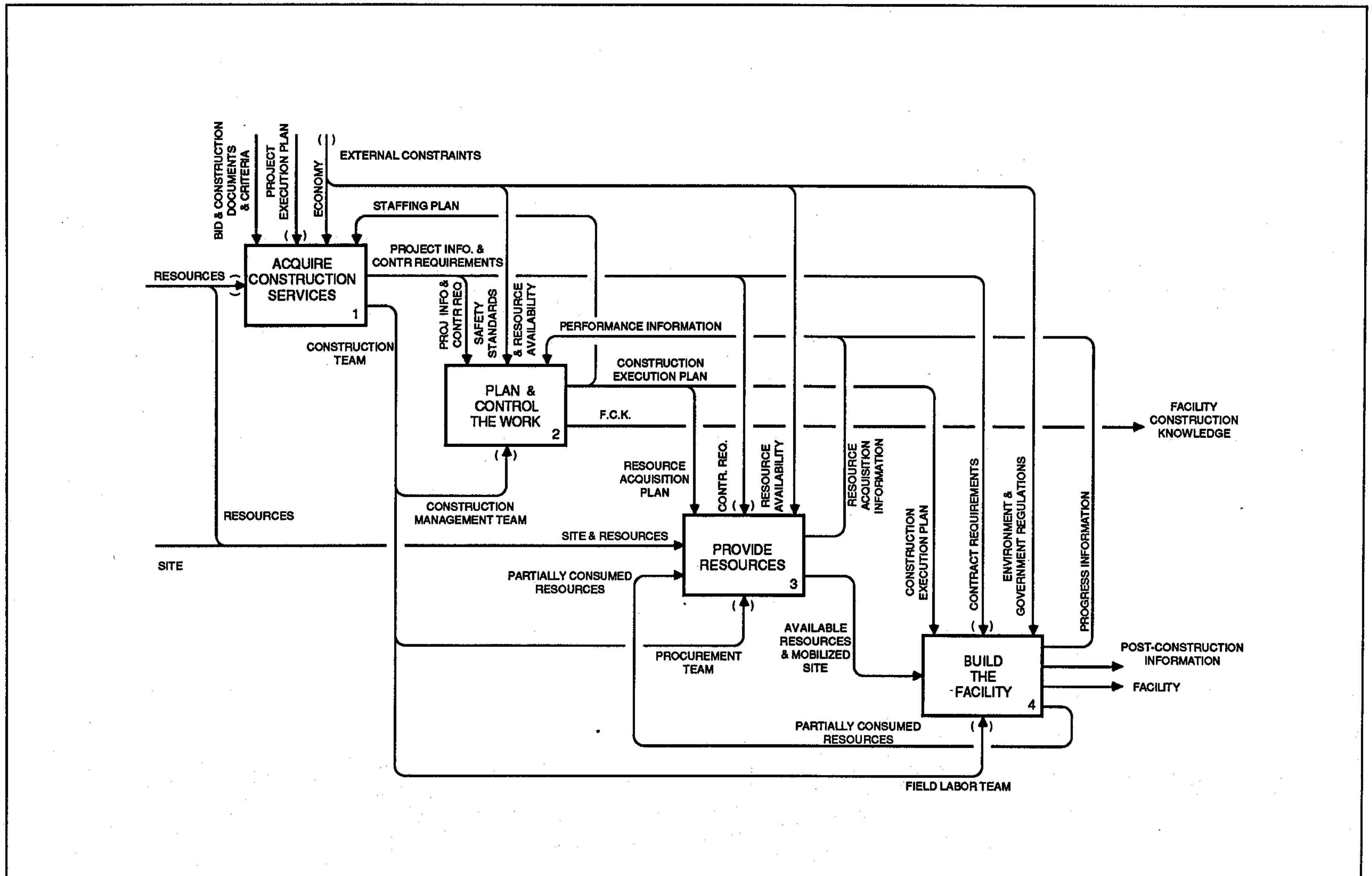
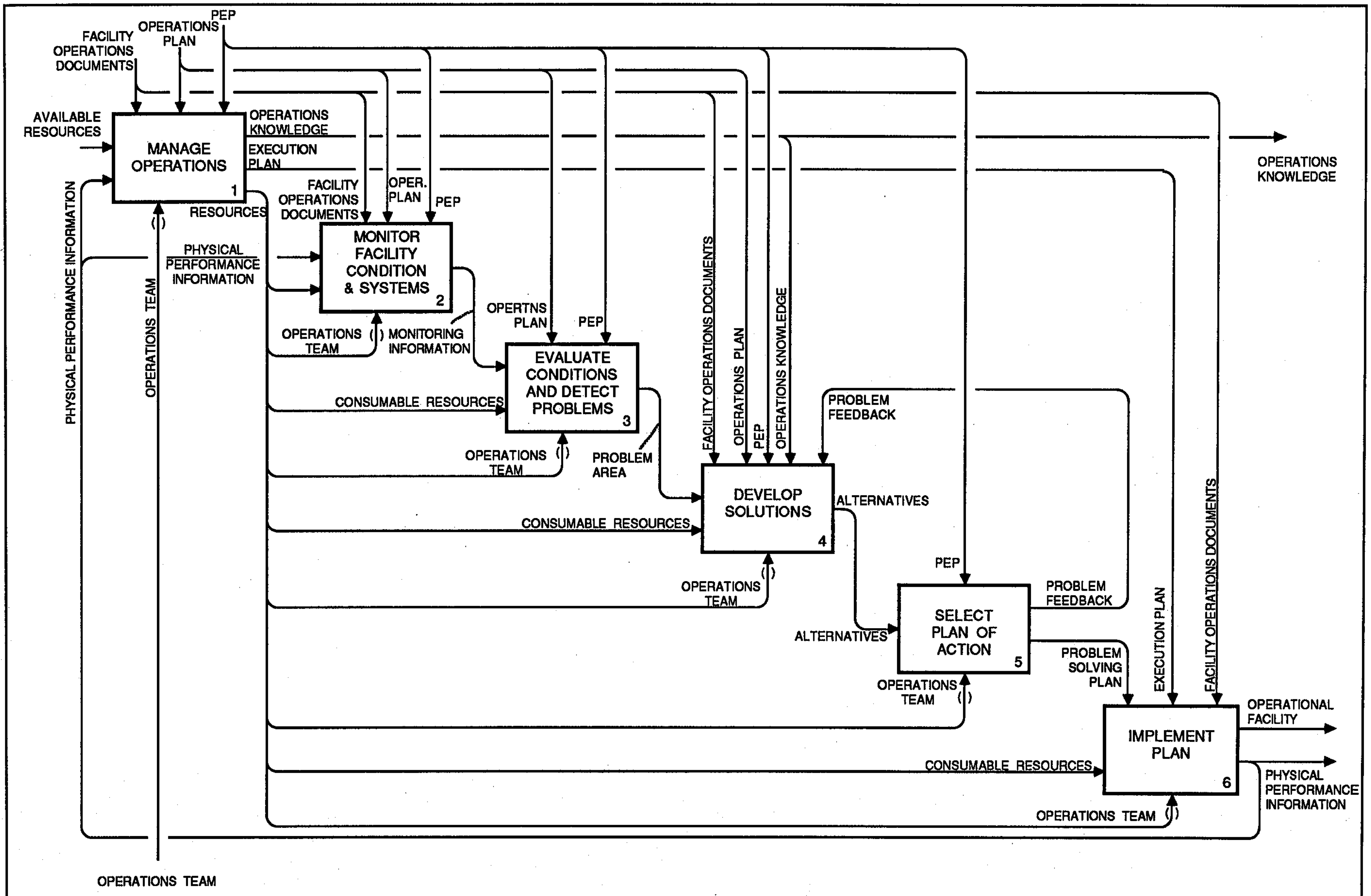


FIGURE D-7: DESIGN FACILITY (NODE D)



NODE: C	TITLE: CONSTRUCT FACILITY	

FIGURE D-8: CONSTRUCT FACILITY (NODE C)



NODE: O	TITLE: OPERATE FACILITY	BY: MMG	CHECKED BY:

Figure D-9: Operate a Facility (Node: O)