Knowledge-Based Approach to Modular Construction Decision Support

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Abstract: The present paper focuses on the decision-making methodology involved in deciding whether or not to use modular construction techniques in building a petrochemical or power plant. The paper identifies those factors that help construction owners and engineers involved in conceptual project design in their modularization decisions and proposes a formal framework for decision-making support. A computerized knowledge-based system assisting in this task is presented and discussed. The system performs feasibility analysis based upon various factors classified into five influencing factor categories—plant location; labor-related; environmental and organizational; project characteristics; and project risks. The system also performs an economic analysis to determine the impact of modularization on cost and schedule. The performance of the system is validated comparing its recommendations with those of the experts in the construction industry. A statistical hypothesis test, conducted on the recommendations of the system and those of the experts, proves the system's credibility.

Introduction

A module is a product resulting from a series of remote assembly operations. It is usually the largest transportable unit or component of a facility. A module consists of a volume fitted with all structural elements, finishes, and process components that, regardless of system, function, or installing craft, are designed to occupy that space. Modules may contain prefabricated components or preassemblies and are frequently constructed away from the job site (Tatum 1987). However, for large-scale projects, the modules may be fabricated on site if space is available.

In the initial stages of industrial and commercial project designs, construction owners and engineers are often faced with decisions involving the pursuit of one of the two options in project realization: modular or traditional design and method of construction. The research presented in this paper compiled the knowledge for decision support and presents a computer system application that makes it possible for professionals in the industry to run a detailed feasibility study for modularization quickly and easily. The system is intended to be used by project managers, project engineers, construction site managers, project control managers, operation managers, engineering managers, and construction managers during the conceptual stage of a project.

According to some projections for the future, modular construction has the following advantages over jobsite assembly (Perkowski 1988):

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J. Constr. Eng. Manage., 1993, 119(1): 115-130

- Time is saved since more assembly work can be done in parallel with on-site activity.
- All interfaces are tested earlier.
- "As-built" drawing documentation is minimized, thus reducing error-omission potential.
- Labor costs are usually lower due to the existence of a relatively stable labor force in a factory environment unhampered by weather or physical jobsite constraints on assembly.
- A learning curve can be derived from experience on similar units, as well as from the supervision of available on-site Quality Assurance/Quality Control staff.
- Factory fabrication usually has a greater potential for automation than construction site.
- More cost-effective selection of fabricators is available, especially if offshore options exist, within a lump-sum bidding environment.

Despite the advantages just listed, modularization is not used on a widespread basis. According to Mullett (1984a, b, c, d), the reasons for this are the following:

- Modularization entails more engineering than traditional design and construction methods.
- It requires more materials and additional work to assemble these materials.
- It requires a more expensive mode of transportation.

The feasibility of construction modularization depends on the specific project, organizations involved, social, legal and environmental conditions, and so forth. In some obvious project environments, such as remote site, harsh weather conditions, etc., modularization is the only feasible choice, and in other situations, the decision to modularize is not so obvious. Therefore, at the initial stage of a project, management has to make a decision whether or not to further investigate the modularization potential. Under certain conditions it is relatively easy to decide to use modularization, for example, when building offshore production platforms, Arctic oil production, or desert area processing facilities. However, in not-so-obvious cases, for ill-perceived convenience, and due to the lack of adequate decision support, owner's management does not even consider modularization as an option to conventional methods.

The writers have compiled the expert knowledge for decision support that enables the decision maker to perform an initial feasibility study on the use of modular construction technology. The motivation of this effort has been threefold:

1. Because of the lack of documented sources of information about modularization decision support, there is a need to compile knowledge obtained from experts in the field into a structured resource.
2. Due to the absence of a systematic process to perform a feasibility study related to the options of implementing modular technology on a proposed project, there is a need to produce one.
3. Based on feedback obtained from large owner and construction firms,

there is a need for a computer-based application tool to aid in the performance of an initial modularization feasibility study.

These objectives are achieved by identifying those attributes that help in deciding whether or not to use modular construction, by developing the criteria for decision making, and by developing a computerized framework for decision making.

Past Studies on Modular Construction

During the early 1980s several authors wrote on the subject of modular construction, primarily based on their own experiences working on projects involving some degree of modularization. In a comparative study of modular and barge-mounted plants versus conventional stick-built plants, it was found that there are potential savings of about 10% in the capital cost of a project if the modular construction method is used. This saving is the result of substantial savings possible during the construction phase that more than compensate for their higher design and engineering costs (Glaser et al. 1979; Kliewer 1983; Marcin and Schulte 1982).

