BALANCING ENGINEERING AND MANAGEMENT IN CONSTRUCTION EDUCATION

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ABSTRACT: Many of today's construction projects require both complex technology and sophisticated management techniques. Experience prevails in the requirements for management positions, but appropriate education can assist prospective managers to maintain steep learning curves in rapidly acquiring this experience. The Business Roundtable's study of construction education recommended increased emphasis at the graduate level. This paper describes a graduate program, including both technical and management elements, to prepare engineers beginning careers in construction. Although complete coverage of all suggested technical and managerial subjects is not possible in a single program, this proposal may assist in increasing discussion between educators and industry professionals regarding the relative priorities for background in the technology and the management systems required for construction careers. It may also assist prospective graduate students in selecting the mix of engineering and management courses which provide the best preparation for the construction career paths they choose.

INTRODUCTION

Preparing students for the challenges of managing large construction projects is an important responsibility and a difficult task. The highly varied types of programs now in use (8) indicate substantial differences both in priorities of topics and approach. The Business Roundtable's study of construction management education (2) found that owners generally prefer a bachelor of science degree in engineering as a background for project managers and construction managers. Contractors favor a degree in building construction.

This paper seeks to identify the key elements of a graduate educational program focused on preparing students for careers in managing large construction projects. It focuses on the difficult decisions required to balance engineering and management topics in construction education. The paper does not accept several traditional arguments regarding the development of managers in construction. These include: (1) Experience is the only appropriate basis; (2) good managers are born, not made; and (3) certain types of construction projects change so much that manager preparation is not possible. Rather, the construction education program proposed here is based on the belief that an understanding of basic technical and managerial principles will allow entry level personnel to more rapidly gain the experience and knowledge necessary to manage construction.

In focusing on a graduate construction program, the curriculum described in this paper assumes an engineering undergraduate background. It is not based on a specific curriculum, but rather, on several

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existing programs as well as observations of career paths for engineers in construction.

In developing the subject matter, this paper includes five major topics. First, we will briefly overview construction career opportunities to gain background regarding educational requirements. Next, we will examine the current structure of construction education and present an overview of a graduate program designed to balance engineering and management elements. Then, we will examine both the technical and the managerial elements of this program in detail. Finally, we will describe curriculum design and implementation and highlight conclusions from this analysis.

Construction Career Paths

The difference in work operations on construction projects make career paths different from those in engineering. A sequence of positions assisting entry level personnel to rapidly gain broad experience (15) includes assignments in field engineering, field supervision of work activities, and support functions such as materials management, project control, and contract administration. On large projects, the long duration of individual activities may create the risk of an extended assignment and specialization. This less desirable career path, resulting from the intense demands of the current project, delays high-potential personnel from obtaining management responsibility and inefficiently uses scarce personnel resources.

These differences in possible career paths for construction projects result in several implications for educational needs. First, entry level personnel soon broaden their involvement past a single, technical discipline. This movement from a specific technical focus to the broader requirements of construction engineering, and then into management, may be accelerated on projects involving multiple disciplines, such as industrial, as compared to building or heavy construction. Second, engineering, management, and support activities each require a basic understanding of underlying principles and techniques. Many gain this through experience. Prior exposure through educational programs can vastly accelerate this process. Third, although it is impossible to prepare for all technical and managerial elements of construction, total neglect of any major segment can hinder an individual's career development.

Construction Education

Oglesby (8) identified three major approaches to construction education. Approximately 70 civil or other engineering programs currently graduate nearly 1,500 students each year with some construction exposure. The approximately 30 civil engineering departments offering a five year master of science program graduate roughly 500 students each year. The over 50 "construction" schools, devoting more attention to construction management and techniques with less emphasis on technical engineering subjects, also graduate approximately 1,500 people per year. Other reviews of construction education (3,5) have proposed curricula for specific types of projects and forms of project organization.

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This background indicates a concern for the special needs of construction education.

