Introducing New Process Technologies into Construction Companies

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Abstract: The words innovation and technology are considered by many as "not applicable" to the construction industry. Yet when defined in simple terms, they very much apply to every construction company. A new technology is a product or process that a company has not previously used in its operation. Innovation is seeking, recognizing, and implementing a new technology to improve the functions a company is performing. With such definitions in mind, this paper develops a set of guidelines for contractors to successfully introduce new technologies. The present state of innovation in the construction industry and several existing models of innovation are described. Based on this review, a set of questions is developed and used to examine the conditions surrounding six case studies of successful introductions of new technologies. Based on these findings, a process for implementing innovation is proposed and applied to both small and large contractors. Several characteristics of innovative companies are described. Guidelines for the industry to foster innovation is followed by an example of a university–industry collaborative partnership.

INTRODUCTION

The construction industry is lagging most other fields in taking advantage of new technologies. Research and development accounts for an embarrassing 0.4% of the annual construction output in the United States (Lemer 1989). By sacrificing innovation, we are compromising improvements in safety, productivity, cost-effectiveness, the quality of life, and U.S. competitiveness with foreign companies. The key question is then: How does a construction company break away from its traditional ways and introduce a new technology?

OBJECTIVE

The objective of this paper is to answer the preceding question by providing the contractor with a set of guidelines for the successful introduction of a new process technology into his/her company. These guidelines will describe the people involved in the "technology transfer" process and their roles, the steps in the process, and the necessary elements for success.

Research Methods

This research was conducted in three stages. The first stage identified several key definitions related to innovation and technology. The present state of innovation in the construction industry and several existing models of innovation were then reviewed.

The second stage of the research analyzed each model. The principal

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writer used key characteristics of these models as the basis to develop a comprehensive set of questions. This set of questions was designed to collect information on the processes by which new technologies were introduced. Six different cases of innovation were identified by the writers and studied by direct interview with the innovators and their company members.

Next, the data generated in the case studies was analyzed to determine the key steps in the innovation process. These led to the development of the innovation model—a detailed process for implementing innovative change. Results were extrapolated to form guidelines for companies to support innovation and specific industry recommendations were developed.

Definitions

Several key definitions are needed to orient the reader to the study. "Construction technology" is the combination of construction methods, construction resources, work tasks, and project influences that define the manner of performing a construction operation (Tatum 1987). "Invention" is necessary to develop these new technologies. Invention is "the process by which a new idea is discovered or created" (Rogers 1983). Innovation can be defined in several ways. "Construction innovation" is the first use of a technology within a construction firm (Tatum 1987).

For the purpose of this model, new technology and innovation in the construction industry are defined as follows. "New technology" is a product or process that a company has not previously used in their construction operation. "Innovation" is seeking, recognizing, and implementing a new technology to improve the functions a company is performing. An important implication for this study is that what may be considered a new technology to one company, may not necessarily be that to another. A small firm may be introducing the personal computer to the way it does business for the first time, while many companies have had them for years. Nevertheless, the fact that the former has never used it before, and is now improving its work processes through this introduction, makes it an innovation.

"Process innovation" is an improvement in construction methods designed to accomplish usual construction operations or to improve the efficiency of a standard operation (Tatum 1989). "Product innovation" is an innovation that produces a qualitatively superior product (Tatum 1989). The present study focuses on new process innovations in a company but the results can be extended to product innovation.

Need for Innovation in U.S. Construction Industry

Innovation is increasingly being recognized as essential to the success of the industry. Constructed facilities are becoming much more complex, and therefore greater technological sophistication is required to build them. Also, owners show an increasing desire to get the most out of their investments in constructed facilities. *Building for Tomorrow. . .* (1988), Tatum (1989), and Lemer (1989) each cite advanced technology as one promising way to satisfy both of these needs. Begoust and Willman (1989) further support this view by stating: "While there will always be those who shy away from using new technologies for fear of increasing their construction liability exposure, . . . the creation and evaluation of new products will continue to result in high-quality, dependable, and cost-effective buildings."

While the need for innovation is widely recognized, the appropriate research and development (R&D) activities in the United States are lacking (Moavenzadeh 1985). A more innovative environment exists in several foreign firms because R&D has been integrated into overall operations (*Building* 1988). In addition, Lemer (1989) says that: "Design and construction firms pay far more for liability insurance than they do for research in this country, . . . the threat of large jury awards for damages, often made with little relationship to cause, is stifling innovation."

This lack of research and development in the U.S. construction industry has adverse international implications. American contractors have been "rapidly losing the technological edge" they had in the 1960s (Moavenzadeh 1985). The U.S. construction industry is losing ground to foreign competitors in both international and domestic markets. Awards to U.S. contractors in overseas markets declined by 60% from 1982 to 1987. Foreign-owned construction firms won 3.5% of all U.S. construction contracts in 1987, more than double the amount won in 1982 (Wright 1989). Further, the Office of Technology Assessment study of international competition in service industries concluded that advances in construction technology, over the following two or three decades, will lead to huge increases in productivity. Currently, however, it is foreign competition that has the lead— especially the Japanese who do much more research on basic construction processes (*Building* 1988).

The need for improved innovation by the U.S. construction industry is apparent. Improved research and development efforts are the preferred method cited in the literature. Clearly a model to guide contractors is needed.

MODEL DEVELOPMENT

Several case-study–based models that describe successful innovation practice were reviewed. The essential components of these were included in a questionnaire. This questionnaire was used to collect data, in case-study format, about the circumstances surrounding six innovations in U.S. construction companies. A simplified innovation model was then developed from these data and is described in this paper. This model can be used by small and large companies alike.

Models of Innovation

Several models exist that describe how the rate of innovation may be increased in a firm and/or how technology may be transferred into an organization. They are not all developed specifically for the construction industry, but they are used to identify key elements of a comprehensive model. Each is discussed chronologically.