In various studies of modular projects, it was found that the construction methods used at the module yards result in substantially improved productivity due to the controlled manufacturing-type environment. The net result was reduced overall project cost and improved schedule for projects requiring large amounts of imported labor (Zambon and Hull 1982; Glaser and Kramer 1983).

A plant that is to be built in a modular fashion poses some difficulties. Design must be decided upon earlier, changes are more difficult, and there is additional design of steel work. Lifting and transport costs are larger. Nevertheless, with an early decision on preassembly and modularization these problems can be handled easily (Whittaker 1984; Tan et al. 1984). The ultimate impact of modular construction should be reduced project capital costs as well as a broad slate of intangibles that will positively impact overall corporate profits (Clement and Brock 1989).

A detailed study of the subject was performed by Tatum et al. (1987) in a report to the Construction Industry Institute. They conducted a study of the major modular projects from initial decision to final design. None of the authors referenced previously, however, has developed a comprehensive decision methodology that can provide assistance to an inexperienced or even an experienced project manager in the decision-making process for modularization.

In the past, modular construction methods were used only when certain project constraints were present, such as underdeveloped and remote construction site, a construction site with hostile environmental conditions, a construction project requiring special tools, skills, or techniques that were available only in controlled shop environment. In those situations, the advantages of modularization were: (1) Fewer, less-skilled field workforce required; (2) fabrication, assembly, and testing of major sections of the plant was accomplished by skilled labor in an environmentally controlled shop, which usually results in a more reliable, higher quality plant; and (3) an earlier on-line completion date than would otherwise be possible, with resultant overall cost savings and a better rate of return.

As can be seen from these studies, the final decision whether or not to modularize involves a multiattribute/multicriteria decision-making process.

J. Constr. Eng. Manage., 1993, 119(1): 115-130

It depends entirely on the individual project characteristics. The decision maker has to look at various project-related factors (such as location, transportation costs, labor availability), identify his/her objectives (e.g., cost minimization, reduction in schedule) and select the proper method—modular construction, conventional construction, or a combination of both.

Relevant Decision Methodologies

In general, multicriteria decision-making problems can be solved by using mathematical programming, simulation, decision analysis, and other statistical procedures or artificial intelligence/expert systems (Mitra 1988). For construction method selection problem, the last two procedures need special consideration.

A wide variety of problems that require choosing, evaluating, planning, and allocating resources, and assessing risk can be represented and analyzed by applying one of the quantitative methods of decision science. One of the commonly used methods in decision analysis is the weighted-factor method. In this method, the decision maker, using a consistent scale, such as 0 to 10 or 0 to 100, provides the relative weights to each criterion and a rating of each alternative, based on each criterion. Subsequently, the total rating for each alternative is computed as the summation of criterion weight multiplied by rating of the alternative, based on that criterion. The alternative that receives the highest total rating is selected as the best.

Also, classification or discriminant analysis can be used for solving multiattribute problems. Discriminant analysis and classification are multivariate techniques concerned with separating distinct sets of objects (or observations) and with allocating new objects (or observations) to previously defined groups. Discriminant analysis is exploratory in nature and is often used on a one-time basis in order to investigate observed differences when causal relationships are not well understood. Classification procedures are less exploratory in the sense that they lead to well-defined rules, which can be used to optimally assign a new object to the labeled classes (Johnson and Wichern 1988). Discrimination and classification methods are not appropriate here since the decision maker may not know the value of a certain attribute. He/she may also not have past data as each problem is different.

Decision theory can be used to some extent to solve construction method selection decisions related to modularization, though it alone may not be sufficient since it requires that the decision maker have full information about the values of all the selection factors or provide subjective estimates for them, and must give a rating of each alternative. However, some of these methods can be utilized in conjunction with other approaches for better results.

In light of these limitations, expert systems methodology seems to be the most suitable approach for decision support for modular construction method selection (Salah 1991). Apart from simpler programming with the availability of state-of-the-art programming tools, expert systems are easier to use, can be designed to handle uncertain or unknown values for attributes, and are well suited to real-world problems. In addition, to enhance the decision-making capabilities of an expert system, certain decision-making paradigms can be embedded.

