



**PRELIMINARY RESEARCH ON PREFABRICATION,
PRE-ASSEMBLY, MODULARIZATION AND
OFF-SITE FABRICATION IN CONSTRUCTION**

by

Carl T. Haas
Walter R. Fagerlund

A Report to
The Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
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Preliminary Research on Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication in Construction

Executive Summary

Recent advances in design and information technologies, combined with increasing emphasis within the industry to address cost, schedule and labor issues, have proven the use of prefabrication, preassembly and modularization to be more viable than ever. Key factors influencing the decision-making on use of prework, including new technologies and a changing construction environment, have also expanded and changed. Successful implementation of prework requires a systematic analysis and decision-making process to evaluate the potential benefits and barriers to using these methods on projects.

The research team extended prior CII research efforts, identified state-of-the art practices of prework, and developed a decision framework to assist project teams in considering possible use of prework on their projects. In developing the decision framework, the research team focused on identifying the requirements for effective use of prework on industrial projects. The preliminary research presented in this report has been continued to further structure the framework and develop it into a computerized tool.

Prework is not for every project, but it can bring major performance improvements for the right ones. Using the framework described in this report, the construction industry can apply the experience of many seasoned prework users to its projects and if the project fits, the industry can realize the benefits from use of prework.

Preliminary Research on Prefabrication, Pre-assembly, Modularization, and Off-site Fabrication in Construction

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Chapter 1: Introduction

OVERVIEW

Prefabrication, pre-assembly, and modularization are strategies that have the potential to: (1) significantly reduce project duration, (2) improve productivity, (3) reduce labor needs and costs, and (4) have a positive impact on supply chain problems. Collectively known as prework, each is more or less applicable under specific conditions. Prework was found by a Construction Industry Institute (CII) Constructability Task Force to offer a substantial opportunity to improve project performance and overcome external and internal project challenges such as adverse site and local area conditions, lack of skilled labor, and demanding schedule, among others (Tatum et. al. 1987).

The successful application of these construction methods requires proper planning and decision-making processes. It is generally accepted that the tradeoffs for realizing the benefits of prework include project requirements such as increases in the amount of preplanning, engineering and coordination required for the project. The nature of prework tends to increase requirements for design and procurement logistics. In the past, companies have relied on expert knowledge, checklists, industry-wide tools or some combination therein to account for these requirements.

Given the fragmented nature of decision-making regarding prework coupled with challenges faced by the industry, a clear need for a decision-making process has emerged. Because of new technologies and a changing construction environment, factors influencing the decision-making process have expanded and changed in the last decade. These changes result in the need to reevaluate the role of prework and how decisions are to be made regarding the level and scope of its implementation.

New technologies such as computer controlled fabrication equipment, 3D CAD, electronic transfer of data, and the internet have provided opportunities for advances in design efficiency and coordination. While these technologies may provide overall project benefits regardless of the construction method, certain prework impediments can be directly reduced through the use of these information technologies.

Recent trends in construction emphasize smaller scale assemblies that exploit the capabilities of 3D CAD technology to ensure accuracy, precision, and visualization. In a Center for Construction Industry Studies at the University of Texas study, it has been estimated that the use of prefabrication and pre-assembly has increased approximately 90% over the last fifteen years (Eickmann 1999). The study was based on an extensive survey of over 27 construction professionals with a combined experience of over 700 years.

Other recent influences of information technology include advances in supply chain management. Information technologies have the potential to allow transmission of a “just-in-time” order for a rebar assembly to a fabrication plant and have that plant deliver the assembly within 24 hours, from scrap metal to final assembly and delivery. More common industrial applications include structural assemblies, piping spools, wiring harnesses, and pre-cast concrete modules. While this is an ambitious idea, it is now technically feasible. The capability and beneficial use of information technology on design and construction projects is advancing rapidly. The resulting ability to develop CAD models that include knowledge required for use of prework along with extensive engineering, procurement, and construction information about all the components of a plant is a major advantage for the potential use of modularization and pre-assembly. By its nature, prework contains more physical and organizational interfaces, providing opportunities for improvement through the automation made possible with CAD and other information technologies.

Changes in the current construction industry climate also align well with the concepts of prework, further justifying the updated frameworks reflecting these changes. The current shortage of adequate labor and skills can potentially be handled to a certain extent by prework. Increasing owner emphasis on safety, cost and schedule control for projects can also be potentially addressed by prework.

Adequate decision-making with regard to prework will require the inclusion of these technologies, as well as industry climate impacts and all influencing factors driving or impeding implementation. While some companies have employed prework methods successfully, the overall industry culture still has not fully recognized the potential for project improvements. Beginning with a set of comprehensive decision frameworks developed through the analysis of the methods already employed, dissemination of such a

tool through CII's consortium of owners, designers and contractors could provide the influence on the industry needed to establish prework as a best practice.

OBJECTIVE

The main objective of the research is to develop guidelines and frameworks for determining the level and scope of prework on a construction project. In support of this main objective, the research will also seek out the state-of-the art in prework decision making based on factors collected through literature reviews, interviews with leading companies, and insight from experts in the industry. More specifically, these factors include subjective and quantifiable project drivers, benefits and impediments to the use of prework.

SCOPE

The research covers the decision-making processes for the use of prefabrication, pre-assembly and modularization for industrial construction practices throughout the world. These processes include industry tools, checklists and planning methods. Project owners, suppliers, fabricators, engineers, and/or contractors may carry out these practices.

METHODOLOGY

The research methodology begins with a literature review of the past practices regarding prework for industrial construction. The research team then reviews the information to date and prepares for data collection regarding current practices. This preparation includes the identification of leading companies in the industry and the development of a questionnaire to collect the appropriate data. The team next conducts site visits to the leading companies and summarizes the data into trip reports.

Once the data has been collected, the team reviews the information and begins to structure guidelines and frameworks for prework decisions. Based on the team's expert judgment, data is filtered and combined to develop the framework structures. Upon completion of the frameworks, the team then will present the products for beta testing and eventually use in the construction industry. In addition, full documentation of the data will be archived for dissemination into the general body of knowledge.

Chapter 2: Background

Past research has identified that the use of prework has the potential to positively impact the construction process. Through studies conducted by CII, academic institutions and individual company cases, the drivers, benefits, impediments and the effects of these factors on decision-making for prework have been well documented in the literature. Further improvement of decision-making process for determining scope of prework for projects has only begun to be explored. The following chapter outlines the current knowledge regarding decision making, as well as the drivers, benefits, and impediments that support the process.

While the concept of prework projects can be traced back to Egyptian pyramids and Greek temples, the modern construction industry has only begun to take significant advantage of these construction processes in the past few decades. A recent study at the University of Texas revealed that the use of prefabrication has increased by approximately 86% in the last 15 years (Eickmann 2000). These activities can be found in many disciplines of construction, as shown in Figure 2.1. Prefabrication and preassembly was identified as existing to some extent in virtually every discipline. Major areas of prework included piping, structural assemblies and equipment.

