Volume 3
Number 2

Summer 1998

The Journal of Construction Education

K. C. Williamson III, Ph.D., ***Editor/Publisher***

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A Tri-Annual Publication of
The
Associated Schools
of
Construction

ISSN 1522 8150

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Any requests, suggestions, questions, or reports regarding this service should be directed to:

Editor/Publisher
Kenneth C. Williamson III, Ph.D.
Langford Building A, Room 427
College Station, TX, 77843-3137
Tel: 979.845.7052
E-mail: jce@taz.tamu.edu

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The Journal of Construction Education

Summer 1998

Volume 3
Number 2
pp. 55 – 143

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Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 60-72

1522-8150/98/$3.00/Educational Practice Manuscript

Electrical Construction Management Specialization Program: A Formative Evaluation

Kirk Alter
Purdue University
West Lafayette, Indiana

Construction educators are good at studying the technical aspects of construction, at creating new curricula, and promoting their visions of the future of construction education. They are for the most part, though, not trained as professional educators, and may not be fully aware of all of the well-tested models designed to aid in focusing critical self-examination on the courses and programs, which they teach. It is too easy, especially in times of a strong construction economic climate, to be remiss in carefully evaluating the content and quality of extant curricula. Evaluation should not be left to accreditation bodies such as ACCE, but instead should be part of a continuous process by construction educators to improve the quality of education delivered. The focus of this paper is to examine a new curricula in its formative stage to both improve that curriculum, and to perhaps create an impetus for collective self-examination of existing curricula.

Key Words: Program Evaluation, Curriculum Evaluation, Electrical Construction Management, Provus Discrepancy Model

Introduction

A survey of the *Proceedings* of the Annual Conferences of the Associated Schools of Construction from 1987-1997 shows that of all of the papers published that approximately 18% focused on curriculum development, 3% focused on program development, 2% focused on curriculum evaluation and 2% focused on program evaluation. As an organization committed to promoting excellence in construction management and technology education the Associated Schools of Construction (ASC) seems unusually silent on the matter of careful and continuous evaluation of courses and programs currently offered. Certainly, it would be fair to assume that calls for development of new curriculum are signals to indicate that at any point in time someone is looking at specific parts of the curriculum of personal interest. While the 7% contribution towards program development and curriculum and program evaluation indicates that there is an occasional interest in taking a broader look at the direction of construction education it does not send the signal that this is a very significant concern for construction educators.

It seems problematic that ASC faculty charged with providing the highest quality construction education possible rarely publicly evaluate their curriculum and programs. The only recent articles published, Shahbodaghlou & Rebholz (1994), and Yoakum (1994), focus broadly on program design and outcome assessments. While both program design and outcome assessments are important, they fail to direct an introspective examination of the curricula being taught everyday in the ASC schools. Outcome assessments are particularly suspect in a boom construction economy where demand for construction program graduates is so high that ASC schools may possibly gain a overestimated opinion of the quality of their curricula and programs. A business maxim adhered to by successful firms is that the time for careful introspection and creation of plans to improve and change is when you are at the "top of your game". The notion that a course, curricula, or program is the "best", and therefore not subject to review or change should be an anathema to all educators. It may be prudent for ASC schools to consider performing closer, and more frequent self-examinations and making them public to ensure that they are practicing continuous improvement in their organizations.

The absence of published evaluations of curricula and programs may be simply the result of no clear models or examples. The purpose of this paper is to examine a fledgling new program in electrical construction management, in order to hopefully provide both meaningful input to that program, and to perhaps provide an evaluation model for others to use.

Electrical Construction Management Specialization (ECM) – Program History

An ELECTRI21 study of 160 electrical contractors and 90 U.S. colleges and universities funded by the National Electrical Contractors Association (NECA) entitled "*Developing a Curriculum for Electrical Building Construction and Contracting*" (Lew & Achor, 1994) found that 96% of the contractor respondents felt that a college educational program was needed in electrical construction management. The intended program would focus on developing a specialization program in electrical construction management. Some of the tasks identified as important in creating such a specialization program included development of courses, development of student recruitment programs, student internship & placement programs, faculty recruitment, development of student organizations, and the use and equipping of laboratories. Additionally, the findings of the study indicated that "major discussions with industry representatives and other universities concerning the content and goals of such a specialization had to be accomplished initially to give the program direction." (Lew & Achor, 1994)

Summary – The precursor to developing a specialization program in electrical construction management was an industry needs assessment (1994), providing some direction on how to collect more data on program design.

Next, a proposal was developed and submitted in June 1995 to NECA for funding of the "*Implementation of an Electrical Construction Management Curriculum*." (Alter & Lew, 1995) The purpose of the proposal was to seek initial funding for the development of an electrical construction management specialization program. The project was designed to focus on the development of electrical construction management courses, development of a marketing plan, student recruitment, placement of graduates, and a national effort to begin the process of offering similar programs at other universities. Specifically, the grant proposal was to deliver work product in the forms of 1) formulating and convening an "Electrical / Mechanical Construction Management Conference," 2) developing courses designed to provide instruction in subject areas identified in the ELECTRI21 report, and 3) developing and implementing a marketing plan.

The grant was fully funded by NECA, and work began on designing a specialization program, which would meet the stated goals and objectives of the grant proposal.

Summary - The NECA grant (1995) provided the resources to begin work on the development of the specialization.

Upon award of the grant in June 1995 work was begun to develop and implement an electrical construction management program. A new faculty member whose primary area of responsibility was in the area of electrical construction management was hired for the school year beginning August 1995. The following is a synopsized chronology of the evolution of the specialization program:

Fall Semester 1995 - The new faculty member teaches a core introductory course in electrical materials & methods. The existing text used is not particularly relevant, the existing course manual is disorganized, and the faculty member randomly experiments with both curriculum and instructional methodology in a search to provide effective instruction.

Spring Semester 1996 – The faculty member abandons the existing text, and compiles a rudimentary new course manual. Consideration is given to altering the delivery format of the class, to changing from three 50-minute lectures weekly to two 50-minute lectures and one 2-hour lab. The core course is refocused from a survey of the entire field of electrical construction management to an introduction of electrical materials and methods. This shift more closely resembles the approach used in providing general construction management education.

Fall Semester 1996 – The faculty member continues to refine and develop the course manual, and introduces the National Electrical Code (NEC) as a primary source for the class. A lab component is added for the first time, accomplishing a shift in the instructional delivery method. The faculty member solicits the assistance of the local NECA Chapter, and the first student chapter of NECA is formed. 10% of the department student population joins (60 students). A first meeting of electrical, mechanical, and university representatives is convened to discuss the formation of an alliance to determine, develop, and promote electrical and mechanical construction management programs at universities throughout the country. The faculty member develops a course in electrical estimating.

Spring Semester 1997 – The faculty member continues to refine the electrical materials and methods course (core course), and offers for the first time, a course in electrical estimating. The course is provided to 12 students, and the faculty member works closely with industry representative in designing and delivering the course. The course is experimental in nature, and success of course is difficult to define. The faculty member proposes a new course for Fall 1997 in the area of electrical and mechanical design build. The faculty member formally proposes an electrical specialization program to the department curriculum committee consisting of courses in materials and methods (core), electrical construction estimating, electrical construction management, design/build for MEP contractors, and one elective from a proposed list of acceptable electives. The proposed curriculum changes are accepted by the department committee, and forward to the school curriculum committee for approval. Department faculty members publish a journal article entitled "*Development and Implementation of Electrical and Mechanical Specialization Programs in the Undergraduate Curriculum*." (Alter, Koontz, and Lew, 1997) as a result of their 1996 "Contractors' Survey for Electrical/Mechanical Building Construction Education" outlining the goals and objectives of the specialization program.

Summer 1997 – The faculty member writes a grant proposal to NECA to develop a national student scholarship program in electrical construction management. The grant proposal is accepted by NECA, to be funded Summer 1998. The faculty member continues course development on all courses approved by the department curriculum committee. Student interns work for electrical contractors in Indiana, Illinois, California, Oregon, Washington, Colorado, Arizona, and Kentucky.