A knowledge-based expert system requires the utilization of expert knowledge rather than past data. Since such an approach is intended for use by diverse industrial owner, commercial owner, and engineering organizations and because expert systems are fairly transparent, the user can gain better confidence in the system. Also, the analysis performed at this stage will consider not only the qualitative decision factors listed earlier, but also the decision maker's individual preferences and choices. Thus, conclusions reached at this stage might vary from one organization to another.

In summary, most of the information to be evaluated in order to solve the problem is qualitative. Thus, a hybrid expert systems approach has been determined as a suitable method for modularization decision support system design. Additionally, there are significant numbers of experts available for knowledge acquisition. Also, the decision model requires that some cost information be processed, which can be handled by integrating the expert system approach with an algorithmic computational procedure.

Prototype Development Process

A search for all relevant resources and research related to the domain of modularization has been performed. The knowledge represented by members of the Construction Industry Institute modularization task force and their associates has been solicited and compiled, comprising a major knowledge-acquisition personal effort of about seventy hours (Fisher and Skibniewski 1992). These efforts produced valuable references on industrial process plant and power facility modularization and preassembly.

A total of 24 interviews were conducted. Of these companies, 18 were engineering and construction (E&C) companies that had considerable experience in the field of modularization. Of the remaining six, four of the companies were owners, one a fabricator for pretrochemical plants, and another a shipbuilder who developed expertise in the construction of modules.

During face-to-face meetings with interviewees, a tape recorder was used to capture all the discussed issues in ten of the sessions. In fourteen sessions, a video camera was used so that interviewees were at liberty to write notes on the board or use any other type of audio-visual devices. Most of the interviewees discussed the importance of modularization and the risks involved with it. It was often stressed that a feasibility study should be made at the inception of any project to determine if the use of modularization technology would produce positive results. The interviewees provided a wealth of knowledge and experience in the field of modularization feasibility. All of them were also able to provide follow-up information. When there was a conflict of opinion of the experts on an issue, the resource subcommittee of the modularization task force helped resolve the conflict.

Decision Factors

There are several factors that need to be considered when evaluating a project for modularization (Fisher and Skibniewski 1992). These factors can be determined with varying degrees of certainty, but are all essential in modularization decision making. Through several knowledge-acquisition sessions with the experts on modular construction at major engineering companies, the writers have distinguished the following major decision factor categories: plant location, environmental and organizational, plant characteristics, labor considerations, and project risks (see Tables 1–5). Each of the tables represents a major factor category. Column 1 of each table gives the decision attribute, columns 2 and 3 present the weights of each decision attribute in prescreening and detailed feasibility study of the knowledge-based system, respectively. The columns 4–8 show the possible values an attribute can be assigned by the user.

J. Constr. Eng. Manage., 1993, 119(1): 115-130

TABLE 1. Major Factor Category—Plant Location

Attributes (1)	Relative Weights: Pre-screening (2)	Relative Weights: Detailed feasibility (3)	Values: 4 (4)	Values: 3 (5)	Values: 2.5 (6)	Values: 2 (7)	Values: 1 (8)
Transportation accessibility	15	22	Excellent	—	Good	—	Poor
Module fabrication capacity	5	17	Poor	—	Good	—	Excellent
Increased costs in shipping and handling	—	9	Very low	Low	Average	High	Very high
Additional crane costs	—	9	No increase	Little increase		Notable increase	High increase
Module size	10	9	Small	—	Medium	—	Large
Climatic conditions	15	6	Poor	—	Fair	—	Good
Labor availability	15	6	Unavailable	Limited		Adequate	Excellent
Transportation-equipment availability	—	6	High	—	Normal	—	Low
Transportation-equipment timing	—	4	Not critical	—	Somewhat critical	—	Critical
Bulk-commodity availability	—	2	Low	—	Average	—	High
Bulk-commodity quality	—	2	Unacceptable	—	Somewhat acceptable	—	Acceptable
Bulk-commodity cost of transport	—	2	High	—	Moderate	—	Low
Bulk-commodity time to transport	—	2	Significant	—	Moderate	—	Insignificant
Construction-equipment availability	—	2	Low	—	Moderate	—	High
Construction-equipment quality	—	2	Suitable	—	Somewhat suitable	—	Not suitable