Rogers (1983) devised a six-step innovation process for an organization. The steps in this process are as follow: (1) Agenda setting, in which the need is defined and technology of potential value is sought; (2) matching, in which the need is considered along with the technology; (3) decision making, in which senior management decides to adopt or reject the new technology; (4) redefining/restructuring at which point the technology and the company's structure are modified to fit each other; (5) clarifying in which the relation between the technology and the organization are clearly defined and the technology is put into regular use; and, (6) routinizing in which the technology is made an element of the organization's everyday activities. In addition, Rogers identifies five factors that influence the decision to adopt a new technology: knowledge, persuasion, decision, implementation, and confirmation.

Shaffer (1985) developed a five-step innovation-development process for the U.S. Army Construction Engineering Research Laboratory. The technology-transfer activities are as follows: problem identification, research and development, field demonstration, product/system authorization, and product/system application.

Tatum (1987) describes the following elements of the innovation process in construction firms: Recognize the forces and opportunities for innovation; create a climate for innovation; develop the necessary capabilities for innovation; provide new construction technologies; experiment with and refine the new technologies; and implement the new technologies on projects and in the firm. Tatum (1989) complemented this model with a description of elements of organizational structure and culture that foster construction innovation. These include: Establishing supportive policies and priorities; maintaining flexibility in grouping and providing the necessary technical resources; facilitating intraorganizational and interorganizational coordination; and staffing to satisfy the requirements for key positions.

The Construction Industry Institute (CII) (Haggard 1991) proposed that innovative CII concepts be implemented by construction companies through the use of pilot projects: "Controlled projects implementing specific CII concepts to measure their value." They outline the following requirements for a company involved in a pilot project: senior management commitment, early planning, a paradigm shift, rewards to innovators, early selection of people, orientation and training to key members, the proper contract vehicle, and identification of needed resources. CII also proposes the following guidelines to assist in executing a pilot project: Start early, establish entire team commitment, organize the team with innovative and motivated people, develop a project execution plan, continually monitor and document progress, prepare an analysis of the results quantifying the benefit-to-cost ratio, communicate lessons learned throughout the company, make recommendations to change standard procedures as appropriate, and recognize the contributions made by the project team members.

The latest model of innovation focuses on expert system technology. de la Garza and Mitropoulos (1991) describes his T^2 process as a method by which a new technology is transmitted to individuals and organizations who ultimately adopt them. The stages in this process are as follows: recognizing the forces and opportunities for exploring new technologies, identifying new technologies, committing the initial resources, evaluating the technology, deciding on its adoption, developing and implementing applications for the technology, and confirming its value. The process can take either a top-down or a bottom-up approach, depending if senior management initiates the technology-transfer process, or if it is done by an individual who does not belong to this group. The main factors that affect the T^2 process include: the attitude of senior management toward technology, the organizational environment, the position of the individual who identifies the technology, the technological capabilities of the organization, and the state of maturity of the technology.

Model Analysis

Rogers' (1983) and Shaffer's (1985) models focus on transferring new technology into the social system. Their general ideas do not address any industry specifically, but serve as a basis for later models. Tatum's (1987) model is directed toward the construction industry, but its complexity and the number of roles that it designates to key personnel, is not conducive to practical use by small companies. The Construction Industry Institute does

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not provide a step-by-step model like the other four. Their steps are more of a set of guidelines to assist a construction company in executing one of CII's pilot projects. Finally, the de la Garza and Mitropoulos (1991) technology-transfer model focuses on the transfer of expert system technology.

Structuring Data Collection

Key categories and common attributes of each of these models were used to develop questions to guide the interviews. These attributes were reduced to nine broad categories and one category for miscellaneous comments. The broad questions leading to each category follow:

1. Was technology sought as a result of a specific project or for the sake of innovation?
2. Who in the organization saw the need for new technology?
3. Who evaluated the new technology? Who decided to implement it?
4. Is top management supportive of innovation? What is the organizational climate?
5. Were field people skeptical of new technology? Solution.
6. Was there ever a thought of discontinuing the use of the new technology?
7. Is construction research and development feasible?
8. From where did the money for the new technology come?
9. How/who provided feedback to evaluate success/failure of the new technology?
10. Miscellaneous comments.

Interview Method

Each broad question was asked to the innovator and the users of the innovation. After determining the success of an innovation, the interviewer collected data in 10 categories. The interviewer had a checklist of key points to be covered in each category. When collecting the data, the primary writer allowed the respondent to respond freely and comment on related issues. The answers were recorded and cross checked with responses to the same question from others involved with the given innovation. Based on these responses the model was developed.

Selection of Case Studies

The writers selected six successful innovations in companies for the study. The criteria for selecting an innovation were that the innovation was a well-defined, discrete activity; documentable evidence of success existed; those responsible for implementing and using the innovation were available; and that the writer could witness the innovation and meet with those involved. Two innovations were implemented in small companies, two in midsize companies, and two in large companies. All innovations were process improvements.

These six construction companies and their new technologies were: CRSS Constructors, New York—three-dimensional computer-aided design (3D CAD); Bechtel Construction, Gaithersburg, Md.—3D CAD; Hensel Phelps Construction, Greely, Colo.—self-climbing jump form for exterior architectural concrete; Beacon Construction, Boston—up-down construction method; Pinehurst Homes, State College, Pa.—personal computer; and Glenn O. Hawbaker, State College—laser-controlled grading.

RESULTS

The results are presented in several stages. First the impact of the six innovations are presented. Next specific data on the innovation is tabulated by key factor. Finally an analysis discusses key findings.