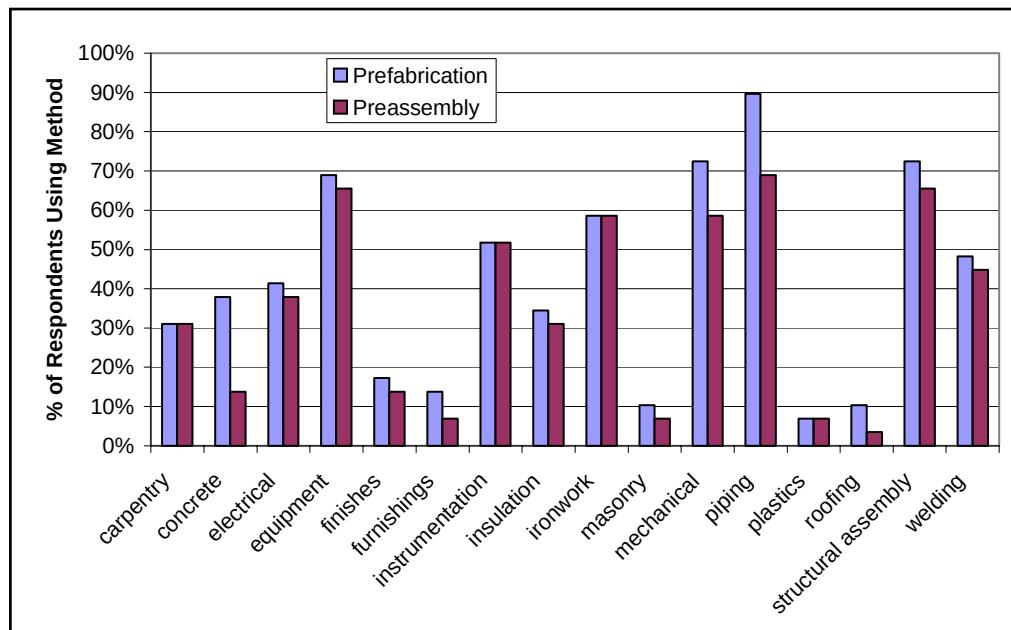


Figure 2.1: Pework use in construction (Eickmann 2000)

Appropriate timing and preliminary investigation also characterized successful decision-making regarding prework. The decision to use prework should be done early in the project planning. One drawback to this early requirement is the fact that the scope of the project must be well defined, as the design and transport of the assemblies will be based on set sizes and quantities. This reduction in flexibility can be an unattractive part of the project to the owner. Project scope can be altered, but usually at a higher than average premium and can easily negate the schedule and cost benefits that would have been realized. For these reasons, the decision the use prework may be most appropriate when made as early in the project as possible. Preliminary investigation involves the careful qualitative and/or quantitative analyses of the drivers, benefits and impediments are traditional methods for the prework decision process. While the timing of the decision is critical, the decision must also be made with the proper level of information (Tatum et.al. 1987).

As a result of the insight gained from the CII study in the late 1980's, a modularization decision-making software tool called MODEX was developed. The software, also called Modularization Expert, was created to enable project teams to evaluate the feasibility of using modularization for industrial construction projects. Incorporating important factors identified by the research team into its expert system architecture, the software provided three levels of feasibility analysis for the user. These included prescreening, detailed feasibility, and economic analysis. The prescreening process was a quick evaluation requiring minimal information to determine the general potential for modularization. If the project is determined to have a certain potential, the program proceeds with the detailed feasibility study and economic analysis. Project attributes for this section include plant location, environmental factors, organization, plant characteristics, project risk, and labor conditions (CII 1992).

Later studies validated the use of MODEX through testing with project data. The choice of developing the software as an expert system was deemed appropriate given the ease of use of expert systems, the ability to handle uncertainty, and the system's suitability for real world problems (Murtaza et.al. 1993). Even later work identified MODEX as a best practice in the decision making process for modularization in industrial construction (Mulva 1996).

Other software was also produced using the data collected by the CII task force. Beyond the expert system of MODEX, some research was conducted into the use of neural networks and multimedia technology to assist in the decision making process. One program used a multilayered, self-organizing neural network along with data from the CII research to determine the level of modularization to be used in a project. The system was found to be 80% accurate when tested with data from ten projects. The initial results concluded that the neural networks could produce the necessary accuracy for decision making (Murtaza 1994).

Another system incorporated multimedia technology with the project data from the CII task force. The Multimedia Decision Support System (MDSS), combined project data with the MODEX system. The system consists of four modules. Module one includes criteria for decision making and weighting factors. The second module contains the database of project information for the project in question. The third module includes a graphical database, with pictures and images regarding project information such as site conditions and transportation routing. The fourth module takes the previous three modules into account and uses a group decision-making algorithm help determine a solution (Vanegas 1995).

Beyond the work by CII and the subsequent following research, other sources have identified decision factors for prework. Providers of prework, such as companies specializing in modularization, have identified decision factors in industry journals and through marketing efforts. One major modular provider identified the factors in Table 2.1 when considering the use of modularization. Each area under consideration contains quantifiable costs and benefits.

Table 2.1: Project parameters for feasibility of modularization (Deemer 1996)

• Overall Cost	• Detailed design
• Schedule	• Procurement
• Safety	• Fabrication
• Operability and maintenance	• Transportation
• Quality	• Construction
• Impact on the local environment	• Secrecy
• Marketability	

From these projects, academic researchers and industry professionals alike have been able to identify the drivers, benefits, and impediments on the use of prework. These aspects all affect the decision making process and the understanding of their impact is necessary for adequately determining the scope of prework. One limitation of these products was that many of them were based on expert system theory. Products such as MODEX and others attempted to collect and integrate all the knowledge available at the time to develop a single solution to determining prework application and level. Additional enabling technologies and project factors have altered the requirements and possible solutions for implementing prework. Technologies such as the internet, 3D CAD and digital imaging did not exist as widespread during this earlier research. Project factors have also changed as a result of a changing market and newer technologies. Market conditions have dictated newer products from facilities such as increases in the pharmaceutical and biomedical fields. Other factors such as labor issues, cost constraint emphases and other economic factors have also further shaped the industry in ways that may have been difficult to predict in the previous research. Therefore, the research proposed within this report will work to integrate the newer technologies and project factors while still allowing for future flexibility should additional consideration be required.

DRIVERS AND BENEFITS

Drivers and benefits for prework are often closely related and play a critical role in determining feasibility. Many drivers and benefits for the use of prework have been recognized, but they often vary with the type of prework under consideration. In general, modularization has been driven by project or site constraints such as harsh weather conditions. Preassembly and prefabrication are typically driven by cost and schedule issues. For example, pipe spools may be more economically prefabricated in a dedicated pipe shop location.

The traditional project factors driving desired benefits also apply prominently when considering prework. Cost, schedule, quality and safety are main drivers. Subcategories supporting these themes include productivity, risk reduction and environmental factors. Prework has the potential to positively affect the project in each of these areas (Gibb 1999). The reduced cost of fabricator labor compared to on-site workers combined with the

increased productivity of the manufacturing facility translates into schedule compression with minimal cost impact (Tatum et.al. 1987). Lack of availability of skilled, on-site labor may also play a factor into the decision to use prework. Shortages of skilled labor could be a strong driving force (Murtasa et.al. 1993).

Cost

Cost savings mostly consist of the differences between fieldwork and shop fabrication productivity and support costs. Other savings may be associated with overhead reduction, transportation and installation efficiencies and future projects. A CII study of industrial construction projects found that in some cases, estimates in cost reduction were 10% for overall project cost and 25% for onsite labor costs (Tatum et.al. 1987). Cost reductions were attributed to the lower cost of offsite labor. Shop productivity is often better than field because of controlled conditions, closer supervision, and easier access to tools. Controlled conditions such as ground level work, climate control and consistent lighting directly impact productivity. Given the closer proximity of workers and workspaces, supervision requirements and time to access necessary tools decreases in the shop. Often in the field the supervisor or the worker in need of a tool must cover large distances to accomplish tasks. In addition to productivity cost savings, prework can decrease costs associated with fieldwork.

Since some or all of the work is relocated to an offsite location, costs associated with site infrastructure and overhead can be reduced. Fewer workers on site translate into fewer costs for accommodations in remote locations, scheduling onsite work, and other onsite logistics. Other cost savings may include savings from fewer material deliveries and reduced crane usage. The cost of transporting a large assembled unit may provide savings over many shipments of individual pieces, including tracking and storage costs.

Future requirements for expansion or conversion of capital facilities may benefit from the use of prework on existing projects. Some prework can be designed to for expansion or relocation. For example, modular units may be designed for replacement or expansion depending on market conditions. Prework designs may also provide opportunities for replication, reducing costs associated with learning curves and engineering.

Some less quantifiable cost savings that are apparent include environmental impacts. Relocation of work offsite potentially reduces impacts to the field site. Reduction in infrastructure, influxes of construction workers and economic disruptions to the local communities may be reduced by prework (Deemer 1996). Additionally, work offsite may reduce material waste, pollution associated with dust and noise and overall energy costs (Gibb 1999).