TABLE 2. Major Factor Category—Environmental and Organizational

Attributes (1)	Relative Weights: Pre-screening (2)	Relative Weights: Detailed feasibility (3)	Values: 4 (4)	Values: 2.5 (5)	Values: 1 (6)
Module import restriction	5	15	None	Moderate	High
Offsite access concerns	5	15	Simple	Moderate	Complex
Local/social restrictions	—	10	High	Moderate	None
Social issues	—	10	None	Somewhat present	Present
Fabrication capability	—	10	Good	Fair	Poor
E&C experience of modularization	—	5	High	Moderate	Low
Early involvement with owner	—	5	High	Moderate	Low
Owner receptivity to modularization	—	5	High	Moderate	Low
Understanding of modularization	—	5	High	Moderate	Low
Early involvement of operators	—	5	High	Moderate	Low
Willingness to fund modularization study package	—	5	Willing	Possible	Not willing
Willingness to live with design constraints	—	5	High	Moderate	Low
Continuous involvement with E&C	—	5	High	Moderate	Low

MODULARIZATION DECISION SUPPORT SYSTEM

System Architecture

A framework for modularization expert (MODEX) hybrid knowledge-based system for owner's engineering support in construction modularization decision-making has been developed. This computerized framework contains a three-step analysis as described next. The flowchart of MODEX is presented in Fig. 1.

The advantage of the three-step analysis approach is that a user need not spend a long time in one session answering queries concerning the project. Also, if the decision-making problem is fairly simple, it can be solved at the first step and the decision maker need not spend additional time to acquire the recommendation for a trivial problem. Even in the case of complex problems, the user has the option of stopping the analysis after any step and utilizing the intermediate recommendation to make the decision.

TABLE 3. Major Factor Category—Plant Characteristics

Attributes (1)	Relative Weights: Prescreening (2)	Relative Weights: Detailed feasibility (3)	Values: 4 (4)	Values: 2.5 (5)	Values: 1 (6)
Physical constraints of plant	—	19	None	Few	Substantial
Process/system density	5	15	High	Moderate	Low
Existing facility impact	5	12	High	Moderate	Low
Modular design expertise	5	12	Existent	Somewhat existent	Nonexistent
Laydown area availability	—	6	Restricted	Moderate	Unrestricted
Flexibility of equipment location	—	6	Excellent	Moderate	Poor
Process height of construction	—	6	High	Normal	At grade
Proprietary security required	—	6	No	Somewhat	Yes
Cleanliness requirement	—	6	Strict	Moderate	Not significant
Repeatability	—	6	Numerous	Somewhat present	Not present
Project type	—	6	Nonevolving	Somewhat evolving	Evolving

TABLE 4. Major Factor Category—Labor Considerations

Attributes (1)	Relative Weights: Prescreening (2)	Relative Weights: Detailed feasibility (3)	Values: 4 (4)	Values: 2.5 (5)	Values: 1 (6)
Reduction in job site labor force	—	37	Substantial	Moderate	Insignificant
Difference in labor cost (site/shop)	—	14	Much lower	Slightly lower	Same
Increase in productivity	—	14	Significant	Somewhat significant	Insignificant
Labor skill level	—	14	Low	Average	High
Labor type	—	14	Union	Mixed	Open shop
Possibility of jurisdictional problems	—	7	Not present	Somewhat present	Present

Prescreening

At the end of this stage, the user will receive an answer to the question of whether or not the project lends itself to modularization. If not, the user can stop the analysis and decide to utilize a conventional construction method. If the project lends itself to modularization, the user needs to continue with a more detailed analysis with MODEX.

TABLE 5. Major Factor Category—Project Risks

Attributes (1)	Relative Weights: Prescreening (2)	Relative Weights: Detailed feasibility (3)	Values: 4 (4)	Values: 2.5 (5)	Values: 1 (6)
Increase safety in shop environment	—	20	Significant	Somewhat significant	Insignificant
Schedule reduction	5	16	Significant	Moderate	Insignificant
Increased planning and engineering	—	16	Insignificant	Achievable	Significant
Difference in quality control costs	—	16	Significant	Somewhat significant	Insignificant
Decreased costs in equipment testing	—	16	Insignificant	Somewhat significant	Significant
Maintainability of site	—	16	Easy	Somewhat difficult	Very difficult

The prescreening stage requires only a minimum of information usually available at the early stages of a project conceptualization. A weighted-factors method is used to determine the initial feasibility. Factors to be considered at this stage are generally those related to project, site, and transportation. The weights given to each of these factors are provided in the system. If the total weighted score is less than a set threshold value (<25%), then the suggestion for the decision maker is to use the conventional nonmodular method of construction. However, if the score is higher than the set value (>25%), then some degree of modularization can be used, and further decision analysis is needed. This threshold was determined through a consensus of the Construction Industry Institute's modularization task force by evaluating several major projects based on the prescreening factors.