The Business Roundtable's study team on management education identified a variety of four-year programs in construction and project management (2). Most focused on either construction management or civil engineering. The team concluded that owners prefer that project management or construction management personnel hold a Bachelor of Science degree in an engineering discipline. Many contractors prefer a degree from a building-construction school. Therefore, both types of undergraduate programs are needed.

In reviewing the graduate construction programs, the study team concluded that: (1) A graduate program is needed to provide added education in management skills; (2) a graduate program would assist in upgrading the skills of those in industry; (3) there is now little incentive for those with bachelor degrees to attend graduate school; and (4) graduate degrees will enhance the prestige of construction and assist in attracting and retaining the necessary management personnel with high potential (2).

Overview of Construction Engineering and Management Curriculum

An educational program designed specifically for future managers of construction projects (see Table 1) should meet several objectives. First, it should equip the students with the principles and the concepts necessary to rapidly understand construction methods, operations, and management techniques and build an experience base. This includes a

TABLE 1.—Summary of Construction Engineering and Management Curriculum

Course name (1)	Credit units (quarter) (2)	Quarter taken (3)
(*a*) Technical Segment		
Construction Engineering	04	1
Construction Methods and Operations	04	1
Computer Applications in Construction	03	2
Advanced Technical Elective	03	1, 2, or 3
(*b*) Management Segment		
Human Behavior and Construction Organization	04	1
Industrial Industrial Relations in Construction	04	2
Project Control Techniques	04	2
Legal Framework of Construction	03	2
Accounting and Finance for Construction	04	1
Construction Business Strategy and Marketing	03	3
Managing Construction Operations	03	3
Managing Electives	06	1, 2, or 3

Note: Total technical segment credit units = 14; total management segment credit units = 31; total quarter units = 45.

technical understanding of the completed facility and its construction and a managerial perspective on planning, directing and monitoring construction operations. Second, it should build an awareness and respect for the engineering, procurement, and other major tasks required for successful project execution. This assists in obtaining necessary support and in avoiding getting "snowed." Third, the program should prepare the student to get along with subordinates, peers, and superiors; to assume responsibility; and to lead construction personnel. These human relations skills are critical.

The technical segment of such a program, as described below, builds a broad-based engineering background, applies engineering principles to the construction situation, and provides a technical framework for analysis of construction methods and operations. This technical foundation conforms to the German (7) emphasis on technical preparation for managing high technology operations, and the high Japanese levels of technical support staffing for construction (10).

The management segment emphasizes planning, direction, and review (14) as the major management responsibilities. It also recognizes the necessity for strong human relations skills in managing construction organizations. The intense demands for progress and the complex sources of motivation in construction demand this.

Contents of the Technical Segment

The suggested curriculum to prepare students for the technical aspects of managing construction projects includes five major subdivisions. The first two, the essentials of engineering disciplines and construction engineering, provide a sound technical foundation in the applicable engineering disciplines and experience in their application to practical construction problems. The technology of construction and the analysis of construction operations, the next two components, develop a technical awareness of the requirements and the risks involved in construction methods and activities. The final segment, computer applications in construction, provides a technical understanding of this tool which is sufficient to allow its effective use in meeting the special requirements of construction.

Basic Engineering Principles.—A study of fundamental principles and concepts in each of the basic engineering disciplines provides an essential first element of the technical segment. Concepts important in understanding the constructed facilities include: (1) Fluids; (2) thermodynamics; (3) electric power; (4) foundations and structures, and (5) materials science. This fundamental technical background is necessary to communicate with design engineers regarding problems, to analyze the design consequences of technical changes required by field conditions, and to interpret the plans and specifications for field construction personnel.

The bachelor of science engineering curriculum for many engineering disciplines includes many elements of this technical discipline core. However, recent emphasis of high technology subtopics in these subjects may lessen the relevance of this material to construction. If the students do not obtain adequate coverage as a part of the undergraduate program, they should take supplemental courses. In addition, the grad-

uate construction engineering and management program may require at least one advanced technical elective to refresh analysis and problem solution techniques and provide greater depth in a specific area of student interest.