Schedule

Schedule often drives the use of many forms of prework. Considerations such as outage requirements or market conditions may dictate schedule as a driver. Increased productivity and activity desequencing are typical ways of improving schedule with prework. By relocating work to off site locations with higher productivity, schedule savings are possible. One study in the area of building construction estimated a reduction in onsite labor of 40-50%, along with compressed schedules due to shorter critical paths (Warszawski 1990). Industrial construction has recognized similar benefits. For example, nuclear reactors designed using modular methods and off site fabrication have seen improvements in schedule length and control (Kupitz and Goodjohn 1991). Desequencing examples may include fabricating structural steel offsite while foundations are poured onsite. Desequencing may also be appropriate when permitting delays onsite work. Fabrication may continue offsite while permitting delays activities at the project location.

Other schedule benefits associated with prework include risk management. While prework provides opportunities to compress schedule, some of the most attractive drivers are improvements in schedule control. Off site work schedules by nature contain fewer inherent risks due to conflicting crews, weather delays or interferences with ongoing operations.

Quality

Pework may be driven by quality requirements. Fabricating components away from the site also allows higher quality control due to the controlled manufacturing facilities in which the components are constructed. Pipe racks that were once assembled on-site were subject to the weather and took up space on-site for assembly. Prefabricated

racks can be assembled in a fabricating facility under controlled conditions and then shipped to the project site.

Quality increases due to the controlled conditions under which construction is accomplished. For example, a structural steel assembly for a petroleum refinery that was once constructed over a hundred feet in the air can now be fabricated at ground level, in a controlled environment. The assembly can later be hoisted as a whole into place requiring only a few connections.

Safety

With prework, workers face less exposure and companies receive more opportunities for decreasing safety risk. Prework may reduce exposure to weather, heights, hazardous operations and neighboring construction activities. Workers indoors at a fabrication shop are not affected as much by temperature, wind and precipitation extremes. Since much of the prework is done at grade level, fewer safety harnesses are required and workers can focus more on the work. Less workers onsite also translates into reduced craft congestion and exposure to ongoing operations.

IMPEDIMENTS

While the drivers for prework help to determine the use of prework as an option, the decision to implement is influenced by the balance between the potential benefits and impediments. Common challenges faced by projects include increased engineering requirements, increased transportation considerations and decreased flexibility of scope. Other impediments can be grouped into site constraints, along with coordination, communication and organizational requirements.

Engineering

Case studies have estimated that engineering costs can increase as much as 15% and home office costs 5-15% per unit of prework. Depending on the extent of prework, it may be necessary to complete 90% of engineering design prior to construction, as opposed to the 40% generally necessary for conventionally built projects (Tatum et.al. 1987). Complex modular assemblies may require greater completion of engineering prior to

assembly due to complexity of interfaces and shipping envelopes. Interface management and transportation requirements may not only increase degree of completion requirements, but also account for a large portion of the estimated 15% increase in design.

Physical interface management requires further engineering to assure compliance between fabricated assemblies. Since components are fabricated in the shop and shipped to the installation location, additional engineering is required to insure compliance. Interfaces may include the connection between a pipe rack and equipment such as compressors or vessels. Other examples might include the connection between different floors on a stair tower or the connections between several structural steel preassemblies. If the assemblies are connecting to a foundation poured on the site, careful monitoring of the as built bolt locations and the final fabrication of the mounting angles to assure compliance during erection.

Design dimensions and loading may be dictated by transportation limitations. For example, the size of a large module for a power plant may be constrained by the lift capacity of a crane or the load capacity of a wheeled vehicle. The size of structural steel members of the module may be designed for peak loads experienced during the transportation or lifting process. These factors are examples of why engineering requirements and transportation considerations are increased.

Transportation

Transportation logistics play a large role in determining prework feasibility. Size and weight limitations, route restrictions, permitting and the availability of lifting equipment are among the considerations to be made for the coordination of construction. Size and weight may vary depending on the delivery method. Roadways, railroads and water transport all have limitations. The availability of these methods may dictate the type of prework selected. Water access may allow large modular units, while limited road access may constrain prework to smaller preassemblies or prefabricated components.

Methods of delivery may not only be dictated by access at the fabrication site and the project, but also by the routes to and from. Routes must be able to handle loads and the necessary permitting acquired. Once the components reach the site, additional lift planning may be required, especially for heavier lifts. While the number of lifts may be reduced, the

complexity of each lift generally increases with the increase in level of prework. Key considerations for heavy lifting include lifting points, rigging and early involvement of the lift contractor (Gibb 1999). Other factors include impacts on construction schedule, site design, as well as consideration for crane cost, availability and the cost of designing the plan itself. As trends in the industry move towards greater use of prework, heavy lift planning needs will increase also (Hornaday 1992). The impact of additional lifting requirements must be factored when determining prework feasibility.

Contracts and engineering may also be affected by increased transportation requirements. It may be necessary to secure transportation contracts prior to design completion (Stubb and Emes 1990). In some cases, the engineer may be required to design at risk, with calculations and drawings being completed prior to transportation permitting (Smock 1992).

Flexibility

Scope flexibility may decrease, especially with the use of modularization, since their use requires a well-defined scope early in the project planning stages. This is due to the increased engineering and transportation requirements. The scope must be set early to insure adequate design and integration upon construction and final assembly.

Site Constraints

Other factors affecting the use of prework include the local economy. In areas where the cost of labor is low, prework may not provide an economic advantage. Another concern is the knowledge base of designers concerning prework components. Engineers may not have experience with such construction projects and therefore prefer traditional methods. In addition, some specific areas of modularization, such as home building, may fluctuate with the market demand (Warszawski 1990). This could translate to industrial construction for industries experiencing increased market demand in locations with energy shortages. One example in the power industry has been the modularization of new power plants to compress the construction schedule with cost savings associated with earlier time to market. One power plant contractor was able to reduce schedule by 40% by using

modularization to build 150 and 450 MW power plants. While construction costs grew from 0.5-2.7%, the total plant investment savings ranged from 12-15% (Smock 1992).

Coordination

Once the decision to use prework has been made, it is necessary to understand the extensive coordination required prior to and during construction operations. Coordination of design, transportation, tracking, and installation are critical components for successful implementation. This section outlines the project specific coordination needs as relating to prework in construction. The organization of those people involved in the process will be discussed further in the next section.

In addition to the transportation and design issues discussed, adjustments in the work breakdown structure, terminology, drawings, progress measurement, and scheduling may also have to be coordinated. Rather than systems, the work breakdown structure will deal with units. These units or modules may require new terminology for referencing drawings and schedules. Interface drawings may be required in addition to traditional plans. Progress measurement may also be in units rather than systems. The installation process may affect schedule considerations such as the critical path (Tatum et.al. 1987).

Further coordination may be required for materials management and supply chain scheduling. The complexity of assemblies, integration, and delivery provide opportunities for computer control (Stubb and Emes 1990). Standardization of these processes could help to further reduce the overall cost and schedule (Smock 1992).

Communication

Given the increases in coordination for projects utilizing prework, effective communication is necessary. Effective communication between project participants includes distribution of information regarding decisions, designs, transportation requirements, and schedules. In order to coordinate between multiple sites with critical scheduling, open communication must exist between owners, engineers, suppliers and contractors.

Organization

The roles of different project participants are affected by the use of prefabrication, preassembly and modularization. The relationships between owners, engineers, contractors, and suppliers are important to the success of the project. Just as the specifics of the project must be coordinated, so must be the people involved. The number, level of involvement, and contract requirements may vary compared to conventional methods.

Generally, the role of the design firm and the contractor is reduced. While the engineering design required increases, much of the work is transferred to the supplier or offsite fabricator. This results in decreased fieldwork and activity at the actual jobsite. The contractor's role is reduced by the decrease in manpower size and duration in the field. The one design discipline whose role may increase is the structural design firm or department, given the complexity of the lifting and transportation requirements. The role of the supplier increases, and in some cases the supplier works directly with the owner. This can bypass the design firm and contractor, further reducing their involvement (Tatum et.al. 1987). Management requirements for the project will increase, since a strong client presence may be required at the fabricator to maintain cost, schedule, and quality control (Stubb and Emes 1990). Regardless of the amount of work shifted throughout the project organization, early participation and effective communication are keys to success.