Impact of Innovation on Companies

It is difficult to generalize how a new technology will affect productivity, profitability, or other aspects of a construction company's business. Much depends on the technology itself, the specific project conditions under which it is being implemented, and how the technology fits into the overall company strategy. The following statistics from the case studies indicate the positive effects of innovation:

- CRSS's use of 3D CAD for updates to the owner on the progress of their hospital renovation project provides owner satisfaction, and prevents interferences in the contractor's work by the ongoing operations of the existing hospital.
- Bechtel has improved its efficiency on projects using 3D CAD by reducing construction interference from 5% field man-hours, to less than 1% and by substantially reducing rework on these projects. They also show schedule reductions of 1 to 7 months and craft performance improvements of 26% to 59%, on a study of nine fossil fuel projects using 3D CAD.
- Hensel Phelps saved approximately $5,000,000 by using the cast-in-place architectural concrete over the other options. The construction schedule was also accelerated by this system's capability of providing both the structural and architectural components in one unit.
- Beacon Construction shaved 4 months from their project schedule at Rowes Wharf, due to the use of the up/down construction method. The interest expense savings alone, substantially offsets the $2,000,000 cost premium of the innovative method.
- Pinehurst Homes used a personal computer to more than double the estimator's productivity, and the early response provides unquantifiable customer satisfaction.
- Hawbaker's use of laser-grading technology increases the daily productivity of a single grader by 15%; and decreases the cost of fine grading by 25%. The final quality cannot be quantified, but is substantially better.

Innovation Process

Fig. 1 provides a summary statement of the responses made by key personnel from each of the aforementioned firms describing the process used to introduce each new technology. The key question categories are shown as column headers in Fig. 1. Based on these responses, essential features and factors critical in the innovation process for these contractors formed the basis for the model of innovation proposed in the next section. While the case studies are varied in their context, a closer review of the data shows

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QUESTION COMPANY & TECHNOLOGY	Was technology sought as a result of a specific project or for the sake of innovation?	Who in the organization saw the need for new technology?	Who evaluated the new technology? Who decided to implement it?	Is top management supportive of innovation? Organizational climate?	Were field people skeptical of new technology? Solution.	Was there ever a thought of discontinuing the use of the new technology?
CRSS CONSTR. **3-D CAD**	Project Specific To meet client needs.	Project Manager	Evaluation: National Tech. Manager Decision: President	Yes. Willing to wait for return. Rewards innovation. Functional participation at all levels.	Yes. Must provide training.	No. As problems surfaced, solutions were found.
BECHTEL **3-D CAD**	Innovation: "Skunkworks" To be leader in the industry.	Engineering Management	Evaluation: Skunkworks, then technical task force. Decision: Engineering Management	Yes. Technical grant program. Suggestion program. Hire innovative, motivated people.	Yes. Training. Involve them in evolution of concept.	No. Many problems, correct them on the spot. You must expect failure and be responsive.
HENSEL PHELPS **Self-Climbing Jump Forms**	Project Specific To meet project specifications.	Team: Superintendent General Super. Project Manager	Evaluation: Team, specially PM. Decision: Vice President & Area Manager	Yes. "Bonds for Gimmicks." Brainstorming sessions on projects. System for info. exchange.	Yes. Put a dedicated crew from beginning of mock-up to end of job so they have input throughout.	No. Clock kept ticking & job criteria didn't go away. Meet each problem with innovative solution.
BEACON CONSTR. **Up/Down Construction**	Project Specific To reduce risk on project.	President and Senior Construction Manager. Input from architect.	Evaluation: Architect and President. Decision: Top Management.	Yes. Willingness to listen to suggestions. Hire bright people. Creative problem solving.	No. People accept anything that will make their job easier.	No.
PINEHURST HOMES **Computer**	Overall company need. To be more competitive.	President	Evaluation: President Decision: President	Yes. Keep current with trade journals and competition. Hire energetic people who want to learn.	Yes. Select employees carefully. Evaluate capacity of employee and match them with appropriate job.	No. Must be committed.
GLENN O. HAWBAKER INC. **Laser-Controlled Graders**	Overall company need. Scope of company's work changed.	Chief Engineer	Evaluation: Chief Engineer Decision: President	Yes. At the field level: file things in back of your head for later use. Always look for better ways.	Yes. Provide training. Take interest in field personnel. "We are going to use it with you or without you.	No. Adjust machines and modify system to meet your needs.

FIG. 1. Summary of Innovation Process by Company

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QUESTION COMPANY & TECHNOLOGY	Is construction research & development feasible?	From where did the money for the new technology come?	How/who provided feedback to evaluate success/failure of new tech.?	Miscellaneous Comments.
CRSS CONSTR. 3-D CAD	Yes, if done from practical view-point. Must develop a plan including time and $ needed & expected return.	Annual fund set up by company for trying out new technology.	Project team: Usually only when things go wrong. Owner: Impressed because he was kept updated consistently.	• Work with developers and other suppliers. • Must have one champion who introduces new technology, believes in it, knows how to use it himself, and supports it throughout introductory phases. • Any new innovation must be preceded by a thorough business plan.
BECHTEL 3-D CAD	Yes. You are not going to be a leader if you wait until somebody else develops or uses something new.	Original research done as "skunk-works": two engineers given $ to go off to the side and "play."	Always being evaluated by engineers on projects using the new tech. Refined based on their comments.	• Important to pick a system that is right for your company. Not necessarily the most advanced; but one you can modify to fit your needs. • Never be satisfied. • Need determined, innovative and motivated people.
HENSEL PHELPS Self-Climbing Jump Forms	No. This is up to the product industry and trade organizations like ACI, AISC, etc...	GMP job, so new tech. was offered to owner and architect as value-engineering and they agreed.	Crew: commented on safety and function. Owner: Satisfaction with final product.	• Hold annual seminars to encourage superintendents to share experiences. • Small department that serves as information exchange between projects. • Work with suppliers. • Requires a champion.
BEACON CONSTR. Up/Down Construction	No. No innovation for the sake of innovation. Just solve problems which arise.	Budgeted in the project.	The success of the project and the subsequent use of the technology on other projects are evidence of success.	• Hire bright, innovative people even for field positions. • Select project team carefully; right people on job. • Communication is more important than training. • Creative problem solving: don't look to what has been done before. • Requires a champion.
PINEHURST HOMES Computer	Not in this size company. Up to each individual to keep current.	Bought at a reasonable price from company going out of business.	President (self-evaluation): Saves a lot of time.	• Suppliers should offer new products at a discount. Would benefit both the contractor and supplier and would increase the rate of innovation. • Must be ready to invest in something that will not pay off right away. • Try new things on spec homes.
GLENN O. HAWBAKER INC. Laser-Controlled Graders	Not in this size company. Done on an individual basis.	Company investment based on benefit-cost analysis.	Field people: Now they don't want to let go of new tech.	• Must compare need to cost. • Must make sure you have the people qualified to use new tech. • Requires a champion.