Fall 1997 - Electrical methods & materials, and Design/Build for MEP contractors are offered and fully subscribed. NECA students and faculty member attend the NECA annual convention in Miami Beach in October presenting on program progress, and attending an intensive seminar on fiber optics. Annual ECM specialization course sequencing begins with fall semester offerings of materials & methods, and design/build, and spring semester offerings of materials & methods, and estimating. Electrical construction management is offered by both other faculty members in the department, and as an independent study, and electives are taught by either the primary faculty member or outside of the department. The first two graduates of the program exited the department in December 1997.

ECM Program Evaluation

Evaluation Rationale

The electrical construction management specialization is still in its infancy. The stated program design and purpose have been well received by both industry and academia. It is being funded by both the university and industry. Student interest is building, with a rapid influx of students participating in the NECA student chapter.

So why, then, evaluate the program now, when everything seems to "be coming up roses?"

The answer is that now, with the program still in its infancy, we should look at the program to assess whether we have adequately defined it, and to determine if the means of installation are congruent with the design. This is especially important, as it is intended that this program will be a model for first, the consortium of schools in the alliance developed as part of the NECA grant, and later for other interested ASC schools.

Evaluation Model

Program evaluation is a well-developed field of study in the educational arena, yet there are no apparent references to the use of formal evaluation techniques in the records of the proceedings of the ASC over the past ten years. The purpose of program evaluation is to provide two fundamental groups of decision makers' information. The first target audience is all those who make decisions to improve and/or stabilize specific programs – this group would include the faculty member/s delivering the instruction, the curriculum committee, and the department head. The second target audience is those who make decisions to retain or terminate programs – this group could include the curriculum committee, department head, and dean.

There are two basic schools of thought on program evaluation – the utilitarian perspective, and the intuitionist/pluralist perspective, and both have very well developed positions and techniques. Further, the tools of evaluation are extensive and include methods of obtaining group input, indicators of academic achievement, alternative methods of assessment – including performance assessment and portfolio assessment, assessment of affective characteristics, and qualitative methods of inquiry (Gredler, 1996).

Before undertaking any program evaluation the evaluator must consider the following:

1. The type of evaluation to be conducted - formal vs. informal, formative vs. summative.
2. The definition of evaluation to be used.
3. The purpose of the evaluation.
4. The key emphasis of the evaluation.
5. The role of the evaluator.
6. The relationship of the evaluation to program objectives.
7. The relationship of the evaluation to decision making.
8. The theoretical constructs underpinning the evaluation.
9. The criteria for judging the program.

The Provus Discrepancy Evaluation Model

The Provus Discrepancy Evaluation Model – designed by Malcolm Provus in 1969, is a well tested and commonly accepted utilitarian model to use in evaluating academic programs. He defined evaluation as the process of agreeing upon program standards, determining whether a discrepancy exists between some aspect of the program and standards governing that aspect of the program, and using discrepancy information to identify weaknesses of the program. His stated purpose of evaluation is to determine whether to improve, maintain or terminate a program (Gredler, 1996). His model is primarily a problem-solving set of procedures that seeks to identify weaknesses (according to selected standards) and to take corrective actions with termination as the option of last resort.

With this model, the process of evaluation involves moving through stages and content categories is such a way as to facilitate a comparison of program performance with standards, while at the same time identifying standards to be used for future comparisons. This seems to be a particularly useful technique to employ when evaluating a fledgling program like the ECM specialization.

The Provus method identifies four specific stages of all programs. The stages are:

> *Stage 1: Program Definition* – where the purpose of the evaluation is to assess the program design by first defining the necessary inputs, processes, and outputs, and then, by evaluating the comprehensiveness and internal consistency of the design. Evaluation Stage 1 asks the question, “Is the program adequately defined”?

Stage 2: Program Installation – where the purpose of the evaluation is to assess the degree of program installation against Stage 1 program standards. Stage 2 asks, “Is the program installed as defined in Stage 1”?

Stage 3: Program Process – where the purpose of the evaluation is to assess the relationship between the variables to be changed and the process used to effect the change. Stage 3 asks, “ Are the resources and techniques being used congruent with the goals of the program?

Stage 4: Program Product – where the purpose of the evaluation is to assess whether the design of the program achieved its major objectives. Finally, in Stage IV the question is asked, “ Are the program objectives achieved in the implementation”?

At each of the four stages the defined standard is compared to actual program performance to determine if any discrepancy exists. The use of discrepancy information always leads to one of four choices:

1. Proceed to the next stage of evaluation if no discrepancy exists.
2. If a discrepancy exists, recycle through the existing stage after there has been a change in either the program’s standards or operations.
3. If #2 cannot be accomplished, then recycle back to stage 1 – program definition, to redefine the program, then begin the discrepancy evaluation again at stage 1.
4. If #3 cannot be accomplished terminate the program.

Use of the Provus Discrepancy Model

The Provus model is most effective under the following circumstances:

1. When the type of evaluation desired is formal, and the program is in the formative, rather than summative stages.
2. When evaluation is defined as continuous information management addressing program improvement and assessment, and where evaluation is a component of program development.
3. Where the purpose of evaluation is to improve, maintain or terminate a program.
4. Where the key emphasis of evaluation is program definition and program installation.
5. Where the roles of the evaluator are those of facilitator, examiner of standards, observer of actual behaviors, and design expert.
6. When at each stage of evaluation program performance is compared with program objectives (standards) to determine discrepancies.
7. Where the program evaluation procedure is designed to identify weaknesses and to make determinations about correction or termination.
8. Where the theoretical construct is that all stages of programs continuously provide feedback to each other.
9. Where the criteria for judging programs includes carefully evaluating whether:
    a. The program meets established program criteria
    b. The actual course of action taken can be identified, and

c. A course of action can be taken to resolve all discrepancies (Gredler, 1996).

Provus Terminology Defined

The following definitions will be useful in understanding the evaluation which follows:

Inputs – a) the things the program is attempting to change, and b) things that are prerequisite to program operation, but which remain constant.

Process – those activities which change inputs into desired outputs.

Outputs – the changes that have come about including a) enabling objectives, b) terminal outcomes, and c) other benefits.

Enabling Objectives – intervening behaviors/tasks which students must complete as a necessary basis for terminal outcomes.

Terminal Outcomes – the behaviors the clients are expected to demonstrate upon completion of the program.

Design Criteria – contains a comprehensive list of program elements (input, process, output) that become the standard of performance in Stage 1.

Stage 1 Provus Evaluation of the ECM Specialization Program

As this program evaluation is being conducted in the very formative stages of the program, and since the strengths of the Provus model focus closely on program definition and program installation it was decided to attempt to use Provus methodology in examining the electrical specialization program. Some limitations of this evaluation include the application of only the first stage of the Provus model - dealing with program definition, and leaving out the Provus examination of program installation, program implementation and outcomes. The choice to only examine the first stage of the program evaluation as described by Provus is the simple result of the current status of the program. The Provus model is explicit in its prohibition of moving on to subsequent stages until discrepancies in the current stage are remedied. The program has only recently been defined, and is still in the early moments of program installation. According to the Provus model, the most important thing we can do right now is to carefully examine whether the program is adequately defined. Stages 2-4 would only be carried out after a thorough examination of Stage 1 to determine if any discrepancies exist.

Stage I - Program Definition

The basic question posed in this stage is, “Is the program adequately defined?” Specific information needs to be gathered regarding the program purpose, required conditions, and transactions. Definitions of student entry behaviors, staff qualifications and training, curriculum and instruction methods and materials, facilities requirements, and administration conditions must be derived. Further, program definition must be analyzed for ***clarity, internal consistency, and comprehensiveness***.

Why do all of this? In order to provide justification for going on to the next developmental stage - program installation. The ECM specialization program can be justifiably terminated under the following conditions if determined at this stage:

1. Resources don't meet minimal levels to operate the program
2. Program components are inconsistent with each other, or with other programs in the department, or
3. The program defies comprehensive definition

Electrical Construction Management Specialization Program Definition Template

This template has been designed according to the Provus model of program evaluation for Stage 1. At various points in the template there exist enumerated blank lines. This occurs where no written program definition currently exists, and represents a clear area of discrepancy within the Provus model. Correction of this discrepancy would need to occur before moving on to Stage 2 – Program Installation, under this model.