Detailed Feasibility Study

At this stage, a detailed study is performed to determine which design and construction method is more advantageous for a given project. The system will answer this question based on the relevant qualitative factors and on other preferences expressed by the project management team. MODEX will also determine the level of confidence assigned to the advice given to the decision maker. At the end of this stage, the user would be advised as to what degree of modularization is appropriate for the project.

Economic Study

This is the final stage of analysis by MODEX that provides the answer to the question regarding cost savings (or loss) and reduction in the construction schedule time possible by adopting some degree of modularization (assuming that a change in the length of schedule can be translated into an overall cost savings). There are significant differences between the costs of the various construction categories of a modularized and a stick-built conventional project. Because the characteristics of modularized projects are often very different, the cash-flow patterns of expenditures may also be different.

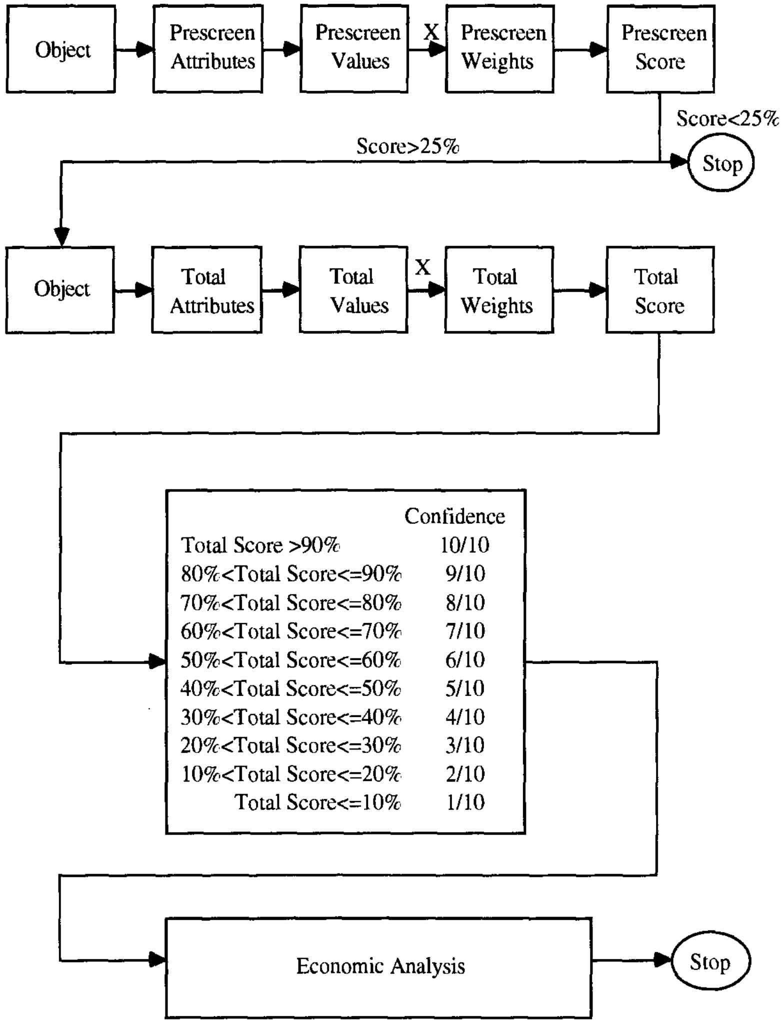

FIG. 1. Detailed Flowchart of MODEX

After the modularization-expert interviews had been conducted, a tentative table that included all the different categories of the construction project was compiled. This table shows how costs differ between the same categories depending on the nature of the project, modularized or conventional. The table is based on a project considered within the United States and it reflects the experts' experience with modularized and conventional projects in that region.