FIG. 1. *(Continued)*

remarkable similarity in answers from each company. There are however, some differences in the responses when examined in detail. These follow.

Factors Influencing Innovation Process

When reviewing the data, one can see that the main factors that influence the innovation process are the size of the company, the type of innovation, and the breadth of application of the innovation.

Company Size

Table 1 outlines the differences between a small and a large contractor as they relate to financial, research and development, internal communication, and management issues. It should be evident that size is not a barrier to innovation. These data were obtained from evidence and examples of each innovation gathered by the principal writer. These were then generalized to form Table 1. The model presented in this paper has been developed to include the process for both large and small firms.

Type of Innovation

In the construction industry, responsibility for and control of product innovation generally rests with the material and equipment suppliers. Architects, engineers, and specification writers have control in that they can include new products in projects by specifying them. Involvement in the preconstruction phase of the project is crucial for the contractor to suggest products that will be specified for that job.

Construction companies have full control of process innovation. Innovation can range from the introduction of computers into a new area of the

TABLE 1. Variations in Innovation Process in Small and Large Companies

Factor (1)	Small company (local contractor) (2)	Large company (national contractor) (3)
Financial risk	Disproportionately large risk because it cannot be spread over a portfolio of projects.	Ability to spread risk over a large number of projects. Better able to fund new technologies.
Research and development resources	Often lacks qualified technical specialists and resources to support a formal R&D effort.	Ability to attract highly skilled technical specialists. Can support an R&D department.
Internal communication speed	Efficient and informal communication networks. Fast response to problems. Easy adaptation to change.	Cumbersome communication channels. Slow reaction to problems. Slow and difficult implementation of change.
Management style	Lack of bureaucracy. Innovative managers can quickly take advantage of new opportunities.	Centralized decision-making process and increased number of management levels. These further hamper communication, conceal problems, and inhibit change.

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TABLE 2. Variations in Project-Specific and Companywide Innovations

Factor (1)	Project-specific innovation (2)	Companywide innovation (3)
People involved	Project team.	Formal department or position within the company; apart from project work.
Time and resources available	Constrained by project schedule and budget.	Schedule and resources are not linked to any one project. Time is not as crucial. Separate budget exclusively for new technologies, to be used on several projects.
Scope of technology search	Very focused: that which will solve the problem on this specific project.	Very broad. Every activity that the company is performing can be improved.
Payback period	Short-Term: no longer than the duration of the project.	Long-Term: belief that the upfront investment on innovation will be offset, in the long run, by the technological advantage it will give the company.

construction operation; the use of new estimating or scheduling software; or a new way of handling procurement or submittals. In other words, the implementation of any method that improves the efficiency of the standard operation is process innovation. The training of personnel in new ways of doing business is very important to continual improvement and cannot be overlooked. Recognizing that a construction company, especially a construction manager, has much greater control and can achieve a greater impact with a process innovation, the model focuses on this.

Breadth of Innovation

Table 2 contrasts several factors involved in innovating to meet the challenges of a specific project, with those involved in taking a companywide approach to innovation. Much of today's innovation, especially in small firms, solves the problems that arise on a specific project. The innovation model focuses on a companywide approach, which may be easier to stimulate and manage, yet offers suggestions on making project innovation more effective.

INNOVATION PROCESS MODEL

Fig. 2 is a model of the innovation process. The innovation process can be divided into four major stages: identification, evaluation, implementation, and feedback. In the sections that follow, detailed descriptions for each of these phases is further developed from both the project specific and the companywide perspectives. Finally two applications of this generic model and specific guidelines are developed for both a small company and a large company. The section that follows is a summary of the combination of the steps found common to the successful innovations. It is descriptive in nature

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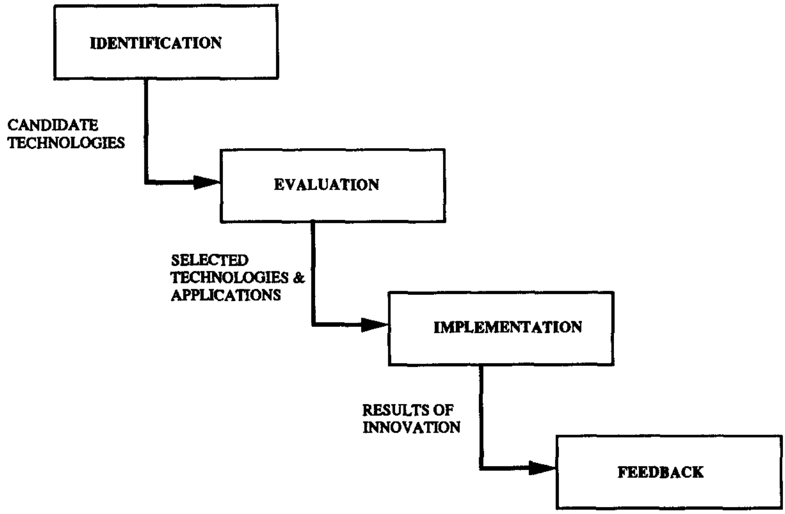

FIG. 2. Innovation Model for Contractors

because the information does not really allow itself to be sensibly presented in tables.