A. General Program Criteria

I. Overall Statement of Objectives and Rationale for the Program

Program Rationale -

- There is a definite need for electrical construction management education at the college and university level. (Lew & Achor, 1994)
- Currently many colleges and universities focus on the management aspects of general construction. (Syal, et al, 1995) (Alter, 1996) The next important step is to develop programs to address the specific needs of electrical construction in the areas of management and technical skills and knowledge.
- There was extensive agreement between electrical contractors and educators that there should be a combination of mechanical and electrical subject matter in the curriculum. (Koontz & Alter, 1996)
- Marketing programs are needed for recruitment of students, placement of students in the industry, and the development of electrical construction management programs among other universities.

Program Goals & Objectives -

- Hire qualified faculty with experience in electrical construction management
- Develop a curriculum which will provide depth and breadth in the area of electrical construction management without significantly extending students' undergraduate academic careers
- Establish student organizations to foster educational, service, and social experiences which will be fundamental to the longevity and success of the program
- Develop well paid, high quality student internships and co-ops where students will gain experience in the industry

- Craft a student recruitment program to entice students to commit to the specialization option
- Work with industry to place graduates of the specialization in full time positions
- Create a consortium of industry and academia experts to develop and execute a national strategic plan in executing specialization programs
- Develop a marketing plan to educate industry and potential students of both the product and opportunities afforded in the specialization programs
- Develop and equip labs to provide practical applied instruction in electrical construction management

Discrepancy Evaluation Comments. The statements of program rationale do provide some insight into the raison d'être of the program, but they are neither clear nor succinct. Recommendation - Consult with consortium members to clarify and make them more succinct. The statements of objectives seem to be very thorough and complete. Recommendation - See *Program Outcomes* Recommendations

II. Scope of the Program
   a. Number of Students, Schools, and Industry Participants Involved
   b. Contextual Description of Participants
   c. General Description of Staff

Discrepancy Evaluation Comments. The intended scope of the program is not clearly defined. No information is provided which describes the student, school, or industry populations. No contextual information is provided. In spite of a major objective of "hiring new faculty", no description of existing faculty, or faculty qualifications exists. A "consortium" was created to "spread the gospel", yet no criteria is defined for how participating schools were selected. Recommendation - Compile data on proposed student population impacted by the program, including demographic statistics, critical mass requirements, and contextual background of target audience. Define the characteristics of schools which may be affected by, or which may become participants in the program (or a similarly transportable program). Create general job description and preferred qualifications of faculty and staff participating in the program.

B. Program Outcomes
   I. Major Objectives of the Program - the changes that are expected to take place in program participants as a result of their experiences in the program.
      a. Terminal Objectives - as a direct result of the electrical construction management specialization program, it is expected that the students will have the following skills:
         1. ____
         (e.g. Student will be able to quickly recognize and identify the electrical scope of work in a set of construction documents)
      b. Ultimate Objectives - those things, which it is, expected that the electrical construction management specialization program will contribute to its participants in the long run.
         1. ____

(e.g. Student will gain increased and better job opportunities as a result of participating in this program. Industry partners will gain access to a larger, more qualified applicant pool)

II. Enabling Objectives - in order to bring about the major objectives listed, the student must first accomplish several things through the program:

a. Incremental tasks on path to achieving terminal objectives:

1. ____

(e.g. Student will be able to read and interpret electrical plan and specs. Student will be able to list all electrical systems found in buildings, …)

b. Other Benefits - benefits expected to accrue to the community as a result of the electrical construction management specialization program include:

1. ____

(e.g. The overall quality, safety, and profitability of electrical construction in the community will be upgraded as newly trained managers enter the industry)

Discrepancy Evaluation Comments Regarding Outcomes. While there are nine "Goals and Objectives" cited under the overall statement of program objectives, they are not clearly classified or identified in the categories of Major Objectives, Enabling Objectives, or Other Benefits. It is difficult to determine which stated program objectives have priority or significance as currently presented in "laundry list" form. Recommendation - Provide clear definition on how to classify objectives using this model to consortium members, and classify the original nine stated program objectives. Where necessary or appropriate add or delete objectives to clarify the intended outcomes of the program.

C. Program Antecedents - identify contextual information, participant characteristics, qualifications, and required program support .

I. Students

a. Selection Criteria - describe what students are eligible for the program, including data on the number of students (student pool), the number of schools (school pool), and expected sample populations. List any prerequisites for the program.

b. Entering Behaviors - identify common observable characteristics of the selected student population which must be taken into consideration when planning instructional activities (e.g. most students in construction management programs have no experiential basis in the area of electrical construction, and thus will need to be provided with elementary instruction in terminology, materials, methods, and applications)

II. Staff - identify necessary qualifications of staff participating in the program.

(e.g. Faculty must have an understanding of the electrical contracting industry, and have at least minimal knowledge of the purposes and techniques of the instructional materials and methods being implemented).

III. Support - identify the support required to make the program viable.

a. Administrative Support - identify the support required at the department, school and university levels.

b. Human Resources - identify the persons whose services are important to program implementation, and describe their roles.

   c. Media - identify the materials, equipment, and other resources to be used, and their purposes.

Discrepancy Evaluation of Antecedents. The existing program definition is built upon a needs assessment survey. There is little information extant describing antecedents in the areas of students, staff, and support. Recommendation - Confer with consortium to identify and define program antecedents.

D. Program Process - clearly identify the processes, which will be implemented to install the program.
   I. Student Activities - enumerate the student activities, including both a careful description of the activity and the rationale behind it.
   II. Staff Functions - enumerate the specified functions and duties of the staff members.
   III. Intra-staff Communication and Coordination - describe the means of communicating and coordinating the program among staff.

Discrepancy Evaluation of Process. The course syllabi provide a description of student requirements for each course, but could be improved by more carefully and precisely identifying student activities, staff functions, and intra-staff communication and coordination. Experimental courses, or courses being taught for the first few times need to be much more carefully defined and monitored for recognizing discrepant outcomes. While a specialization program has been identified and approved by the department curriculum committee, the specialization program as a whole does not have a clearly explained process or rationale. There have also been intra-staff communication and coordination problems, especially in the area of internships and placement. This clearly seems to be a result of the lack of clear program definition and communications.

Conclusions Regarding the ECM Specialization Program

The ECM specialization program has been well received by both students and industry, but according to the evaluation template applied in this paper it demonstrates some opportunities for improvement in the Stage 1 phase of program definition. Since the program has now moved into the installation stage (2), it is important that all discrepancies discovered in Stage 1 be corrected as soon as possible. Some specific recommendations include:

1. Carefully define and describe the specialization program process, including clear definitions of each of the program components including each course, recruitment, internships, placement, etc., and how the process leads to fulfillment of objectives.
2. Create a program document which clearly describes and communicates the program to all participants, and which defines each participant’s role.
3. Establish clear installation criteria which are congruent with the yet to be clearly articulated program definition.

Conclusions Regarding Program Evaluation in ASC Programs in General

While agreeing with Aldous Huxley that, "There's only one corner of the universe that you can be certain of improving, and that's your own self," this author believes that there is a need for program administrators to better understand that the installation and continuance of construction management curricula and programs, whether innovative or not, involves a high risk of failure and erosion over time. There is a need for programs to be evaluated more carefully, and for evaluators and curriculum committees to better understand the kind of information administrators need if the cost of these risks is to be minimized (Provus, 1969). Both administrators and faculty must see evaluation as a continuous information-management process which serves program-improvement as well as program assessment purposes. The complexity and concomitant high cost of effective evaluation must be recognized as a necessary management and time expense. Everyone concerned with construction management education must be willing to spend larger sums for evaluation if we are to maintain the highest quality of construction management education among ASC schools.

Those involved in curricula review and program development must recognize:

1. The natural development stages of any program.
2. The evaluation activity that is appropriate to each stage.
3. The dependence of administrators on information obtained through evaluation if they are to make sound, defensible decisions.