An integrated approach combining the utilization of a heuristics-driven knowledge base containing decision rules on modularization with a data base containing past records of realized modular construction projects and their relative cost advantages has been adopted for estimating cost and schedule changes. Example information imbedded in the data base and containing approximate percentage differentials of individual cost compo-

TABLE 6. Cost Comparison of Extensively and Partially Modular Plants with Conventional Plants

	Petrochemical			Power		
Category (1)	Conventional relative weights (2)	Percent difference between extensively modular and conventional (3)	Percent difference between partially modular and conventional (4)	Conventional relative weights (5)	Percent difference between extensively modular and conventional (6)	Percent difference between partially modular and conventional (7)
Owner costs	5	10	5	5	10	0
Project management, administrative and project engineering	3	10	5	1	10	5
Engineering and design	11	20	10	5	20	10
Major equipment	36	2	1	44	2	1
Bulk commodity	12	15	10	21	15	7
Site preparation	2	−10	−5	2	−10	0
Transportation and lifting	3	25	10	2	25	10
Field indirect costs	7	−15	−10	4	−15	−10
Direct labor	19	−15	−8	12	−15	−10
Construction management	2	−15	−10	4	−15	−10
Schedule	—	−25	−15	—	−25	−15

nents of an industrial process plant facility is presented in Table 6. MODEX can retrieve this information from the data base and utilize a spreadsheet to calculate the total cost differential of modular versus conventional project for final decision making. A similar procedure is used to estimate the schedule time differential.

Validation Procedure and Results

After completion of the MODEX prototype, its copies were distributed to certain volunteer validators and the Construction Industry Institute's modularization task force member companies for validation. The validators were asked to run at least three cases, one that was clearly conventional, one that was clearly modular, and one that was a borderline situation. The validators were also asked to perform economic analysis using MODEX so that the economic study step could be evaluated. Prior to running MODEX, the validators were asked to fill out a validation form that asked them to provide their confidence value (from 0 to 100) for modularization for each major factor category, the weight of each decision factor category for final decision making and potential cost savings (or loss) if modularizaton is used. The validators were also asked to comment on such issues as user-friendliness, semantics, and grammar of rules and help screens of the knowledge base. The suggestions of the validators were incorporated in the system where considered appropriate.

J. Constr. Eng. Manage., 1993, 119(1): 115-130

A statistical analysis was performed to compare the results obtained from the validators and MODEX. For each test case, there were five recommendations, one for each influencing factor category. Therefore, in 20 cases there were 100 independent recommendations and a statistical inference could be made on the results obtained by MODEX and the validators. A paired t-test was conducted to check if the recommendations provided by MODEX closely match with the recommendations of the validators. The total number of cases for the t-test was 96 since there were 4 missing values in the results received from the validators. The hypothesis test designed is as follows:

$$H_O\colon \mu_D = 0 \quad \text{(1a)}$$

$$H_A\colon \mu_D \neq 0 \quad \text{(1b)}$$

where μ_D = mean difference between recommendations of MODEX and the validators. The test statistic for this hypothesis is

$$t_0 = \frac{D}{\left(\frac{S_D}{\sqrt{n}}\right)} \quad \text{(2)}$$

where D and S_D = mean and standard deviation of the paired differences; and n = sample size, which is 96 in this case. The analysis was performed using Statview™ and the results obtained are shown in Fig. 2. Based on these results, it can be concluded with a 91% confidence that the mean values of the recommendations provided by MODEX and the validators are not significantly different.

Example Application

The following is an actual case study performed to test how MODEX responds to project situations that are typically not considered for modularization:

> In late 1988, a major oil company initiated conceptual project activities for a distillate hydrotreater unit at its refinery in Wales. The unit was designed to provide 20,000 BPOD of diesel product, with a maximum sulfur content of 0.15 weight percent, to meet new regulations.
>
> Hydrotreating technology was provided by owner's research department and a schedule-A-process design package was developed by owner's engineering division. Inquiries for long delivery reactors and

Paired t-Test X_1: Validator Y_1: MODEX

DF:	Mean X - Y:	Paired t value:	Prob. (2-tail):
95	-.031	-.108	.9141

Note: 4 cases deleted with missing values.

FIG. 2. Result of Paired t-Test on Recommendations of MODEX and Validators

```
The Plant Location suggests modularization, confidence  80 %.

The Labor Issues suggest modularization, confidence  77 %.

tion.

THE QUALITY AND/OR CLEANLINESS REQUIREMENTS FOR THE FABRICATION ARE?
Strict                    Moderate <               Not Significant


PLANT CHARACTERISTICS FACTOR
If the plant has many areas containing a high degree of repetition (i.e.
pump stations, exchanger banks, piperacks, valve manifolds, etc.),  it
might lend itself to repeated modules with natural breaks.

THE INSTANCES OF COMPONENT OR SYSTEM REPEATABILITY IN THE PROJECT ARE?
Numerous                  Somewhat Present <       Non Existent
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FIG. 3. Example Question

In summary, the Relative Weights and Confidence Factors are:

CATEGORY	RELATIVE WEIGHT	CONFIDENCE FACTOR
Plant Location	27 %	80 %
Labor Issues	24 %	77 %
Plant Characteristics	19 %	85 %
Social Category	18 %	89 %
Risk Category	12 %	72 %