Step 1: Identification

In this first step, three questions need to be asked:

1. Why should one look for new technologies (motivation)?
2. Where should one look for new technologies (sources of innovation)?
3. Who should look for new technologies (technology identification)?

Motivation

The chief motivation for innovation on a specific project would be to solve a problem that has not been encountered before. On the other hand, three motivations were identified for innovations on a companywide basis. The first was to improve business practice. Each operation that the company performs may benefit from new, more efficient technologies. A second motivation was to keep the company competitive in the marketplace. The market is moving toward more complex facilities, and owners are demanding more for their money. Innovative companies should have an edge when seeking these jobs. Also, as others begin to take advantage of technology, it is becoming riskier not to innovate. Those who don't keep up will not meet basic industry standards and will not survive in the long run. A third motivation was for the company to be recognized as a leader in the industry. Leaders typically take the greatest risks but stand to reap the greatest rewards. A specific technology can give a company unique capabilities or advantages, which will attract clients whose projects can use these techniques.

Sources of Innovation

Six key sources of innovative technology were identified in the survey as: (1) Suppliers, such as product manufacturers and software developers; (2) subcontractors; (3) the contractor's competition; (4) construction research organizations and universities; (5) employees; and (6) formal in-house development efforts. Clearly companies need a mechanism to formalize these contacts and a mechanism to foster innovation.

Technology Identification

As mentioned before, the goals of the company as a whole should be to be innovative and continually improve. Change needs to be seen as opportunity not as risk; this type of environment fosters innovation. As such, every employee has the responsibility to keep up with new technologies. Each individual should keep up with developments in the industry through trade journals and industry seminars. Each should critically look at his/her job to see where improvements can be made.

A formal position should also be established with that person's primary job being to look for and evaluate new technologies, without the distractions of project commitments. This can only be a part of a company that takes the long-term, overall view to innovation.

On a project basis, the project team members are the primary sources to identify technology. The team should be formed early in the preconstruction phase so that there is time to consider several alternatives. Also, the project team can take better advantage of the contractor's expertise during this planning stage.

Innovation plans should be made for each project during the preconstruction phase. These should outline the work processes in which new technologies will be used, the training that will be needed, and the costs associated with these. Regular brainstorming sessions including the owner, architect, engineers, contractor, key supplier, and subcontractors should encourage innovative solutions to problems as they develop and to look for areas that lend themselves to new technologies.

On a companywide basis, an individual must be identified with this responsibility. In a large company this may be a "director of development," a full-time position financed from a preset percentage of the company's profits. In a smaller company, it could be the task of an officer in the company.

The selected individual must know the company well in order to assess whether an innovation is compatible with its goals. He/she must be technically knowledgeable to capably evaluate alternatives, must have good communication skills, and must have the ability to recognize industry directions. In addition, this must be a bright and innovative person who is not afraid of change. Finally, they must be trusted by upper management and respected by project managers, employees, suppliers, and subcontractors.

All project managers should at some point hold this position, through a rotation system. This way, they will appreciate the effort of the present director of development, help them when needed, and realize the importance of the position. Most importantly, they will carry the "always looking" mind-set with them to their project-manager positions. Hopefully, innovation will eventually be second nature to them, and they will perform the function of director of development as a dual role when running their projects. The formal position may, at that point, no longer be needed.

Step 2: Evaluation

This phase has the same essential steps whether the innovation is a project-specific or companywide one. The evaluator changes but the functions are similar. First the director of development or the project manager analyzes the benefits versus the costs of the alternatives he/she has identified in the previous stage using the following criteria:

- Degree to which the innovation supports the overall company/project strategy.
- First cost of the new product (product innovation) or equipment/software (process innovation).
- Time needed to develop or adapt the product or accessories to meet the needs of the company.
- Impact on different departments within the company (i.e. scheduling, estimating) and their standard operations.
- Payback period. Will the new technology pay off within the life of the present project? If not, can future projects benefit from this first-use and produce profits in the long run? Will training be needed, how much, and is it readily available? What is the impact on project schedule and budget?
- Cost savings over conventional methods.
- Difficulty of implementation.
- Impact on morale, quality, and safety.

Second the director of development or project manager develops a business plan to present to upper management based on this analysis. Finally, upper management decides on the implementation of the new technology based on the proposed plan.

Step 3: Implementation

Several ideas for successful implementation follow:

1. Choose a small project. For a first-time implementation of a new technology, this size project is more manageable and will present less risk to the company.
2. Choose a competent project team. They should possess the needed technical capabilities and a positive attitude toward innovation and change.
3. Involve the architect and the owner as soon as possible. If they are involved in the development and planning stages of the new technology, they will feel a sense of ownership and be more willing to cooperate.
4. Provide the necessary resources. This not only involves money, but also people. It will be necessary to relieve the members of the project team from other duties that may compromise their total commitment to the innovative project. Remember that a sacrifice may have to be made in the short-term in exchange for a gain in the long run.
5. Train the team members. New technologies often require making changes to the standard operations. Not investing in training will lead to misuse of the technologies, inefficient use of their capabilities, frustration, and early abandonment of the innovation.
6. Invest time in planning. This is an important step on any project, but it is specially crucial when trying something new. The team needs to be familiar with the requirements of the project to be able to predict, and be prepared to deal with, problems that may arise. A little bit of time up front may save a great deal of time later on.