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Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 73-78

1522-8150/98/$3.00/Educational Practice Manuscript

The Construction Alternative for High School Students

Amaury A. Caballero, Jose D. Mitrani, and Gustavo Roig
Florida International University
Miami, Florida

Ransom Hill
MacArthur South Sr. High School
Miami, Florida

Nelson Perez
Miami-Dade County Public Schools
Miami, Florida

This paper presents an alternative career path for at risk young people of high school age to obtain skills preparing them to enter the construction industry; the third largest economic engine in the State of Florida. The limited options available to these problem youngsters, combined with the scarcity of skilled labor in construction, presents a unique opportunity for a partnership between a university based construction program and a local public institution. The resulting endeavor is, from a funding perspective, mutually beneficial for both institutions. The program also demonstrates how a professional construction education program can fulfill both the educational and service components of its mission. The program described has been successfully working since 1995 at MacArthur South Senior High School in Miami-Dade County. It is a partnership between the Department of Construction Management of the College of Engineering at Florida International University and the Miami-Dade County Public School System.

Key words: Construction, High School Students, Electricians, At-risk Students, Alternative Program.

Introduction

Construction is the largest industry in the USA, directly employing about 6,000,000 workers. In southeast Florida, comprising Miami-Dade, Broward, Palm Beach and Monroe Counties the volume of construction is on the order of $7 billion per year. In Miami-Dade County alone, 20,000 - 40,000 workers are directly employed in construction. The construction industry contributes with approximately $4 billion per year to the gross county product, which constitutes the 10.5% of the total gross county product (Otazo, 1997).

This high construction volume draws significant numbers of new and returning employees to the industry. These employees come from a broad spectrum of educational backgrounds but a common characteristic is a lack of skilled training. This has a detrimental effect on both productivity and quality. The situation is aggravated by the relatively low educational performance of Florida in public education. Florida ranks as the 4th largest state in population but is only ranked 48th in education.

A significant number of high school students cannot or do not want to continue their education at a college level. These include at-risk students. These young people need alternative means of self-support. They are a natural source of potential skilled laborers for the construction industry. Providing them with the opportunity to obtain skills in well-remunerated and respectable trades is beneficial to all. These skills will permit these young people to get a job in the trades because they are prepared and like their work, not because they lack other options.

At-risk Students

Within the set of high school students there is a group, which requires special attention. This group is comprised of the at-risk students. The following is the profile of an at-risk student:

1. Academic performance one or more years below actual grade level in mathematics and reading.
2. Pattern of excessive school absences for a period of at least three months.
3. Pattern of excessive class cuts for a period of at least one-month.
4. Pattern of classroom disruption for a period exceeding one month.
    a. Disregard for rights of others in the classroom
    b. Unjustifiable defiance of authority
5. Inappropriate behaviors, interests or aptitudes that would make success in a typical school unlikely.

Other characteristics of these types of students are:

1. High potential for violence
2. Student does not speak English
3. Serious drug or alcohol involvement
4. Six or more months of voluntary truancy
5. Psychotic or pre psychotic behavior
6. Bizarre, unprovoked or irrational behavior of emotionally disturbed student

The behavior of these students is frequently motivated by family situations and social conditions, which are aggravated as the child grows. A lack of manual and intellectual skills is typical in the majority of these students. This leads to low self-confidence, among other characteristics. These students need a place in which to develop their potential, build self-esteem and test their skills and abilities. They also need to have the possibility of a good job when finishing high school. If this possibility is not available, the tendency is for these young people to gravitate towards the marginalized, disenfranchised lower socio-economic layers in order to get “easy money” and eventually become delinquents.

As a way of reducing the problem that these at-risk students represent to society, the Miami-Dade Public School System has created 16 high schools offering alternative programs. These are educational programs which are designed to offer variations of traditional instructional programs and strategies for the purpose of increasing the likelihood that grade 4 through grade 12 students who are unmotivated, or unsuccessful in traditional programs, remain in school and enroll in a program of study that leads to a high school diploma or its equivalent (Florida School Laws, 1996). In Table 1, the number of students per year in both normal and alternative programs in Miami-Dade County from 1990 can be seen.

The table also shows the percent increase in the number of high school students for both types of programs from 1990 to 1996. It is interesting to note that the share of the student population in normal programs decreased from 96.89 % to 95.35 % between 1990 and 1996. This means that the share of the student population in alternative programs has increased from 3.11 % to 4.65 %.

Table 1

Number of students

Year	**No. Of students in Normal Programs**	**No. Of students in Alternative Program**	**Total No. of Students**	**% of students in Normal Prog.**	**% of students in Alt. Prog.**
1990	80,891	2,594	83,485	96.89	3.11
1991	83,540	3,092	86,632	96.43	3.57
1992	82,072	3,147	85,219	96.31	3.69
1993	83,039	3,586	86,625	95.86	4.14
1994	83,291	3,586	87,158	95.56	4.44
1995	86,004	4,027	90,031	95.53	4.47
1996	88,464	4,314	92,778	95.35	4.65

The increase in at risk students in alternative programs, coupled with the scarcity of skilled laborers in construction, presents a unique opportunity for a partnership between a university based construction program and a local public institution. It is a unique and creative way to address both problems simultaneously. It is beneficial to the people trained, to the institutions involved and to society as a whole. Furthermore, the resulting endeavor is, from a funding perspective, beneficial for all as well.

The Apprentices for a Positive Tomorrow Program

Apprentices for a Positive Tomorrow is a program designed to provide skilled training in residential electrical wiring to at risk high school students. It has been implemented at McArthur South Senior High School in Miami-Dade County, Florida. McArthur South Senior High School receives students from 13 high schools in the area. It has an annual enrollment of approximately 315 students.

During the last two years, the Department of Construction Management in the College of Engineering at Florida International University has been working together with MacArthur South Senior High School in implementing a program teaching a practical sequence of courses in electricity. The objective of the program is to develop skills in these students, which will increase self-confidence and at the same time, prepare them in the practical application of this knowledge and then getting them related jobs in the construction industry. The success of this program has motivated the Miami-Dade Public School System to bestow a grant upon the College of Engineering at Florida International University for $18,800. This partnership is mutually beneficial because it is possible to take advantage of the fact that dual enrollment permits both institutions to claim the FTE for funding purposes. The budgets of both institutions depend heavily on FTE generated.

Course Characteristics

The course is offered in high school as two elective subjects, under the name of “Electrical Wiring in Residential Construction” and "Practical Electricity", two hours per day, five days per week, during one semester. This represents 180 classroom hours where practical skills and theoretical concepts are developed. The classroom is housed in a 32’ by 22’ room, where the students have constructed partitions for the electrical installations. At the beginning of the course, the students work on tables, learning how to use the different tools and how to connect simple circuits at low scales. These circuits use electrical boxes, pipes and wires that have been used during the past semester. This gives the opportunity to the students of familiarizing themselves with tools and electrical materials, without using new materials for beginning practices, which will otherwise represent a waste of resources. When the students have acquired enough practice, they learn to install different electrical circuits at real size on the partitions using Romex, EMT, PVC, liquid tight, etc.

Everyday, the class is divided into two parts: First, a theoretical background is taught and later, different tasks are assigned. The students are assigned these tasks individually or in-groups of two, depending on the type of work to be accomplished.

In this way, the students learn the necessary theory and the practical aspects that they will need in their jobs. These aspects include the practical installation of any fixtures in a house, the reading of blueprints, and the calculations of the service entrance and branch circuits.

Course Objectives

1. To explain the principles and the basis of electrical circuits and electrical properties of conductors and isolators.
2. To describe the electrical circuits components.
3. To teach how to select essential tools for residential wiring and discusses the basic principles of tool use and care.
4. To teach safety and grounding essentials.
5. To teach the theory and practice of residential electrical installations.
6. To describe the service entrance and its characteristics.
7. To give the fundamentals of residential wiring calculations.
8. To teach how to prepare and read prints and wiring circuits.
9. To teach the related aspects of the NEC.

After finishing this course, the student will be capable of:

1. To properly use the essential tools for the electrician.
2. To install boxes and conductors, to realize electrical installations using pipes and other materials used for the same.
3. To calculate residential electrical circuits.
4. To recognize the essential materials and components used in residential wiring

In Table 2, the number of enrolled and promoted students each semester is presented.