```
***** MODEX RECOMMENDATION *****
The combined analysis recommends modular construction with
a confidence of  80 %
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FIG. 4. Summary of Results

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          Modularization is estimated to be 80 percent,
                 The Economic Table is Table B
(A) Conventional Construction Cost is $    51 million
(B)      Modular Construction Cost is $  54.5 million
(C)      Modular Construction Savings $  -3.5 million  (A-B)
(D)   Production Schedule Savings are $   6.9 million
            Total Project Savings are $   3.3 million  (C+D)
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FIG. 5. Summary of Economic Analysis

compressors were issued to aid in overall project schedule compression.

Owner's project management team, combining its refinery and engineering division personnel selected a major engineering and construction company in England to provide detail engineering, procurement, and construction management services, under a fixed-fee, cost-reimbursable contract with completion bonus incentives. Detailed engineering began in late June 1989.

A target 20-month schedule was established for the project and execution plans were developed to achieve this objective. Successful execution of these plans achieved the schedule objective.

Major contracts were awarded for shipping, hauling, and heavy lifts, site preparation, main civil work, module fabrication, mechanical hookup, electrical/instrument hookup, and finishing civils. All contracts were awarded on a unit price basis.

Owner's operations personnel provided active project participation in planning and executing precommissioning activities and unit acceptance. Performing these activities in parallel with construction completion activities shortened the traditional schedule and oil-in date.

Integrated instrument loop checking teams were effectively used to provide reliable instrument circuits consistent with demanding schedule requirements.

The project was completed in February 1991 with an on-site investment cost of $52 million.

The project's characteristics were subsequently run through a MODEX consultation. MODEX's conclusion recommended modularization with a confidence of 80%. This recommendation was in direct agreement with the owner's analysis. The owner estimated the modularization plant cost $1 million more than a conventionally built plant would have cost. MODEX is less optimistic; it estimated a modularized plant would cost $3.5 million more than a conventionally built plant. The MODEX estimate of schedule savings agreed with the owner's. Fig. 3 shows a sample question of MODEX, Fig. 4 shows the summary of the analysis for modularization, and Fig. 5 presents the summary of the economic analysis.

Conclusions and Recommendations

This research was conducted to facilitate the use of modularization and to produce a tool for the use by various professionals in the construction industry aiding in determining the feasibility of a given project for modularization. MODEX, a product of this research, enables that task. It is expected that experts will find MODEX useful for conducting preliminary studies of industrial construction projects that may benefit from modularization. A construction professional will also be able to predict the approximate cost saving or increase that modularization is expected to produce in the project under study.

The construction industry of the near future will be one in which skilled labor is in short supply and expensive. At the same time, manufacturing processes will be more efficient and cost effective than they are today. Therefore, the industrialized building methods studied in this research such as preassembly, prefabrication, and modularization are expected to be major options in the choice for future construction methods.

Construction Industry Institute member companies, as well as others, may benefit from this research by utilizing MODEX at the inception of any prefeasibility study. MODEX will enable the user to determine in general whether modularization is worth investigating. It has already been used by a Construction Industry Institute member company within this scope, and it has proven to be a powerful tool. It also encouraged the company to consider modularizing the project. Similarly, MODEX can also be useful to owner companies that need to consider various construction options for any industrial construction project.

It is recommended that more research on the development of MODEX be performed to further improve the accuracy of its decision support capabilities. Specifically, a recalibration of the weights assigned to the decision factors as well as of the cost factors is needed, to improve the accuracy of results. This calibration can be performed by running more test cases using historical data of previous projects that have been modularized. Many experts should also be able to beta-test MODEX to determine its capabilities and to make suggestions that would increase its usefulness.

MODEX should also be adapted to other areas of the construction industry that can benefit from modularization, such as the building construction industry. These changes would eventually make MODEX a powerful tool for general construction engineering and decision support. MODEX would also be enhanced by the addition of another step that would perform quantitative risk analysis with regard to the key factors in making modularization decisions.

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