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7. Hold regular review meetings. Communication also becomes increasingly important on these projects. Progress should be assessed and carefully compared to the schedule and budget. Problems are easier to foresee when holding these regular meetings, and all should be encouraged to voice their concerns. Problems should be solved expediently, without looking back or doubting the continued use of the new technology.

8. Document as much as possible. The better the record on these first-time projects, the more lessons will be learned from them. All differences from normal progress caused by the new technology should be noted, as well as its impact on the schedule, budget, productivity, quality, and safety.

Step 4: Feedback

This step requires an analysis of the implemented innovation once the project is completed. These steps are outlined below. In the companywide model, the director of development is responsible for these steps, although he/she will need cooperation from all parties involved on the project. In the case of project-specific innovations, there is no single person responsible for this feedback stage. Clearly one person (probably the project manager) should not go on to his/her next assignment until this step is completed. It becomes evident that the companywide view to innovation is much more effective in this phase. It is unrealistic to think that the project manager will have time to perform the following activities with the degree of dedication that they deserve.

1. Compile all documentation and analyze the final results. Evaluate the overall project performance as influenced by the new technology. What was its impact on the schedule, budget, productivity, quality, and safety? What problems arose? How could they have been prevented?

2. Make recommendations for future projects. How can the new technology be modified to better serve the company? What project characteristics would be ideal for the success of the new technology? What other uses for the new technology should be explored? How can it be implemented on a larger scale? How can it be integrated into the bidding strategy to give the company a competitive edge? How should the company's planning functions (scheduling, budgeting, etc. . .) be changed to better accommodate the new technology?

3. Reward team members regardless of success or failure. Monetary rewards are certainly preferred, specially if the project was successful. But other types of recognition should not be underestimated. Respect among ones peers and admiration from superiors are psychologically valuable rewards to any individual. In the event of failure, team members must not be punished, but be given a chance to learn from the failure and help correct it on the next job. These will reinforce the value of innovation.

4. Disseminate the information to other projects. Here is where only the companywide view is effective. The director of development keeps up with all projects being performed by the company; this overall view allows him/her to provide the needed information to the appropriate projects. The project-specific approach must rely on each team member to take his/her experience from one job to the next, where it is unlikely that they will face the same problem twice. This drastically diminishes the impact of new technologies.

Another good system for the dissemination of project information is an internal lessons-learned database; where the documentation from each project is entered and is available to all employees. Innovative project managers will routinely look through this information and take advantage of the implementation of new ideas on past projects.

GUIDELINES FOR INNOVATION

To allow a contractor to better innovate, several items of practical interest are now presented. First, a set of elements found in innovative companies is presented. Next, the innovation model is customized for both a small and then a large contractor and comments are made for medium-sized contractors. Finally a set of guidelines for the various members of industry are presented.

Elements of an Innovative Company

The following elements were found in these innovative companies studied and the literature. These elements were not the subject of the survey, rather the principal writer observed these conditions when reviewing the circumstances around the innovative case studies.

Company Strategic Plan

This is the "key" starting point of an innovative company. The company must develop a clear vision that gives a sense of purpose and direction to which everyone can relate. It must address the organization's need and support of innovative ideas over proven technologies. "Management decisions concerning strategic focus are especially important in the development of a climate for innovation" (Tatum 1987).

Long-Term Perspective

There must be an emphasis on long-term benefits versus shorter-term profits. An innovative company must be willing to accept a moderate loss on a current project that is being used experimentally with a new technology. Later implementations of the innovation on a larger scale could far outweigh the original setbacks. This commitment is also exhibited by the establishment of the director of development position. It requires a yearly investment of the company's profits on something that is not associated with any one project where revenues are generated.

Change Viewed as Opportunity Not Risk

Every decision involves risk, whether innovative or not. Innovators need not be high-risk takers, they are prudent and aware of the risks involved in their decision to try something new. Careful analysis and planning can help minimize risk. In fact, sometimes, not being innovative may prove to be riskier. Using old methods to solve new problems may lead to inefficiency and loss of competitiveness. We have seen cases in history like that of U.S. automobile manufacturers, who once were the envy of many nations. After years of complacency, they have lost their leadership in the world automobile industry.

Short Lines of Communication

Top management should be readily accessible to all. Organizational rigidity and multiple hierarchical levels are barriers to innovation. It is im-

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portant to achieve the small-company–type, efficient and informal communication networks, which provide fast responses and easy adaptation to change.

Suggestion and Reward Programs

It is necessary to foster, stimulate, and reward the creativity of all employees. A formal suggestion program shows that the company cares about its people's opinions. It also encourages them to look at their jobs with an eye for improvement. If a suggestion is implemented by the company, the originator should be given formal recognition and a share of the savings resulting from his/her idea.

Innovation Bulletins, Journals, Seminars

It is very important that all employees keep up to date with new developments. The company can encourage this by subscribing the job sites to trade journals, by sending people to industry seminars, by holding their own internal presentations, and by posting innovation bulletins on a regular basis. All people can be creative, and a company can foster this in its employees by the use of the mentioned strategies. Having the proper frame of mind goes a long way in making innovation successful.

Innovation Model for Small Contractor

Fig. 3 shows the four stages in the innovation model, as they relate to a small, local contractor. In this size company, a formal position of director of development is not affordable, thus, in our cases, the presidents of each company assumed this role.