While the roles of project participants changes with the use of pre-assembly and modularization, the complexity of procurement increases. The use of multiple sites for the construction of components and modules adds to the increased need for proper organization. The contractor or fabricator handles the procurement in some cases. Regardless of who procures the materials, the responsible party needs to understand that some items may be required sooner than similar conventional projects. For example, instrument or control components traditionally installed near the end of the project may require procurement earlier for the installation into assemblies constructed prior to transport to the site. These offsite projects become "mini-projects", with their own project management staff and quality control (Tatum et.al. 1987). For these reasons, procurement complexity increases organizational requirements.

In addition to changes in organizational requirements for participants and procurement, project contracting may also be influenced by the use of prework. Generally,

knowledge and influence shifts from the general contractor to the subcontractor or fabricator. Since the subcontractor or fabricator has greater knowledge or in some cases, proprietary knowledge regarding assemblies, they possess a higher profit potential compared to conventional methods. Traditionally, construction down on site was familiar to the general contractor and unit cost driven. With some prework done offsite, the subcontractor has greater control of pricing and maximization of benefits. In some of these cases, it may be beneficial for the general contractor to integrate the subcontractor into its organization. Ideally, the general contractor may benefit from owning the subcontractor (Hsieh 1997).

The type of contract to be used may also be a factor in the organization of the project. Different contracts have been used in the past, with variations depending on the risk assumed. In cases where risk is increased due to the use of new technologies, the contractor may assume the risk with a turnkey style contract. This requires a premium to cover the risk and may reduce cost savings related to pre-assembly and modularization. In order to maximize cost savings by eliminating the risk premium, owners may choose to assume the risk with a more traditional contract. In some cases, owners who have assumed the risk in a more traditional contract such as own-and-operate have realized savings on average of 15% over turnkey options. However, this requires a knowledgeable owner who is disciplined in the management of such projects (Smock 1992).

Overall, the organizational requirements for projects involving prework increases. This is reflected in the changing roles of project participants, increased complexity of procurement, and contracting issues.

Chapter 3: Methodology

OVERVIEW

Research was conducted as part of a project team for CII. The team consisted of representatives from the construction industry and academic institutions. Industry members represented ranged from owners to contractors to design firms, each involved in some way with prework. Academic members represented three institutions and each had prior experience researching prework. Table 3.1 lists the companies and institutions participating in the research. The overall project duration was slightly more than two years.

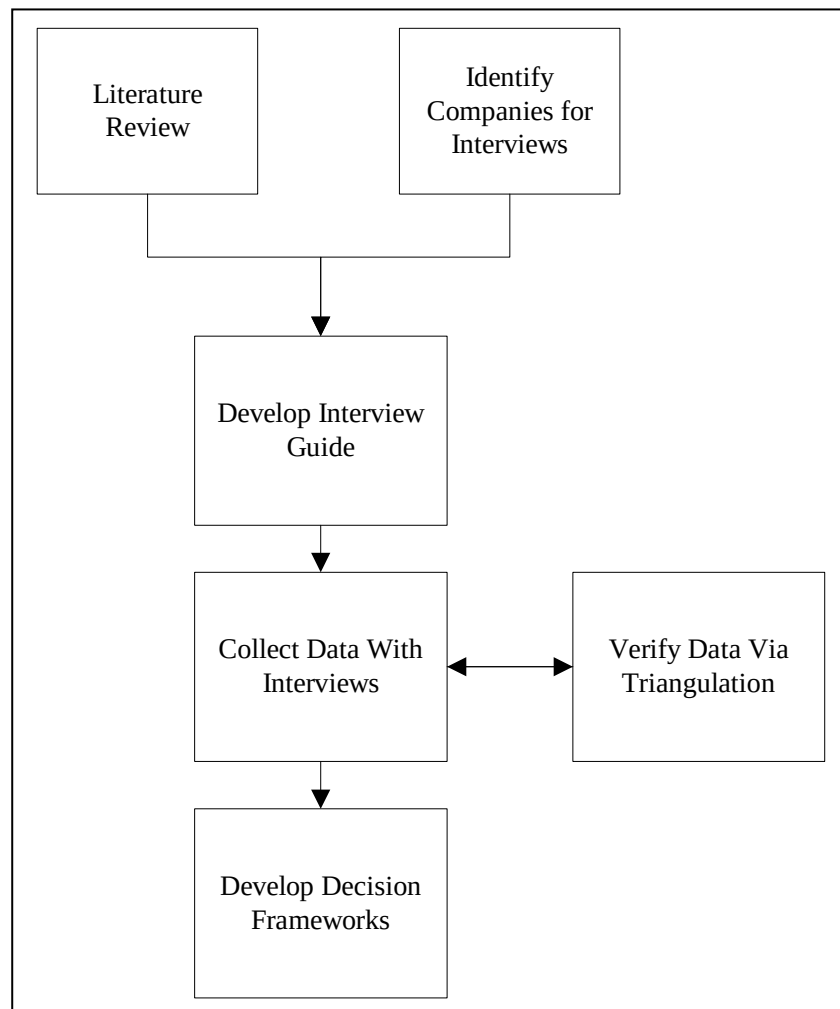
Table 3.1: Team member companies and institutions

• BE&K, Inc.	• Stone & Webster
• Chicago Bridge and Iron Company	• Stanford University
• Eli Lilly Company, Inc.	• The University of Texas at Austin
• Eichleay Engineers, Inc.	• U.S. Army Corps of Engineers
• Georgia Institute of Technology	• U.S. State Department
• Jacobs Applied Technology	• U.S. Steel
• Kvaerner Process	• Washington Group Int'l
• LTV Steel Company	

The methodology for the research follows several steps, shown in the flowchart in Figure 3.1. First, a thorough literature review was conducted to determine the work to date in the areas of prework as discussed in Chapter 2. Team members reviewed the past research and identified companies currently involved in industry-leading practices in the use of prework. Projects were identified for case studies and an interview guide was developed to collect state-of-the-art information. The case studies identified current decision-making processes and timing. The data was summarized initially in trip reports and was verified via triangulation with past research and the expert opinion of team

members. The data was integrated and submitted for dissemination into the industry as part of the products required of the team by CII.

Figure 3.1: Flowchart of Research Methodology



LITERATURE REVIEW

A literature review was conducted to determine the prior research and developments in the areas of prework, and information technologies. The literature included industry journals, conference proceedings, and past CII products. Databases were searched via access through the University of Texas library system.

IDENTIFICATION OF LEADING COMPANIES FOR CASE STUDIES

The project team held a meeting to review the current literature and to identify possible case studies. Given the wide range of industries and types of project participants represented, a broad list of owners, contractors, designers and vendors was generated. The team identified types of prework carried out by the companies and provided points of contact to set up the case studies.

INTERVIEW GUIDE DEVELOPMENT

An interview guide was developed for the case studies based on the literature review and the experience of the project team members. Separate guides were developed for different respondents in order to concentrate on specifics for each. Separate guides were developed for owners, engineer/contractors, and supplier/fabricators. Attempts were also made to remove bias in the questioning in order to assist with validation of results. The complete interview guides can be found in Appendix A.

SITE VISITS AND DATA COLLECTION

Site visits were conducted using the contacts identified and the site visit guide. Points of contact were reached based on the list generated by the team. Academic representatives of the project team usually conducted the interviews over a period of 1-2 days at the site of the case studies. Site visits included meetings at the company home offices, tours of fabrication shops, and walkthroughs of construction sites in progress. In some cases, companies provided examples of their own decision tools and information regarding past projects. The information was gathered into trip reports for documentation to be accessed later for product development. Additional information gathered also included company literature such as informational products including flyers, pamphlets, videos and official internet sites. Trip reports were presented to the respondents and to the project team members for review and verification of the accuracy of the information recorded.

TRIANGULATION AND VERIFICATION OF DATA

In order to determine validity of the data collected, the data from the site visits was analyzed via triangulation with past research and expert opinion. Survey results from past research by the University of Texas were compared to the data collected. Team members with experience in prework also confirmed data collected through the site visits.