Table 2

Number of Enrolled and Promoted Students with A or B

Semester	Enrollment	Students with A orB	Percent
Fall' 95	16	8	50
Spring' 96	20	6	30
Summer' 96	11	6	54.5
Fall' 96	14	4	28.5
Spring' 97	13	4	30.7

Table 2 shows promising results. On average 38% of the students have successfully completed the program, which the authors consider quite good, considering that these are students with serious behavioral problems. More than 20% of the students that finished the course are working as electrician helpers in the construction industry. The students have presented their works in different fairs, with the following results:

1996 Miami-Dade County Youth Fair	First Place
1996 South Florida Regional Science and Engineering Fair	Third Place
1996 Miami-Dade County Youth Fair	First Place (two presentations)
	Second Place (two presentations)
	Special Award

The additional cost of the program is in the order of $60,000 per year, including salaries, tools and materials. Considering that the cost of maintaining a prisoner in jail in Miami-Dade County is on the order of $30,000 per year, the program is self-sufficient if it keeps only 2 at-risk students per year form going to prison.

Conclusions

It is possible to simultaneously address the lack of skilled labor in the construction industry and the dilemma of what to do with at-risk high school students. Florida International University and MacArthur South Sr. High School have been working together, providing needed skilled labor for the local industry as well as education and hope to troubled and disenfranchised young people. Their partnership, Apprentices for a Positive Tomorrow, has yielded promising results: on average, 38% of the students have successfully completed the program, and more than 20% of these are working as helper electricians in the construction industry. Some have decided to obtain more advanced training, with the goal of obtaining journeyman and master electrician licenses in the future. Apprentices for a Positive Tomorrow is a unique and creative partnership, beneficial at-risk young people, the institutions involved, and the local community.

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Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 79-91

1522-8150/98/$3.00/Educational Practice Manuscript

Using Action Research as a Viable Alternative for Graduate Theses and Dissertations in Construction Management

Allan J. Hauck
Colorado State University
Fort Collins, Colorado

Guozhu Chen
Black and Veatch
Overland Park, Kansas

Due to the nature of graduate education in construction management, applied research questions have been more typical than basic research questions. Action research, as distinct from traditional scientific approaches to research, is discussed here as a means to provide structure to the applied research being completed by graduate students in this discipline. This discussion includes an overview of action research principles, a review of a case study involving an action research project which developed a computerized schedule control system and led to a Master's thesis, and a summary of limitations and benefits associated with this approach. Given appropriate levels of control in the selection of research hypotheses, the development of the problem solution, and the application of objective evaluation criteria, many of the limitations associated with applied research can be minimized. This process is demonstrated with numerous practical examples.

Key Words: Applied Research, Action Research, Graduate Education, Construction Management, Schedule Control

Introduction

Historically, research in the field of construction management has involved more *applied research* questions as opposed to *basic research* questions (Mouton & Killingsworth, 1995; Rounds, 1991; Segner, 1990; and others). Authors have noted at least two reasons for this tendency toward applied research topics.

The first reason is the nature of the field itself. Construction management education is fundamentally professional education (Robson & Bashford, 1995). "Construction education is a relatively new academic discipline, created to fill the need for *professionals* [emphasis added] with the specific knowledge and abilities required to manage construction field, office and business operations" (Mouton & Killingsworth, 1995, 45). Education in a profession differs from education in other academic disciplines in that professions are primarily "practice based" rather than "knowledge based." Education of the professional doctor, for instance, is based largely on the study of "what worked" in the past and is grounded in years of practical experience in internship and residency programs. This is not to say that medicine is not firmly rooted in the underlying science of biology and anatomy; in fact, an outstanding background in this "knowledge base" is typically required as a prerequisite to advanced study of the "practice." Because of this professional practice, research in the field of medicine -- as well as the field of construction management -- tends to be applied in nature: it addresses real problems being experienced by practitioners in the field and seeks to provide effective and efficient methodologies to solve these problems. While basic research in the sciences that support these professions is essential for formulating theory and identifying new directions to search for solutions to problems, it ultimately falls to applied research to improve the daily practices of the profession. The goal of applied research is to expand the understanding of "what worked."

The second reason that applied research questions dominate study in the field of construction management is the relative immaturity of the field. Construction management as an academic discipline distinct from design has its origins in the post war era and, in most parts of the country, much later than that (Rounds, 1992). Research questions in "young" disciplines tend to be very practical in nature owing to the need to solve the immediate problems the field of study was developed to address. Engineering disciplines in the early 20th century concentrated on studies of hydrology, improved surveying techniques, and the distribution of electrical power. It has only been in recent years that *basic* research has begun to dominate the various fields of engineering. After decades of addressing immediate problems, these disciplines have begun to search for overriding theories to explain the relationships which were observed. Schools of Business still depend strongly on applied research in management as evidenced by a heavy reliance on the review of case studies (Poorvu, 1992). Likewise, at this stage in the development of the construction management discipline, researchable problems tend to be *applied* in nature - involving the search for improved management practices, more effective field procedures, and new products. The practical nature of research in this discipline was recently reflected in the "National Construction Goals" established by the Construction and Building subcommittee of the National Science and Technology Council (Badger and Magnell, 1995). These goals were established to define priorities for federally supported research and development and addressed the need for reductions in delivery times, operation and energy costs, and waste and pollution. The goals also called for increases in productivity and comfort, durability and flexibility of completed facilities, and workforce safety. Frequently, this applied research involves the modification of tools, materials, and procedures from other disciplines for use in construction. The discovery of overriding "theories" in the traditional sense, to explain and predict observed phenomena, is rare in the field of construction management.

This lack of reliance on basic research in construction management leaves educators in graduate programs in this discipline with an interesting challenge. How can our graduate students be encouraged to solve the very real problems addressed through *applied research* while maintaining the high standards for objectivity, statistical analysis, and rigor traditionally associated with *basic research*? Without an appropriate structure, applied research runs the risk of drawing conclusions which are not tested, cannot be replicated, and cannot be applied to a broader population. These research projects are little more than "book reports" which simply tell the story of something the author has observed. Clearly, our standards for graduate level research must be higher. One possible approach to this dilemma may be to follow the guidelines of action research to provide a structure to graduate studies in applied topics. In the following sections, the action research methodology is reviewed and an example of a graduate thesis prepared under these guidelines is described.

Overview of Action Research

Action research is widely used in the investigation of human behavior and the social world. It emerged as a new approach to research which is more directly relevant to the ongoing work of practitioners. The purposes of action research are to enable systematic investigation and solution of problems experienced by practitioners and their clients, to examine the effectiveness of their work practices, and to take methodical action to resolve those problems (Stringer, 1996).

Action research is distinct from traditional scientific approaches to research. The emphasis of action research is to "improve" while the emphasis of traditional scientific approaches to research is to "prove." Traditional scientific approaches to research seek to test theories that purport to explain why or how the world is as it is. The ultimate aim is to derive lawful statements that explain the nature of the world or the nature of reality. Instead, the goal of action research is to assist people in extending their understanding of their situation and thus resolve problems that confront them (Stringer, 1996).

This investigative approach is not without its critics and potential weaknesses. The literature reveals that there is some argument about the legitimacy of action research. Some academic researchers consider that action research lacks scientific rigor because its internal and external validity is weak. Its objective is situational, its sample is restricted and unrepresentative, and it has little control over independent variables. Hence, its findings, while useful within the practical dimensions of the situation, do not directly contribute to the general body of knowledge (Isaac & Michael, 1981). Others have accepted action research, when properly conducted and controlled, as a legitimate form of inquiry. Stringer (1996) explored issues related to action research and concluded that action research can be a legitimate, authentic, and rigorous approach to inquiry.

The procedures of action research can be simple or very complex. Although several different terms are used to describe the procedures of action research, the basic process is the same. Isaac & Michael (1981) outlined the procedure as a simple three-step sequence (Figure 1)

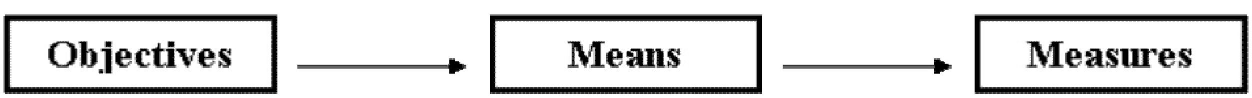

Figure1: Action Research – Three step sequence.