Construction Engineering.—Knowledge of construction engineering allows the students to provide technical support to construction operations (17). Examples include: (1) Design of formwork; (2) design of temporary structures and lifting attachments; (3) technical analysis of construction equipment and planned methods; and (4) design of temporary utilities for construction sites. These utilities include: water, fire protection, welding gasses, compressed air, ventilation and construction power (18).

Each of these activities require the application of fundamental engineering principles and the balancing of an adequate design margin to assure safety and capacity with the very real need for economy. Academic coverage of construction engineering should emphasize the need for judgment in making the design decisions and should recognize both the time constraints and the resultant lack of precision which frequently characterize this activity on construction sites.

Construction Methods and Operations.—The technology for specific construction operations includes the equipment, tools, materials, methods, and tasks required to define construction activities (1). For industrial construction projects, this technology ranges from manual means of handling small material pieces to sophisticated equipment for both heavy rigging and mechanized operations such as automated welding. Heavy civil projects emphasize equipment resources and specialized operations. On building projects, structural and architectural features, construction methods associated with specific materials, and repeated operations dominate construction technology. In addition, the systems required for "smart buildings" increase the number of design disciplines involved in building projects.

The increasing complexity of constructed facilities promise greater complexity in construction technology. Appropriate technical background includes a knowledge of the alternate technologies available along with an understanding of the means to analyze, design, and improve construction methods and operations (9).

Reviewing available technology for construction operations requires classroom discussions and field observations of conventional and advanced tools, materials, and equipment. This instruction should focus on the underlying principles which govern the selection and use of specific technologies. Researchers are providing new tools for the analysis and design of construction operations. These range from models for construction productivity improvement (13) to computerized simulation of construction operations (4,11). Students' familiarity with these technical tools is an essential background for the management steps involved in methods improvement.

Computer Applications in Construction.—The currently available computer tools present an enormous potential for improved management of construction projects. A technical understanding of computer hardware and software capability and a background in using these tools to solve technical construction problems is an important element of ed-

ucational background. The extremely dynamic nature of this field requires that students gain a knowledge of both basic computer principles and the unique requirements for computer applications in construction.

Education in construction computer applications should include: systems requirements and design, hardware capability and selection, programming for construction applications, and use of available software packages. Computer literacy now requires a knowledge of both the large systems necessary for administrative and control support on large projects and the powerful microcomputer capabilities for meeting specific information needs and solving problems at the site.

Contents of the Management Segment

A track of potential management courses in a graduate construction engineering and management curriculum should include the three major areas of people and organization, the business core, and construction project management topics.

People and Organization.—Assisting individuals to build the human relations skills necessary to function effectively and to obtain desired support in a large construction management organization is perhaps the greatest challenge of a construction engineering and management curriculum. The intense individual pressure imposed by construction and the large organizations required for some projects emphasize this need.

These human relations skills include an understanding of current knowledge regarding motivation and leadership, as included in the subject of organization behavior. Classroom and group exercises involving these skills are necessary to reinforce the students' understanding of and ability to implement them. Other practical skills, such as oral and written communication, time management, and the conduct of effective meetings are also important. The variety of alternatives used for construction company and industrial project organization (6,16) emphasize the need for course coverage of this topic.

Coverage of construction labor relations is necessary to develop a background in the United States labor movement and to identify differences in the union and nonunion options. The craft union structure of United States construction requires special attention to industrial relations. Prior exposure to the history and constraints of construction craft jurisdiction (12) will greatly assist entry level managers in understanding field operations. A broader course in industrial relations should also include the special requirements of open shop and nonmanual personnel in construction.

Business Core.—To provide a background for advancement to project management and general management responsibilities, construction managers must become familiar with a series of business core subjects. The quantitative topics in this core include accounting and finance. The qualitative segment of the business core includes marketing, business strategy, and construction legal framework. These management courses should apply the concepts developed in research for business school programs to the special demands of construction projects. The unique legal background of construction and the growing influence of liability requires separate course coverage of this area.