DECISION FRAMEWORK DEVELOPMENT

Academic team members began the synthesis of the data by developing drafts of decision frameworks. The framework structures and data were developed based on the data collected. The data included the trip reports, literature review information, and existing decision tools used by companies to determine the use of prework. These drafts were presented to the project team for revision. The frameworks were then completed based on the team's input and included as one of the products for CII for dissemination throughout the construction industry.

Chapter 4: Data Collected

OVERVIEW

In order to provide the most recent and relevant data for the development of the proposed decision frameworks, site visits and interviews were conducted. Companies were chosen for data collection based on expert opinions of team members experienced in the use of prefabrication, preassembly and modularization. Data was collected from a variety of project participant types and focused primarily in the industrial sector, since the team was composed of mostly members involved in this type of construction. Project participant types included owners, designers, contractors and suppliers of prework. The goal of the sample size was not statistical relevance but a snapshot of the current state of the art in prework. Overall, companies selected were involved in a broad range of activities and typically larger industrial projects. Table 4.1 lists the companies involved in the data collection, as well as the type of project participant. This chapter is meant to be a summary of the data collected. A complete copy of the data collected can be found in the trip reports, located in Appendix B.

Table 4.1: Companies involved in data collection

Central Texas Ironworks	Supplier, structural steel products
Eli Lilly Co.	Owner, pharmaceutical products
McAbee Construction.	Supplier/contractor, industrial
US Steel	Owner, raw steel manufacturing
BE&K	Contractor/Engineer, industrial
Jacobs Applied Technology	Engineer/contractor/fabricator, industrial
ProQuip	Engineer/contractor/fabricator, industrial
Prosser	Engineer/contractor/fabricator, industrial
Fluor Daniel	Engineer/contractor, industrial
Howe-Baker	Engineer/contractor/fabricator, industrial

CENTRAL TEXAS IRONWORKS

Central Texas Ironworks (CTIW) mainly prefabricates steel structural and supporting components for large capital projects. Key features of the company's processes include the use of electronic transfer, bar coding, 3D CAD, database integration, partnerships with customers and plant layout efficiency. Each of these components contributes to the requirements of prework, mainly by addressing design and coordination concerns.

Since prework requires a larger amount of communication due to the need for earlier collaboration and coordination of multiple work locations, the use of information technologies has further enabled CTIW's fabrication of prefabricated components. Through the use of electronic file transfer capabilities, CTIW designers are able to receive structural designs via the internet to be used in detailed design of connections and components. Since design information is often needed earlier in the project life cycle for prefabrication, faster transfer of design data via internet helps facilitate the process. 3D CAD software enables faster detailing of drawings and development of shop drawings for the fabricators. Automatic generation of some shop drawings can be directly sent to an internal database for the computer-controlled fabrication, reducing turnaround and potential for reading errors.

The database containing the design information is linked to the materials management database and the company extranet. Certain materials receive bar codes during the fabrication process that are linked to the database. From the company extranet, customers have a controlled amount of access to component status in the database. Customers can coordinate project activities with the shop fabrication. To further aid in communication and coordination, CTIW promotes partnering with its customers. Partnering reduces redundant project processes and communication.

The layout of the facility also affects efficiency of the prefabrication process. In addition to the links with material databases and design information, the work areas are laid out to optimize fabrication. Work flows from raw material laydown areas to each sequential part of the fabrication process with minimized material handling. Each station is linked to the design database reducing the potential for fabrication error. The large fabrication equipment allows faster and more accurate construction of the components.

Contrasted with more conventional methods of field construction of components, the integration of fabrication and design helps to reduce rework potential and expedite construction.

The required increase in coordination and communication requirements relevant to prework is further facilitated by CTIW's use of information technologies, client relationships and fabrication area layout.

ELI LILLY CO. INC.

Eli Lilly is an owner of large capital facilities for the manufacture of pharmaceutical products and has been involved in the use of modularization techniques for the construction of some capital facilities. Some projects include plants for producing bulk chemicals and finishing facilities for manufacturing drug delivery products such as pills and capsules. Eli Lilly's business requirements and the nature of the pharmaceutical industry help to drive the use of prework techniques. Drivers include business needs, time to market issues, safety and risk reduction. Major impediments include internal company resistance to prework due to lack of experience with the techniques and tighter planning requirements. The company found that overcoming these impediments were accomplished by involving experienced designers and contractors, as well as more subjective decision making by company champions of prework rather than detailed decision analysis.

The business and nature of the pharmaceutical industry produce many factors that drive prework. Time to market can be a critical factor since the timing of product introduction to the market place can have impacts of revenue and market share. The ability to make later decisions regarding whether or not to go forward with a project is facilitated by prework through parallel and offsite activities. Shorter project life cycle translates into late decision-making capability. Additional benefits include the ability to delay projects for business reasons and decrease time to market. Lilly has been able to delay projects without extending completion dates, reallocate money to other projects while delaying construction and also provide opportunities to obtain more accurate design information. Decreased time to market also assists Lilly in delivering products as soon as regulatory approvals are issued.

Beyond business and industry specific drivers, safety and risk reduction are seen by Lilly as further reasons for implementing prework. It is believed that safety increases due to the increased amount of work done at ground level. Modular units for one finishing facility were constructed in units no taller than 14 feet. Safety risk is therefore reduced due to reduced exposure to high work. Other forms of risk reduction include reduced risk of building unnecessary projects or projects lacking useful longevity. By shortening the life cycle process, projects can be built later when market conditions are clearer. The use of modularization also promotes expansion and salvage capabilities when a facility reaches a point of inefficiency. For example, modular layouts can be designed to accept future expansion of production by adding modular units. Furthermore, components can be designed for easier replacement, removal or relocation when industry conditions dictate.

Key requirements for implementing prework and overcoming impediments primarily involve education of project participants and increasing planning for projects. Overcoming impediments such as cultural issues, transportation requirements and scheduling for long lead items were felt to be the keys to the success of modular projects. Cultural issues mainly included lack of experience or knowledge of modular construction by the company's engineering and construction staff. This was primarily overcome through high-level subjective decision-making regarding modularization and involvement of experienced designers and contractors. The project team identified additional planning requirements for transportation of modules and long lead items such as large equipment early in the project to overcome these impediments.

MCABEE CONSTRUCTION, INC.

McAbee Construction, Inc. is a supplier and contractor involved in prefabrication, preassembly and modularization of components for industrial construction projects. The company believes the main drivers for the decision to implement prework include labor and schedule requirements. The main obstacles identified include overcoming client and designer preconceptions about prework and handling the increased planning requirements and information transfer required on prework projects. Key methods for helping these impediments include the use of 3D CAD, extensive team building, and the electronic transfer of information.

The company identified labor issues and schedule requirements as main drivers for the use of prework. In project locations where skilled labor availability and productivity was lacking, part or most of a project can be relocated to a shop environment more conducive to project objectives. The company claims higher productivity in the shop compared to the field due to factory conditions and lower wage requirements. Factory conditions such as indoor work, lower working heights, more efficient tool and equipment layout, and proximity to support elements such as raw material and engineering are believed to promote increased productivity. In addition to labor issues driving prework, schedule considerations are seen as significant. Delays in permitting for projects, existing operations on site and market considerations are seen as some of the main schedule drivers for modular and other types of prework. Work can be completed offsite while permits are awaiting approval. Work onsite and impact to existing operations can be minimized by modularizing or preassembling large portions offsite. Components can be tested and verified at the shop location to minimize start up time after field installation.

The main impediments to prework include client and designer preconceptions and planning and information transfer requirements. It is the company's experience that many clients still have misconceptions regarding operability and maintainability of modular designs. Contrary to the cramped design of older modular skids, the company makes attempts to express the carefully laid out designs of newer modular and preassembled projects. This is primarily achieved through the use of 3D CAD models and examples of existing facilities built using prework. 3D CAD allows clients to "walk through" modular layouts before approving design or beginning construction. An additional impediment to the use of prework includes a required paradigm shift in thinking on the part of the designer. Many designers are typically not schooled in modular design and the art of layout for shipping envelopes. This impediment is typically overcome through team meetings and involving all parties in the design process.