The procedure starts with setting up objectives. In this stage, the following steps are performed:

1. Gather information.
2. Analyze and describe the situation.
3. Define the problems.
4. Decide what objectives are to be accomplished.
5. Formulate testable hypotheses.

The next step is to determine what means will be taken to accomplish these objectives. In other words, what are the particular things the investigator will do in an attempt to accomplish his or her objectives?

The last step is to establish evaluation criteria, measurement techniques, and other means of acquiring useful feedback. The attainment of objectives will be evaluated by these criteria to determine whether they have been accomplished. It is frequently beneficial to adopt a set of outside standards as the evaluation criteria rather than depending on a list of measures developed by the investigator or even the investigator's client. By adopting these outside standards of evaluation (e.g., ISO 9000 standards, OSHA safety goals, or even results attained in previous research), the level of objectivity is increased and the criteria for success and failure are taken out of the hands of the researcher.

Although the procedures of action research have been described here as a linear sequence, it is typically an iterative set of activities. It can be viewed as a spiraling process or, to use the language of quality management, it seeks "continuous improvement."

This methodology described for action research can be adapted easily to the five step process typically associated with graduate research (i.e., corresponding to the standard five chapters of a thesis or dissertation):

1. *Formulation of Research Questions and Hypotheses* - This is common to all types of research and corresponds to the first step of Isaac & Michael's outline ("objectives") presented above. The only difference in action research is the nature and origin of the questions themselves. In this approach applied to construction management research, the questions are extremely practical and may have immediate impact on just a small group or even a single client company. The origin of the questions is from the clients who are experiencing the problem, not from the investigators themselves. As with most other forms of formal investigation, testable hypotheses are still necessary to guide the development of appropriate methodologies.

2. *Review of Literature* - The goals for the literature review are the same for all forms of research: what are the conclusions of other investigators which led one to the current set of research questions and the proposed methodologies to answer the questions? The primary difference in action research is to include in this review possible applications from other disciplines or other industries which may address the research questions presented by the client(s).

3. *Description of the Methodology* - In traditional research, this phase (corresponding to the "means" step in Isaac & Michael's model) describes the research methods used to test each one of the hypotheses identified in the question formulation stage above. In action research, however, this phase takes on a higher level of significance. Frequently, the primary result of action research is the *development* of something: a new procedure, a training module, a computer software application, etc. This development process is, in essence, part of the methodology of the research. Therefore, the goals of the action researcher in describing the investigation are twofold: one, to describe the process used to develop the solution to the stated problem and, secondly, to describe the solution itself. For instance, if the solution to a client-identified cost accounting problem turned out to be the development of new software, the investigator is obligated to describe the process used to develop the software (meetings held, interviews conducted, failed attempts, etc.)

as well as to describe the final version of the software itself. As with any research approach, the goal of this description of methodology is to permit other investigators to replicate both the process *and the product* of the research.

4. *Evaluation of Results* - This corresponds to the "measures" step of Isaac & Michael's model and traditionally is intended to report the results from each of the methods described in the previous phase. In action research, this phase is critical because this is where the investigator applies the evaluation criteria to test whether the solution developed to address the original problem as defined by the client actually worked. The fundamental test of the success of action research is to measure the effectiveness of the solution against a pre-defined set of criteria (preferably external). Without this evaluation step, all that was accomplished was product or process development; there was no research of testable hypotheses. While this objective evaluation of the effectiveness of the solution is critical, it is the lack of or poor quality of this process which leads some authors to question the legitimacy of action research.

5. *Conclusions and Recommendations* - This step is consistent for nearly all approaches to research. Conclusions about the importance or effectiveness of what was discovered are stated and directions for further areas of research are identified. In action research, a report of failure to solve the client-defined problem is typically accompanied by a listing of other possible solutions which were not included as part of the original research and which could be addressed in later studies.

In the following section, these research steps as they apply to action research are demonstrated through a review of the research conducted by a construction management Master's student.

Case Study of Action Research

Research was conducted in 1996-1997 by Chen (1997) which followed the basic procedures outlined for action research. The primary goal of this research was to address a company-specific problem identified by a regional office of a large national homebuilder. As is typical for action research, this problem was practical in nature, external to the investigator, and, while immediately applicable to the client in question, had potential for impact on a broader segment of the industry. The research proceeded as described in the following sections.

Formulation of Research Questions and Hypotheses

The idea for this research project originated in a required graduate course in Advanced Construction Management. Rather than a term paper based primarily on library research, students were asked to apply research methodology to actual, practical problems as identified by members of the Industry Advisory Committee. The response of committee members was solicited by the instructor of the course before the semester began (see Appendix). An executive with the regional office of a major national homebuilder asked, among other things, "Is centralized critical path scheduling feasible for a large homebuilding company?" This broad original question started an investigation of the problem to identify and narrow the scope of the study. This homebuilder was constructing up to 200 homes at a time in fourteen ongoing subdivisions. Each home had about 80 identifiable activities which were being completed by about 16 subcontractors on each house. Some of these subcontractors were involved with many of the homes under construction and some were unique to individual houses.

An existing centralized scheduling system was updated in the main office based on weekly reports from field superintendents. This centralized schedule was developed using an Excel spreadsheet with critical activities identified beforehand using past experience rather that actual job performance. Predictions of completion dates assumed that noncritical activities would never be delayed enough to become critical activities. A simple linear logic relationship was used to calculate the finish dates of activities and individual projects. Average delays of critical activities were used to calculate “productivity ratings” for each project. In addition to numerous homes missing scheduled move-in dates, the following characteristics were noted as disadvantages of the existing scheduling system:

1. the current schedule control system was a time consuming process which could not respond quickly to changes in the field.
2. the current system could not accurately reflect actual project conditions.
3. the current system could not be used efficiently to predict resource requirements and resource allocation.
4. the current system could not evaluate and analyze schedule delays across the multiple projects. (Chen, 1997)

Following an initial meeting attended by key company personnel at which these problems were identified and discussed, this company requested that the researcher design and build a model schedule control system which would address the problems outlined above. It was determined that a demonstration model using just three homes would be developed to meet the initial requirements for this course and that the full model, capable of schedule and resource control for up to 200 homes at once, would be developed as part of the required thesis research.

All that remained in the first phase of this research was to specify a testable hypothesis which would guide the formulation of appropriate methodologies and provide the criteria for evaluation of the results. Based on these needs and the statement of problem, the hypothesis for this study became, “ A model schedule control system for multiple projects using the same resources or overlapping resources can be developed which is perceived to be more effective and efficient and communicate better than the current system being used” (Chen, 1997, 7).

Description of the Methodology

As outlined above, the purpose of the description of methodology in action research is twofold: 1) to describe the process used to develop the solution to the stated problem and 2) to describe the solution itself.

In order to fully describe the process used, the researcher in this sample case recounted the investigation of the original problem, the selection of the scheduling software, and the selection of a model to describe the relationships among components of the schedule control system. The initial problem investigation described the process of eight meetings or interviews held with different field supervisors and senior management personnel. In addition, the current schedule updating process was observed and all existing schedule update reports were obtained and reviewed. Numerous options for scheduling software were reviewed and considered. In the final analysis, the capacity to handle large numbers of activities was the main determinant for software selection. An estimated 16,000 to 20,000 activities would need to be scheduled for this study. Only Primavera Project Planner provided this capacity as well as 24 activity codes, 19 levels of sort, and 28 levels of selection criteria. Finally, a relatively simple model was developed to demonstrate the relationship between the master project schedule (containing all activities on all ongoing projects) and the subproject schedules (containing all activities for each house). While the model showed no external logic relationship between subprojects (houses), their inclusion in the master project schedule permitted the viewing of resource distribution across all projects and the analysis of the effects of changes on one project on all other projects. This model, and the defined use of numerous activity codes, would allow the master project planner in the regional office to produce a wide variety of standard and custom reports on a specific project, on several projects, or for the entire region. These reports could be produced by subcontractor, by subdivision, or by superintendent.