Construction Project Management.—A third part of the management segment contains courses unique to construction management, including construction project control and project management. The control course should develop an understanding of planning, scheduling, cost control, quality control, and materials management. Course work in project management should develop a broad perspective regarding the relationship of construction activities to project feasibility studies, engineering and design, and procurement (19).

Design of Construction Engineering and Management Curricula

The foregoing discussion of desirable technical and management topics highlights several key needs in a curriculum for graduate construction education. The process of designing such a program should include setting objectives and considering each of the following potential problems.

1. The large number of topics and the time required to adequately develop each results in a total curriculum requirement that exceeds the time available in even a one-year graduate program. This requires a balancing of technical and management subjects.
2. Dividing the proposed curriculum into technical and management segments provides important advantages for analysis of requirements and for planning. However, the combined nature of construction engineering and management makes these divisions difficult and unclear. Several topics, such as analysis of construction operations and computer applications in construction, include both technical and managerial elements.
3. Simulating the complexity, pressure, dynamics, and demands for creative thinking in problem solution required on a construction site is very difficult in the classroom. Case studies provide one means of capturing realistic construction problems.
4. Positioning a construction engineering and management curriculum to provide adequate preparation for the many career path options available to graduates is very difficult. Possible variations include the technical or management option, the segment of the construction industry (building, heavy civil, industrial), the size of the project, the type of firm (owner, engineer-constructor, contractor, developer, engineer, or consultant), and the phase of the project.
5. Selecting the level of course positioning also presents a challenge. Major emphasis on the skills necessary at the entry level may allow more rapid early learning, but will require additional training to assume increased responsibility. Total emphasis of project management and general management subjects may leave the graduate unequipped for immediate responsibility and may also increase frustration through unrealistic expectations.
6. Integration and application of the concepts and techniques included in the topics identified previously presents a large teaching challenge. Success in this task greatly assists students prepare for rapid contribution to construction projects.

Decisions in each of these areas allow a program focus adequate to meet specific objectives. The curriculum summary given in Table 1 illustrates one means of covering the major elements in the technical and the management tracts. This program of 45 quarter-units reflects a bias toward larger projects, and assumes an undergraduate background including the necessary engineering principles.

Industry and Academic Perspectives

The writer offered this paper and participated in an interesting session on construction management education at the ASCE-1984 Spring Convention. The session included six papers examining construction management from the consultant's, the contractor's, and the educator's viewpoints. The four panelists who discuss the presentations brought a similarly diverse perspective.

The divergence of two panelists' viewpoints defined the spectrum regarding construction management education. One senior manager from the construction industry indicated that many contractors prefer to train the four-year graduate on the job or with a training program including a planned sequence of differing assignments. They seek entry personnel with high potential for general development, rather than the increased specialization which may result from a fifth year degree. This viewpoint emphasizes aggressive determination to contribute rather than thoughtful analysis. He noted that those recommending the advanced degree were educators.

From the academic viewpoint, one construction faculty member saw a need for additional time to develop fundamental concepts and principles for use during an entire construction career. The fifth year creates a 40 year payback. The difficulty of designing an educational program to cover the diverse challenges of construction, in this view, is analogous to a basketball coach attempting to teach a guard to drive to the basket and score. Basic skills and moves are similar; everything else differs every time the guard attempts this in a game. He noted that all construction projects are different and that a new breed of more analytical managers is necessary to avoid and solve the diverse types of problems inherent in construction.

Conclusions

The differences between construction and other engineering and management responsibilities merit specialized educational programs. The increasing challenges of construction projects require specialized manager background for successful project execution. Curricula including both construction and engineering and management topics can prepare managers for this responsibility.

The series of courses proposed in this paper considers the technical and the managerial elements of construction. The potential problems identified in the discussion of curriculum design indicate the need for carefully defined objectives and program focus. Although many practical limitations make the ideal curriculum unattainable, a challenging exposure to the topics identified could develop the interpersonal skills and

the problem-solving ability essential for managing construction. This step would assist in meeting the objective of strengthening construction education, as outlined by the Business Roundtable. It may also overcome the existing prejudice concerning time spent in advanced education.

APPENDIX.—REFERENCES

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