In the identification stage, the president interacts with suppliers, employees, and subcontractors; studies competing firms; and keeps up with

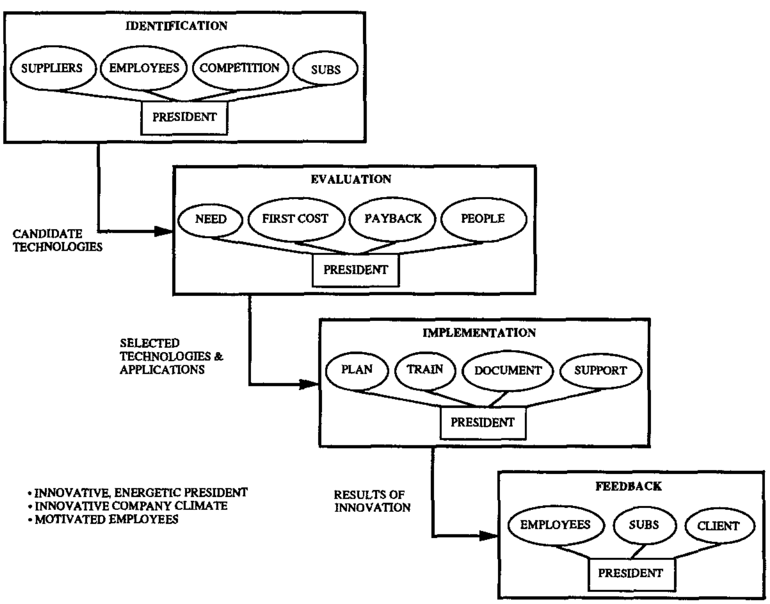

FIG. 3. Innovation Model for Small Contractors

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trade journals to find out new methods or products in his field of work. Partnerships with a supplier of a new product or members of the project team are vehicles to share the risk in introducing the innovation.

In the evaluation stage, the president examines the new product/method and evaluates it against the company's needs. The first cost and the payback rate and period of the new technology should be weighed against the available resources, the company's vision and the intended markets. Finally, the capabilities of the people using the innovation must be taken into consideration to determine if the amount of training needed exceeds the time and resources available.

In the implementation stage, the president has several roles: planning the project to foresee any problems, training key personnel on the new technology, documenting progress for possible refinement of the technology or the implementation process, showing unwavering support of the innovation, and supporting the people involved on the project.

In the feedback stage, the president must again interact with the employees, subcontractors, and the client involved in the innovative project. Impacts of the new technology on operating procedures, cost, quality, schedule, etc., must be identified. Continued learning from each trial and refining the technology will ensure increased effectiveness and a high return on investment.

In order for this innovation process to be effective, the president of the small construction firm must be committed to innovation and must possess the energy to carry the entire burden of this process. The company itself must have an innovative climate, which includes: a vision that focuses on improvement through change rather than by traditional methods; a long-term view to payback; a president with whom employees can readily and freely communicate; an active encouragement of participation from all employees; and, finally, a commitment to develop employees through trips to industry seminars, innovation bulletins, and journal subscriptions. Finally, the implementation of change requires motivated employees who are willing to work with the new technology and solve any problems that arise without reverting to old, established ways.

Innovation Model for Large Contractor

Fig. 4 shows the four stages in the innovation model, as they relate to a large, national contractor. In this size company, a formal position of director of development needs to be established in which the employee works outside the confines of project work. This person needs to be well informed of the company's needs and direction, with a view to focusing on technologies that are in-line with these parameters. He/she needs to be technically capable of evaluating the alternatives and have excellent communication skills for the extensive interaction necessary with people inside and outside the firm. All project managers should rotate through the position, which should be funded by a percentage of the company's profits.

In the identification stage, the director of development interacts with suppliers, subcontractors, and the competition much like the small contractor. Employee input through a formal suggestion program and interaction with national as well as foreign firms can also provide ideas for new technologies. Finally, the director of development should look into taking advantage of research being done by the many universities and several research organizations across the country.

In the evaluation stage, the director of development must first determine

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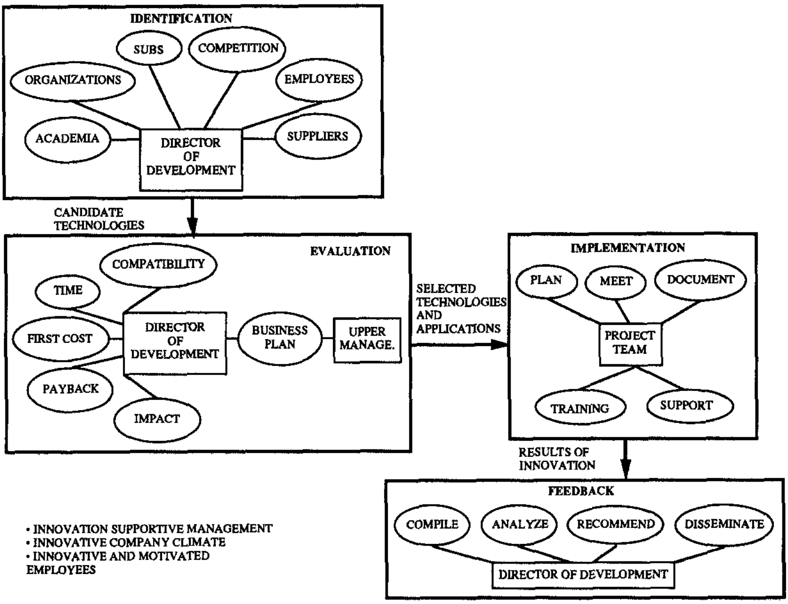

FIG. 4. Innovation Model for Large Contractors

if the new technology supports the overall company strategy. The time needed to adapt the new technology to the company's needs, the first cost, the payback time and amount, the impact it will have on standard company operations, and the impact it will have on employees are then evaluated. The director of development will then develop a business plan for the implementation of the new technology, which includes all of the preceding factors, and present it to upper management who makes the final decision on its use.