Planning and information transfer requirements generally increase on projects involving prework. Increased preplanning and involvement of the owner, designer, contractors, operators and suppliers are keys to successful implementation. This coordination and planning is handled through a team-oriented approach. The team composed of the project participants has regular meetings at different stages of the project

design. Electronic data transfer and email is used to expedite communications, help reduce overhead and paperwork and increase documentation.

US STEEL

US Steel is a large owner company involved in the production steel sheeting and piping stock material for other industries. Capital facilities include large, equipment intensive industrial projects for manufacturing steel. The company has experience using modularization and preassembly for the construction of its facilities. These methods have been driven by goals of outage minimization, testing verification of equipment and risk reduction. Main impediments to the use of prework were identified as increases in preplanning and engineering. Prework is mainly used for equipment or assemblies to be installed during outages with heavy emphasis on pretesting and verification. Constructability reviews, electronic data transfer and partnering are primary methods of overcoming impediments.

The primary driver of the construction of new capital projects for steel production facilities and therefore the usage of prework is the minimization of outage of steel production. Whether the project is designed to upgrade to meet environmental regulations or increase production capacity, the project must minimally impact existing operations. Conversely, the construction process must be protected from safety risks associated with building near ongoing operations. To achieve these goals, many components of construction projects are prefabricated, preassembled or modularized. For example, if a new piece of production equipment is to be installed and it will require a shutdown of the existing facility, every effort is made to preassemble and test the components prior to installation. In addition to reducing the shutdown period and start up time, fieldwork and therefore exposure to hazardous operations is reduced.

Overcoming the impediments associated with prework is handled in several ways. Increased preplanning and engineering associated with prework is generally preferably handled through partnering. By partnering with the project participants, the team atmosphere helps to handle the increased planning and coordination required for prework. Planning transportation requirements and routes, coordinating design information with shutdown schedules and construction considerations are achieved through constructability

reviews. Email and electronic file transfer are used to reduce information request lead times and increase documentation.

BE&K

Handling both engineering and design of industrial projects, BE&K has experience with many types of prework. These mainly include prefabricated and preassembled structural and mechanical components. Some company managers have been involved in modularization in the past but the methods are not typically used currently. Main driving forces for the use of prework include safety, schedule requirements including outages and various labor issues. Major impediments to using prework include lack of industry experience, increased laydown space requirements and increased engineering costs. Key methods of overcoming impediments include contract incentives and improved design and information transfer technologies.

Safety, schedule and labor requirements represent the main drivers for prework use. The company and clients believe that the use of prework decreases safety risk due to reducing high level work. For example, construction of structural steel frames for chemical process facilities may be erected by floor at ground level and lifted into place upon completion. Other examples include prefabricated concrete columns, beams and wall structures built in a factory. Components arrive on site in sequence complete, reducing the need for high formwork or scaffolding. In general, moving work offsite or offplot has the potential to reduce exposure.

Schedule has also driven the use of prework. Outage constraints and time to market issues have required schedule compression and parallel work activities facilitated by prework. Parallel activities have been achieved through prework of structural components. Foundations and other civil work can be handled while prefabricated or preassembled activities occur in parallel. The result is schedule compression to meet the project objectives.

Labor issues play a role in the selection of prework methods. If the current industry or project area lacks adequate skilled labor, prework may provide opportunities to relocate work to areas with more skilled or productive workers. In some cases, increased safety

characteristics of prework have helped to attract and retain workers. For example, some workers prefer to work at ground level preassembling steel rather than high work.

In order to benefit from prework and satisfy driving forces, the company has identified experience issues, increased space and planning requirements as major impediments. Lack of industry experience with prework methods has provided challenges initially to the use of prework. Improved visualization through 3D CAD has helped to analyze prework options and convince clients that operability and maintenance will not be compromised by prework designs. These advances in design have also allowed engineers to reduce drawing rework and identify interferences prior to construction.

Space and information requirements pose challenges in addition to the experience issues. Projects utilizing on site preassembly require additional laydown space for the ground level work. One estimate for preassembling structural components required 50% additional site space in addition to the facility footprint. Other considerations include increased planning and engineering. Increased planning and coordination is facilitated through the use of electronic communication via email, project internet sites and electronic drawing transfer. These technologies have improved communication and coordination between multiple sites. Estimates for engineering increases range from 5-10% more for certain prework. For example, the steel preassemblies required additional design for component lifting rigs and center of gravity calculations.

JACOBS APPLIED TECHNOLOGY

Jacobs Applied Technology provides design and construction of prework solutions, mainly modularization, for the industrial process industry. The company has identified many drivers for using modularization ranging from business to project site-specific characteristics. Major business drivers include time to market, financial viability and technology protection. Primary project drivers include schedule, cost, site constraints, permitting and impacts on existing operations. Impediments to the use of prework mainly consist of transportation constraints and experience issues. Formal decision tools, integrated 3D CAD systems, computer communication technologies and company experience help to alleviate impediments and identify driving factors.

Drivers and impediments play a major role in the decision to implement modularization. The company uses subjective and uncomplicated decision methods to identify drivers early in the project during planning stages. After inquiring about general project drivers such as schedule, safety and labor conditions, possible constraints including transportation limitations and equipment size are identified. Through this decision process and the use of expert judgment, levels of prework for a project are determined. In many cases, one issue can emerge as a primary driver or impediment of modularization. For example, a site located in a remote and harsh environment may dictate the use of modularization regardless of other factors such as schedule and transportation requirements. Conversely, a site lacking transportation access or is too costly to upgrade local routes may require more conventional construction. In either, modularization was dictated or excluded early in the project based on broad factors.

Once the decision to modularize has been made, 3D CAD and other computer technologies are used to overcome challenges involving increasing client awareness of modular layouts, as well as increased requirements for planning, coordination and engineering. The company uses 3D CAD to help clients visualize projects before construction. Design review meetings allow project participants to walk through projects to address concerns regarding constructability, operations and maintenance. Integration of material management information with the 3D model allows faster access to and coordination of project information. 3D CAD also expedites design by identifying interferences and reducing design and construction rework. Other computer technologies such as email, electronic file transfer and offices linked via intranet have helped facilitate the increased communication and coordination required of modularization projects.

PROQUIP

ProQuip is a turnkey provider of industrial process facilities. Prework consists mostly of modularized unit, with preassembled and prefabricated supporting elements. The company provides design, fabrication and installation. Main factors for implementing modularization include site conditions, labor rates, safety requirements and schedule requirements. The main obstacles to implementation are typically transportation requirements, coordination issues, labor unemployment and industry misconceptions

regarding modular design. Emphases on company organization and prior work experience have been ways to counter the impediments. By promoting efficiencies in organizational structure from concept to installation, the company has worked to improve the turnkey process. The company has also worked to alleviate misconceptions by showing perspective clients prior successes through site visits.

Site conditions, labor rates, safety requirements and schedule requirements were specified as the primary drivers. Site conditions may include limited plot space, remote location, and extreme weather. Congested plot spaces surrounded by existing operations or adjacent properties may provide opportunities for prework. Relocating work could reduce congestion and craft density on site. Remote locations lacking infrastructure for field operations may benefit from prework at more adequately supported location. Extreme weather may also drive prework, since elements such as extreme temperature or precipitation may hinder fieldwork.

In addition the site conditions, labor rates were particularly identified by the company as key. A major labor driver identified was the difference between labor in the fabrication shop versus equivalent work done in the field. Cost savings resulting from transferring hours to the shop may offset additional costs of coordination, engineering and transportation. Some company officials estimated that shop productivity could be 30-50% better than field with a 20-40% reduction in hours required to complete the work. The result could potentially include both cost and schedule reduction. In addition to shop labor driving prework via cost and schedule reduction, additional concerns such as adequate labor availability are also potentially addressed through prework. Relocating field hours to the shop may alleviate skilled labor shortage problems related tot the site location.