The remainder of the description of the methodology was a review of the software application developed to address the schedule control problems noted by the client. First, a master project was developed utilizing a standard project calendar, assigning values for four different activity codes to each activity, and assigning resources to each activity. This coding allowed for the various types of reports which would be possible when each of the individual subproject schedules were combined into one master project schedule. Secondly, a number of standard subproject schedules were developed to encompass each of the home styles currently under construction. At this stage, the durations and logic relationships were added for each of the activities following interviews with the project planner, director of construction, and superintendents. The resulting network diagrams were reviewed and modified according to their comments. Next, schedules for each of the projects under construction or currently under contract were created from one of the standard schedules and combined into a master project schedule representing all of the ongoing work of this regional office. Initially, a series of seven standard reports were developed which were intended to provide the senior project planner, the superintendents, and each of the subcontractors with the planning information they would need to better manage their responsibilities. Finally, a complete copy of the original schedule was created to serve as a “target plan”. As the projects progressed, the target plan could be used as a benchmark or baseline for comparing target dates, resources, and costs to those of the current schedule. At this point, the newly developed scheduling system was presented and demonstrated to the senior project planner and other management personnel for their evaluation of the final product as described in the next section.

Evaluation of Results

As stated above, this is a critical phase for action research projects because this is where the investigator applies the evaluation criteria to test the original hypotheses. In the case of this sample research study, the original hypothesis was that “a model schedule control system for multiple projects using the same resources or overlapping resources can be developed which is perceived to be more effective and efficient and communicate better that the current system being used". This provided the basis for the evaluation criteria to be used in this case. For evaluation purposes, this hypothesis was divided into three sub-hypotheses:

1. The model schedule control system would be perceived to be more *effective* than the current system.
2. The model schedule control system would be perceived to be more *efficient* than the current system.
3. The model schedule control system would be perceived to provide *better communication* than the current system. (Chen, 1997, 44)

The researcher developed a questionnaire designed to test these sub-hypotheses which was completed by the management personnel who reviewed the demonstration of the new schedule control system. This evaluation instrument was divided into four parts. The first part contained 11 statements requiring a Likert type response designed to evaluate the *effectiveness* of the new system - defined as the ability to do more things and to do them better than the current scheduling system. The second part of the instrument included questions designed to evaluate the *efficiency* of the new system - defined as the ability to do the same job in less time and at less cost. These questions asked respondents to compare how long it would take to update and print out the weekly reports using the current system and the new schedule control system. They also asked for an estimate of the number of contracts lost during the past year due to houses delivered later than projected and how much of a penalty the company would pay the homeowner for each day a project was delivered behind schedule. This data would later be used to complete a cost-benefit analysis for the adoption of the new system. The third part of the instrument contained three statements designed to evaluate the communication improvements which might result from adopting the new system. The final part of the evaluation instrument contained an open ended question asking the respondents to list other perceived advantages and disadvantages associated with this new system.

The results from this evaluation instrument were described next. Prior to starting the evaluation process, a mean score of "4" or better on a five-point Likert scale was accepted to indicate support for each of the sub-hypotheses because a "4" was defined as "agree" in this study. The hypothesis related to *effectiveness* was well supported with a mean score of 4.485 for all respondents. Ten out of eleven statements were supported at or above the cut-off level. The hypothesis related to *efficiency* was evaluated through the use of a cost-benefit analysis. All costs associated with adopting the new schedule control system were estimated at $19,100. Benefits included time saved in preparing weekly reports and money saved from not losing contracts due to late delivery and not having to pay discounts due to late deliveries. The value of these benefits were estimated at $6417 per month. This resulted in a payback period of approximately three months which was taken as support for this hypothesis. The final hypothesis, related to *better communication*, was well supported with a mean score of 4.667 for all respondents. Three types of communication were evaluated: communication between the main office and the superintendents, communication between the superintendents and the subcontractors, and communication between the scheduling department and senior management. These results were summarized in the next section as described below.

Conclusions and Recommendations

The final section of this research report 1) summarized the research questions and hypotheses, 2) reviewed the methodology used to address the problem statement poised by the client and the outcome of this process, and 3) restated the results attained from the evaluation instrument. It was concluded from this evaluation process that support for each of the original hypotheses was demonstrated through the development and testing of this new centralized schedule control system. This computerized control system was the way in which the researcher addressed the client-defined problem and -- through the application of predefined evaluation criteria -- he was able to demonstrate the level of success in solving this problem. This conclusion reflects the "basics" of the action research process: 1) determine the *objectives* by listening to and investigating the problem(s) identified by the client, 2) develop a *means* (a tool or procedure) designed to address each problem, and 3) define and apply a set of *measures* or evaluation criteria to determine the level of success in solving the original problem (Isaac & Michael, 1981).

Finally, the researcher reviewed recommendations for future study. Due the applied nature of this study, these recommendations were related to the "next steps" required to benefit from the development of this schedule control system. Accordingly, these suggestions primarily were aimed at "implementation" problems. For example, it would be left to other investigators, or perhaps the management personnel themselves, to fully develop a standardized reporting system which would recognize current communication channels and the need for information among the individuals and departments related to the scheduling and control functions. Also, since this system was developed in an non-networked environment, other implementation options could be investigated if and when this homebuilder linked all field offices with the home office through the use of a networked computer system (Chen, 1997). These additional areas of study were beyond the scope of this original research but provided a foundation upon which other students could build a graduate research project.

Discussion

At the beginning of this decade, Ernest Boyer (1990) prepared a landmark text for The Carnegie Foundation for the Advancement of Teaching in which he attempted to redefine the traditional University view of "scholarship". Boyer contended that University scholarship consists of four components:

1. discovery - creating new knowledge
2. integration - synthesizing and interpreting knowledge
3. application - applying and disseminating knowledge
4. teaching - educating and motivating future scholars and practitioners

Boyer advocated that a healthy balance among all four types of scholarship is necessary; recognizing that the needs of different disciplines -- as well as different faculty at various times in their careers -- dictate varying emphasis on and reward for each type of scholarship.

Due to the nature of construction management education being primarily professional education -- and due to the relative immaturity of research in this field -- there is a need for a heavy emphasis on *applied* research in this discipline as opposed to *basic* research. However, there are some inherent difficulties associated with applied research such as a lack of scientific rigor, the inability to replicate the procedures, the challenge of application of the results to a wider population, and the lack of dissemination due to concerns about proprietary information. To build a successful program of research in construction management, which is truly meaningful to the industry being served, these problems associated with applied research must be overcome. To do this, a formal structure must be developed which would allow for the investigation of applied research questions while maintaining a high level of academic rigor and permitting the application of results to a wider audience. It is proposed here that the principles of action research provide one example of this structure.

However, action research has some pitfalls of its own which must be addressed whenever possible in the design of the research study (Stringer, 1996). First of all, these studies typically involve small sample sizes which may make the tools associated with statistical significance testing practically useless. While this problem may be unsolvable in many research designs, every effort should be made to increase sample size whenever possible. Secondly, extreme care should be exercised in the selection of the evaluation criteria. This is a critical step in successful action research and, whenever possible, it is best to find an "outside source" for these criteria. These outside sources might include standards from agencies or professional associations or recommendations from other published research. It is the value of these evaluation criteria which ultimately is the key to rigor and objectivity in the research study. Thirdly, since problems are defined not by the investigator but by an outside "client" for whom this study is not always a top priority, there is an inherent lack of control on the part of the researcher. There is a tendency for research questions to "drift" and a difficulty in simply arranging meetings and interviews with the appropriate parties. This problem can be addressed by establishing early in the process that this is not just about the development of a useful tool, it is also research which must demonstrate the usefulness of the tool. In the final analysis, the inability to control all the variables is the nature -- and the benefit -- of applied research. Finally, due to the practicality of the results, it is sometimes difficult to identify the "stopping point" for the research. For example, in the case study described above, the client may have reviewed the suggestions for further research and insist that the investigator continue with the implementation of the system he developed. This is why the research questions and the testable hypotheses must be well defined in the first step of the study. This defines the "scope of the work" and helps to identify the endpoint of the research (as well as provide future opportunities to other graduate students!).