In the implementation stage, it becomes the responsibility of the project team (including the architect and owner) to plan the project in advance, hold regular review meetings to identify and solve problems early, and document progress as well as the new technology's impact on standard operations. The team should be given training on the technology and be provided with the necessary resources to implement it and solve problems as they arise.

In the feedback stage, responsibility shifts back to the director of development. In this crucial phase, the documentation and feedback provided by the project team and input from all groups involved in the project must be correlated. It must then be analyzed to assess the impact of the new technology on all phases of the project and determine whether it was successful (profitable) or has the potential of being so through lessons-learned from this one project. He/she can then make recommendations for use on future projects, and disseminate the information throughout the company. Finally, the people involved in the innovative project must be recognized regardless of success or failure.

The model for a small and large company have been presented. Clearly there is a point at which a company president can no longer effectively function as the innovation champion. At this point (different for each individual), the duties are transferred to an employee as a part-time duty. As the company grows, this position evolves into a department activity. It is important that this growth be planned carefully. The elements of an innovative company described earlier need to be a part of this type of organization in order for the successful implementation of any change.

Industry Implications: Guidelines for Industry

It seems that more than a model is needed to foster innovation. Following is a guideline derived from suggestions from the six successful innovations and the literature.

Owners

Large owners need to encourage construction companies to use new methods on their projects. By favoring innovative contractors, they will send the message that those who use traditional methods will soon be out of business. Owners can show their commitment to innovation by sharing the risk on projects implementing new technologies.

Government

The government needs to make the investment in new technologies appealing to contractors. As clients on many projects, they can set an example to other owners by assuming the risk involved with adopting innovation on government-sponsored projects. In addition, they can provide financial support for construction research and development. Other incentives may include providing tax deductions or loans for research and development. Also, government regulations such as those enforced by the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) are known to deter innovation. These may need to be reassessed.

Building Industry

Existing agencies in the areas of engineering, architecture, and construction need to coordinate their efforts. Cooperation by these agencies will make available a larger pool of resources, both monetary and technical, which will result in more effective technologies. The nonadversarial relationship of project team members will also result in strong support of innovation on projects; which will lead to more frequent and successful implementation of new technologies. In addition, seminars on innovation, presentations of new technologies in construction, and other industrywide programs should be held regularly and made readily available to contractors. Existing standards, building codes, and labor agreements have been identified as barriers to technological advance; these may need to be adjusted to support innovation. Finally, companies who implement new ideas should be given recognition by others in the industry.

FOSTERING INDUSTRY INNOVATION THROUGH "PACE"

Upon completing this study we became acutely aware of the need for improved innovation in the industry. As a result we gathered our partners in the construction industry, our students and the faculty in the construction program at Penn State and developed the Partnership for Achieving Construction Excellence (PACE), as a mechanism to foster innovation. The mission of PACE is "to establish a working partnership between the con-

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struction industry and Penn State to achieve excellence in construction through process innovation and the development of students into leaders that shape its future." Its three key objectives are:

1. To educate students as future leaders of the construction industry, in methods to improve the management, planning, design, construction, and operation of facilities.
2. To evaluate, research, and develop new construction methods and processes that will improve the quality of the constructed product.
3. To provide a forum for dialogue among its partners and a mechanism for continually improving the knowledge of industry, students, and faculty.

Key PACE activities that foster innovation include: an annual construction roundtable where members discuss key issues facing the industry; a research program through which industry, students, and faculty address problems facing the industry; and an annual research seminar at which members present examples of innovation. Students typically work for one year with one or more industry members to identify a critical area for improvement, develop a new method, select an appropriate technology, and implement the improvement on a construction site. This philosophy has resulted in students that are well versed in new technologies and theoretical models with a taste of real implementation issues on construction projects or in specific companies. More importantly, many students recognize their responsibility to innovate. Industry members are exposed to the technologies and are able to hire these students, first as interns and then upon graduation, to implement these technologies in their companies. This method allows all participants to gain favorably from their invested resources.

CONCLUSION

The U.S. construction industry is lagging behind other industries, and its foreign counterparts, in using new technologies to improve its services. Statistics show that the share of U.S. contracts in domestic and foreign construction markets is decreasing. A big factor in the decline of U.S. leadership in this field is the lack of research and development and subsequent innovation performed by construction companies.

Contractors are intimidated by words such as technology and innovation. But they must realize that these terms simply mean changing the way one does things in order to improve one's performance. Innovation must be a companywide ideal, lead by upper management. They must incorporate the support of innovative ideas over proven technologies in the company's strategic plan. They need to emphasize long-term benefits over short-term profits. They must view change as an opportunity for improvement, not as a risk. And they must create a company climate that stimulates their employees to keep up with current new developments in the industry, and to look for ways to do their jobs more effectively.

The preceding characteristics foster innovation in a company. This paper proposed a four-step process by which such a company can successfully transfer new technologies into their standard operation. In a large company, it requires the creation of the position of "director of development." This full-time position is funded through a percentage of the company's profits and is responsible for leading and coordinating the innovation process. Nevertheless, it must be stressed that it is every employee's responsibility

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to look for improvements in their areas, and to interact with the director of development through a suggestion program. All project managers should at some point hold this position. The goal is that eventually the process of identifying, evaluating, implementing, and disseminating new technologies will become second nature to them; and the full-time position can be eliminated. Size is not a barrier to innovation, which can be a characteristic of any firm. A small contractor can use the model proposed in the present paper by having the president of the company play the role of director of development.

Two of the main barriers to innovation in the U.S. construction industry are the fear of risk and a variety of restrictive codes and regulations. Large owners, especially the government, can encourage the use of new methods by sharing the risk on projects. The government can further help by reassessing existing standards and by providing tax breaks, loans, and other incentives for construction research and development. Unless U.S. construction companies actively strive for technological leadership, they will quickly lose their place in the global economy of tomorrow.

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