Safety and schedule requirements were also seen as major factors driving prework. By transferring hours offsite, prework may reduce craft density and total craft hours on site. Additionally, work offsite is typically conducted in a controlled climate, at ground level and away from ongoing operations that may present hazards. Schedule requirements may also be facilitated by the use of prework. Obtaining market share and time to market requirements have been factors influencing many prework projects.

Overcoming the impediments regarding industry misconceptions, transportation requirements, increased coordination requirements and labor unemployment have been

keys to prework implementation. Industry misconceptions were similar to the impediments identified in other interviews. The company found that many clients still view modular construction as cramped, difficult to maintain, expensive to ship and difficult to install. The company primarily uses past experience and site visits to successful projects to demonstrate accessibility, maintainability and feasibility of modular designs. While the company is moving towards 3D CAD to among other reasons improve customer visualization, the company has been satisfied with site visits and case studies to promote their work.

Transportation and coordination requirements have typically been handled through the company's experience and through organizing overall structure to facilitate turnkey projects. Transportation limitations may be dictated by accessibility to the site. For example, barge access would allow larger prework assemblies such as large modules and preassemblies. Road access only would require smaller prework units. Any additional costs associated with access would have to be weighed against the benefits.

The company has addressed increased requirements for engineering, coordination and communication by improving company organization. This organization takes place at different levels, from organization of disciplines to fabrication shop layout. Sales and engineering offices are integrated into the same office, with fabrication facilities nearby within the same city. Engineering tools and fabrication equipment efficiencies are stressed over high technology. For example, 2D CAD has proven sufficient for design. Fabrication equipment, while older technologies prevail, efficiency is maintained through precise layout and skilled craft workers.

PROSSER

Prosser is involved in the modular design and construction of chemical process facilities. While a site visit was not applicable at the time of the study, information was provided via a company promotional video and a company website. Benefits associated with modularization were consistent with other modular providers. These benefits included reduced safety risk due to indoor, ground level work; schedule compression due to parallel activities, higher productivity, and reduced risk; and cost savings associated with labor factors.

The company outlined a basic decision tool called the “Modular Analysis Program.” The tool covered questions regarding site conditions, labor issues, transportation access, equipment type and other factors. All factors were considered drivers or impediments to implementing modularization. Each question was ranked according to how it influenced the applicability of modularization. For example, a site with poor weather conditions may score high on the survey for modularization. Conversely, a site with very limited access may score low. A final score is given with a range for varying degrees of opportunity, as well as breakdowns of areas such as labor and site conditions.

The company also worked with a large contractor to develop conceptual cost comparisons of modularization versus conventional methods. Differentials between projects included labor cost and productivity rates, engineering costs and transportation costs. Labor cost and productivity rates were a primary driver, with high cost and lower productivity rates of field labor driving the work towards modular construction.

FLUOR DANIEL

Fluor Daniel is a large designer and contractor involved in industrial construction. The company employs prefabrication, preassembly and modularization on many projects. The use of modularization is often decided early during project preplanning and is primarily driven by project and site conditions. Preassembly and prefabrication are mainly considered later during detailed design or construction. These forms of prework are primarily cost issues. Impediments to either of the prework types include obstacles to transportation, increased planning and coordination, site laydown area requirements, and site/contract constraints.

Site conditions and project drivers mainly drive modularization. Remote locations and extreme weather were typical rationale for modular work. For projects involving modularization, decisions to implement modular are typically made early in the project during conceptual design. For project participants unfamiliar with modular issues, the company holds a brief seminar on the benefits, impediments and considerations to be made. Past modular example are presented to highlight individual points. This helps to educate participants and facilitate a team atmosphere, helping to overcome impediments regarding experience, communication and coordination issues early in the project.

Once the decision to use modularization is initially made, the EPC team develops a cost and schedule comparison to conventional methods to determine more precise feasibility. The cost estimate determines costs removed from the site, as well as additional direct and indirect costs. Cost removed from the site may include field hours and engineering design hours moved to the shop. Additional direct costs may include additional engineering required, transportation costs and any added fees or duties. For indirect additions, items may include increases in office staffing to handle expediting or permitting. From these three categories, a cost delta is developed to determine feasibility.

Schedule impacts resulting from modularization are also analyzed as part of the decision process. Impacts resulting from parallel activities, productivity differences between shop and field, and the effects of altering craft density are all taken into account. The result is compared to conventional methods to aid the decision.

For other prework methods, such as prefabrication and preassembly, the decision to implement is typically made later in the project and more from a pure cost analysis. It is the company's experience that while modularization is driven by project and site factors, prefabrication and preassembly are dictated by cost. Where decisions for modularization may involve broader scope and education of the client, other prework method decisions are more straightforward.

In order to handle the increased engineering, communication and coordination issues related to all forms of prework, the company has incorporated advanced computer technologies. 3D CAD, bar coding of materials, 24-hour engineering and electronic transfer of information have all been incorporated. 3D CAD is heavily used on projects to identify interferences and improve project visualization. Bar coding of materials has helped to manage, track and identify components. Since offsite work increases the amount of tracking and transportation needs, bar coding assists with the management of materials and equipment. The use of 24-hour engineering with global engineering offices and electronic file transfer, increases in engineering, communication and coordination can be handled.

HOWE-BAKER

Howe-Baker Engineers Inc. is a firm involved in the design and construction of facilities for the industrial process industry. Modularization makes up approximately 50% of the work with preassembly and prefabrication throughout projects. Key drivers are typically site conditions, labor issues, project type and safety concerns. Site conditions include weather risks, ongoing operations and access. Labor issues typically include lack of adequate labor, high cost of field labor and organized labor considerations. Project type may drive prework if involving congested piping or equipment, unusual alloys or increased amounts of high-level work. The later also addresses safety considerations in what the company's sees as an increasing safety culture in construction.

Impediments to the use of modularization include client awareness, as well as increased engineering, coordination and transportation costs. The company works to increase client awareness of modular design efficiencies by producing successful projects in the form of case studies or site visits. While the company has the capability to use 3D CAD for these purposes, they do not feel it is cost effective. 3D CAD is used however to improve the engineering process. Complex piping and electrical systems generally associated with modular work can be more easily designed in 3D. Interference checking and visualization of complex areas are both better facilitated with 3D as opposed to 2D design.

Overcoming impediments related to engineering, coordination and transportation are seen as key to modular success. Modular design often requires additional steel to reinforce modules during fabrication, transport and erection. Since over designing reinforcement may negate cost benefits, structural engineers work closely with other disciplines to optimize design. This coordination takes place in the form of in-house interdisciplinary collaboration meetings held several times during the design process. Additionally, disciplines work in close proximity to each other to facilitate increased communication. Impediments associated with transportation issues are handled by a dedicated expediting staff. These people handle routing, permitting and other considerations specific to transportation of prework.

The decision to use modularization or other forms of prework is typically handled by staff early in the project. Rather than a formal procedure, flowchart or checklist, the company bases decisions on the experiences of seasoned staff members.

SUMMARY

Many common themes emerge from the information collected in the site visits. The data collected identified many key characteristics common to the prework industry, shown in Table 4.2.

Table 4.2: Summary of Key Characteristics of the Pework Industry

- Careful selection of prework is part of a spectrum
- Pework complexity determines decision timing
- Pework generally requires:
 - Earlier decision making
 - Integrated involvement of project participants
 - Detailed analysis of labor differentials
 - Overcoming lack of industry knowledge
 - Detailed transportation planning and expediting
 - Thorough shop testing and verification
 - Careful supply chain management

Careful selection of prework is part of a spectrum rather than all or nothing. More recently, companies involved in prework have worked to emphasize that the question regarding use of prework is not, “To use or not to use,” but rather, “How much should be used to maximize benefit?” Pework should be deliberately applied to areas of a project and not applied across the board as a percentage of work.

Pework complexity generally determines decision timing. Timely, informed decision making about prework can payback the investment in the time it takes to make the decisions. Each of the companies involved in full modularization stressed the importance of early decisions during pre-planning when using high degrees of prework. In cases with a lesser degree of prework, such as prefabrication used by BE&K and Fluor Daniel, decisions could often be delayed until later in the project during detailed design.

Regardless of the type of prework, every company stressed the importance of coordination of all involved parties. For example, Howe-Baker stressed this coordination through regular meetings between various design disciplines to coordinate interfaces and routing of various components.

Careful analysis of labor differentials was a common factor in determining prework feasibility. Moving work off-site takes advantage of lower wages available in shops and potentially lower costs related to equipment and overhead. Each of the companies carefully evaluated the differences in wage rates, productivity, overall risks, equipment and overhead costs associated with labor. Companies also used prework to address the skilled workforce shortage by replacing mobile, site based, skilled labor with less skilled, but steadier shop based labor which is easier to access for projects.

Overcoming lack of industry knowledge was seen as another key factor in successful use of prework. Many providers of prework convinced less educated project participants that the latest prework could be designed to address maintenance and operation requirements better than the cramped skids characterizing prework 20 years ago. This effort is achieved in many ways, from the site visits to existing facilities performed by ProQuip to the 3D walkthroughs designed by McAbee Construction, Jacobs Applied Technology and Fluor Daniel.

For adequate use of prework, each case required extensive transportation planning and expediting. Careful analysis of shipping options and routes often dictated size and extent of prework. Howe-Baker maintained a specific department to solely handle expediting of equipment and other prework. Fluor Daniel extensively planned transportation routes, including options for expanding or improving infrastructure to meet the optimum prework size requirements.

Each of the companies stressed thorough shop testing and verification of prework components. For example, US Steel particularly took advantage of this to reduce outages to the steel furnaces and production lines. By testing equipment prior to installation, shutdown times could be minimized.

From a supply chain point of view, prework as a form of outsourcing lets the work be done where it is done best and cheapest, and it allows us to take advantage of economies of scale when projects can be assembled from off-the-shelf modular

components. Each company went to great lengths to monitor and maintain records of prework on and off the site.

In addition to these key characteristics of the prework, the data also revealed key enabling technologies that support the use of prework, shown in Table 4.3.

Table 4.3: Summary of Key Enabling Technologies

- | |
|--|
| <ul style="list-style-type: none">• Advanced computer design and visualization• Improved communication through IT• Advanced factory fabrication equipment• Advanced tracking technologies |
|--|

Each of the companies interviewed utilized some form of advanced computer design. The levels of use varied from well integrated 2D computer drawings to highly sophisticated 3D systems connected to component databases and producing walkthrough capabilities. The example of modularization in the pharmaceutical industry represents a case where 2D CAD was successfully used to track modular interfaces. Some cases, such as the examples for Jacobs Applied Technology, utilized 3D modeling to check interferences and connect to component information. Furthermore, McAbee Construction used 3D CAD to improve visualization and aid in educating parties with less experience with prework. The use of 3D CAD generally pays off in terms of communication, interference checking, re-use of design elements, and future application of automated design algorithms and intelligent web agents, but it requires some sophistication and corporate size.

All of the companies involved utilized information technologies to some degree to aid in the coordination efforts required of prework projects. The use of email and electronic file transfer was widespread. Some companies went further to develop intranets for in-house communication or limited client access. This can be clearly seen in the CTIW example. Other examples of IT use include digital imaging. Monitoring progress and identifying possible vendors through digital imaging was evident in the US Steel example of shopping for equipment in Australia via digital pictures and the internet.

Advances in computer-controlled equipment have also provided enablers for the prework industry. Prework facilitates the application of productivity enhancing automation such as robotics much easier than site work. Examples include CTIW's plasma steel cutting tables and McAbee Construction's automated vessel welders.

Prework may also benefit from advances in tracking technologies. By minimizing the total number of units used to construct a facility, prework should make materials management easier and make applications such as radio frequency tagging and bar coding more economical, since fewer expensive tags would be required. CTIW and US Steel have both implemented such technologies and connected them to material tracking databases.

In order to further show these comparisons between the companies with regards to these issues of technology and practices, Table 4.4 lists the characteristics of each including technology, decision tools and prework methods, as well as transportation capabilities. Most companies interviewed were involved in all three types of prework. Level of use with CAD varied. Some companies were involved in simply 2D CAD to check for interferences between systems and prework components. Companies classified as 3D CAD-Low used 3D CAD for design and coordination. Companies classified as 3D-CAD High used software not only for design and coordination but also for 3D walkthroughs or other types of animation beyond the design requirements. These technologies enabled increased visualization for prospective clients, as well as for project participants including operators and maintenance representatives. The next technology category includes digital imaging. Companies in this class used digital imaging and photos transferred electronically to communicate ideas and information. The final technology category is the internet. All the companies interviewed used the internet for electronic communication such as email and transferring files. This was clearly an industry standard, while 3D CAD and digital imaging has yet to gain complete acceptance.

Decision making techniques varied from company to company. While most agreed that a standard decision framework would be useful for determining prework feasibility both for internal and client justification, few companies had made efforts to develop tools or utilize tools already on the market. Companies classified as using the "in-house expert" method relied on the judgment of experienced project managers and data from previous projects. While this worked in most cases, these companies admitted that a third party tool

would be useful in justifying numbers to clients and also assisting less experienced staff with decision-making. Some firms developed tools in-house, such as Jacobs Applied Technology and Prosser. These tools combined the in-house expertise to develop a prework decision tool specific to their company. Only one of the companies interviewed, Fluor Daniel, revealed that that use an outside tool for analysis. Fluor Daniel uses MODEX to supplement in-house expertise.

Transportation capabilities, a key part in determining prework ability, were also tracked and listed in table. This included access by road, rail and barge and is described in detail within each company's trip report in Appendix B.

Table 4.4: Characteristics of Companies Interviewed

	Type of Prework			Information Technology					Decision Making			Transport		
	Prefabrication	Preassembly	Modularization	2D Checking	3D CAD-Low	3D CAD-High	Internet	Digital Imaging	In house expert	In house tool	Outside tool	Road	Rail	Barge
Central Texas Ironworks	X				X		X		X			X	X	
Eli Lilly Co.	X	X	X	X			X	X	X			X	X	X
McAbee Construction.	X	X	X			X	X	X	X			X	X	X
US Steel	X	X	X		X		X	X	X			X	X	
BE&K	X	X			X		X		X			X	X	X
Jacobs Applied Technology	X	X	X			X	X			X		X	X	X
ProQuip	X	X	X	X			X		X			X	X	X
Prosser	X	X	X			X	X			X		X	X	X
Fluor Daniel	X	X	X			X	X				X	X	X	X
Howe-Baker	X	X	X		X					X		X	X	X

Chapter 5: Decision Frameworks

OVERVIEW

The successful application of prework in construction requires good decision-making. The site visits and literature has shown that good decision-making begins with a clear understanding of the potential benefits and impediments to a project resulting from the use of prework. Depending on the nature of the project, participants and the prework, the analysis can vary. Analysis elements such as timing, information requirements, levels of involvement and communication requirements all factor into the decision process. Through the information gathered and research team feedback, decision frameworks were developed to aid project teams in determining the type and amount of prework best suited for a project.

In order to handle the varying requirements, several decision frameworks are proposed. These frameworks are presented as guidelines and represent the state-of-the-art in decision making at the time of the research. While large amounts of information went into development, the frameworks are mainly designed to promote thought among project participants rather than provide a complete solution. Projects by nature are generally unique and characteristics can vary greatly. While data for the framework development primarily came from industrial projects, the framework designers made efforts to allow flexibility and maintain relevance to many types of projects.

Since prework is considered more of as a spectrum of complexity than a all or nothing practice, the use of the decision frameworks suggested must allow for variable timing of decision making. Also, the degree to which a company requires justification of prework use will also determine the extent to which each framework is used for a particular type of prework. For example, one company may be comfortable basing its decision to use offsite preassembly on the results of a relatively subjective analysis of the project drivers and impediments at the strategic level. Another company may feel more comfortable with authorizing certain forms of prework only after thorough and detailed cost analysis. For these reasons, a decision timing map was developed by the research team to identify windows of opportunity. The map helps to guide the user through the timing of