One of the benefits of action research, as well as other approaches to applied research, is the opportunity it provides graduate students to "connect" with the problems they will be asked to solve as managers of construction companies. These graduate students will be hired by companies not to be just another project manager or estimator, but to be effective problem solvers who can identify the "real" problems and develop tested solutions rather than simply depend on past practices. The Construction Management program at Colorado State University is in the process of institutionalizing this part of the graduate students' education through the establishment of the Construction Management Applied Research Center (CMARC). This Center is intended to become a clearinghouse for applied, company specific problems that will be addressed by teams of graduate research assistants and faculty. Some of these research questions -- which are originated by industry "clients" -- will become the basis for graduate theses and dissertations applying the guidelines of action research. The primary mission of the Center is to help solve the pragmatic problems facing the industry while demonstrating to graduate students the practical applications of research methodology.

Frequently, graduate students in construction management fail to see the relevance of research methodology to their future careers in the field. Education in research methods is something they endure so they can get through their theses and return to the challenge of managing companies. As graduate educators, one of the skill sets we should be providing graduate students is the ability to apply the techniques associated with academic research to the demands of the "real world". Because of the implied practicality of action research -- as well as its insistence on academic rigor and objectivity -- this is a tool that can be applied after graduate studies are finished. Too often in the "real world", untested solutions are adopted to solve ill-defined problems with disastrous results. It will be the responsibility of these graduate students to apply the practical tools of action research to avoid this outcome.

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Appendix

Sample Letter to Acquire Action Research Problems

July 19, 1996

RE: Problem Identification for Students in Advanced Construction Management

Dear Sir:

I am teaching the graduate course IS560 - Advanced Construction Management - in the Fall semester starting August 19. As this is the first time I am teaching this course, I am making several modifications to the course objectives. In addition to dealing with such topics as corporate organization, risk analysis, and project planning and execution, one of the objectives of this course will be **to demonstrate the practical use of research methodology to applied industry problems**. Each student will be asked to identify a researchable problem or question being faced by a local company and develop a reasoned analysis and solution to that problem. To that end, I am asking each of the members of the Advisory Committee to help in identifying actual problems being faced by your company or the industry for use as class assignments.

My plan is to have each student select one of these problems and apply the steps of standard research methodology - 1) problem identification, 2) hypotheses formation, 3) methods selection, 4) data collection, and 5) conclusions - to the solution of the problem. I hope the benefits will be twofold: first of all, you will be provided some “free” research time to investigate a problem you don’t have time to look into yourself and, secondly, the students hopefully will see some applications of the dry, “academic” research methods to the realistic problems they will soon be asked to deal with as they continue their careers after school. Whether investigating questions of why one region is experiencing a lower Modification Rate than other regions or what are the market opportunities in the Pacific Northwest, these students must develop an objective, structured approach to problem solving.

Please keep in mind that this will be just a one semester assignment in addition to other course requirements and that the students will have varying levels of industry experience from limited to extensive. I do anticipate that some of these problems may be expanded into fuller research topics for the students’ required theses. This is the same methodology they will use to develop their Master’s theses and my goal for them is to select practical, applied topics. Your input will help focus their efforts.

If you have any questions about what I’m trying to accomplish, please don’t hesitate to call me to discuss ideas. If you are already thinking of some possible problem areas, please jot them down and fax or send them to me at the above address. I look forward to working with you this fall as the graduate students help investigate these problems. Thank you for your continuing support of the Construction Management program.

Sincerely

Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 92-101

1522-8150/98/$3.00/Educational Practice Manuscript

Infusing Practical Components into Construction Education

Bolivar A. Senior
Colorado State University
Fort Collins, Colorado

The importance of integrating practical components in construction education has been emphasized by industry advisory councils and accrediting agencies. This paper presents the most important approaches to infuse such practical components, including some implementation examples. Specifically, it discusses simulation and gaming, case-based instruction, and internships. It also briefly discusses several minor and derived techniques, i.e., service learning, field trips, and application papers.

Keywords: Education, Construction Management, Simulation, Gaming, Case-Based Instruction, Internship, Service Learning

Introduction

The importance of combining practical elements into the teaching of any specialty has been long recognized (e.g., Kimball, 1995; Redlich, 1914; Schon, 1983). The retention of class contents is greatly enhanced when several learning modes are combined in the class delivery (Wankat and Oreovicz, 1993). To achieve this mix of learning modes, the instructor can incorporate laboratory experiences, group exercises, and audiovisual components into lectures. These approaches are particularly critical for Construction Management education. Practical activities are probably more important than theory in this field. Furthermore, the best laboratory for construction management is the construction project itself. There is no substitute for knowledge derived from a guided experience in the field.

Unfortunately, there is no single formula on how to integrate practice into construction education not only because of the number of variables in a construction project, but also because these variables are interrelated in many possibilities and combinations. Situations in construction management are frequently uncertain and ambiguous. Construction managers usually make decisions based on the experience and cases or situations they have previously encountered. This creates a big challenge for construction educators. How can students learn how to integrate the required elements and make appropriate decisions? How can they be exposed to all aspects of the problems, instead of a single aspect? Very often educators teach these elements separately. Although this approach makes problems more manageable, it sacrifices the discussion and understanding of the interrelationships among these elements.

This paper presents a summary of several major techniques used in incorporating practical elements into the construction curriculum, with some insights into their implementation. Specifically, simulation and gaming, case-based instruction, and internships are discussed.

Service integration, field trips and application papers are also included though with less emphasis.

Simulation and Gaming

A first level of practical situations can be found in simulation and gaming. Simulation has been defined by Davies and O’Keefe (1989) as "the construction of an abstract model representing some system in the real world." The ability to create lifelike scenarios without the complexity and dangers of the real world is appealing in many instructional situations. A closely related area is that of gaming. Educational gaming is an important genre of simulation wherein the rules and outcomes are more clearly stated than in other simulations which try to convey more real-life environments. Games usually (but not always) have a conclusion and reflective stage, whereas in other types of simulation the opposite is usually true.

There are many advantages associated with simulation and gaming.

- The complexity of a construction project is difficult to simplify for the beginning student, and the point being made for a particular topic may be obscured by the environmental "noise." In contrast, simulations are designed to emphasize the main points and provide some notion of the effect of other concurrent variables.
- Although a simulation is commonly time-consuming to develop, it is reusable. The instructor gains insight on how to teach the simulation and what conclusions to draw.
- A student making a bad decision in the simulation or game does not have any impact on a real project. Consequently, more fundamental decisions are allowed from the student. Other practical approaches, such as an internship, prevent students from making potentially damaging decisions.
- Simulations provide feedback in a compressed time frame. The consequences of a management decision can be evaluated immediately, as opposed to the relatively long periods of time involved in a construction project.

In the last decade, simulation has been almost entirely identified with computer programs interacting with students. In fact, there are manual games that provide all the advantages of their computerized counterparts. Such a game is the Lego Hotel used at the University of New Mexico by Prof. Greg Howell. In this game, team dynamics are exposed by requesting groups of students to compete in duplicating a complicated figure made with the interlocking blocks used by children. Another manual game is Low Bidder, a bidding game introduced in the 1970s by Entelek, Inc.

The bulk of the current academic and training simulation has been implemented in computer software. SuperBid is another bidding game developed by Siman Abourizk at the University of Alberta, with such details as variable subcontractor reliability and computer-generated financial statements. Even some commercial computer games can be used for training. Maxis/Sim-Business publishes a series of simulators as Simcity. They provide useful scenarios for city planning. Halpin and Riggs (1992) discuss several simulation applications developed with MicroCYCLONE. Halpin (1985) also developed CONSTRUCTO, a comprehensive construction management gaming environment that unfortunately has not been ported to personal computers. Davies and O’Keefe (1989) provide numerous examples of simulation for other industries.

A more sophisticated level of simulations has been developed in the recent past. Georgia Tech is experimenting with "virtual worlds," which emulate, for example, the performance of an excavator operator (Op den Bosch and Baker, 1995). This simulation is strictly sensorial, and does not attempt to draw conclusions for management purposes.

Simulation has limitations as well. It relies on the soundness of its creator’s assumptions, a precarious ground in construction management since the fundamental framework of project behavior is still to be fully understood. Furthermore, the simplified world used in a simulation can be detrimental to the understanding of the complex nature of construction. Finally, a good simulation is difficult and time-consuming to develop. This factor has been a major problem for its widespread use in construction education.

Case-Based Instruction

Case-Based Instruction (known by some as problem-based instruction, although they have minor differences) is at the next level of practice infusion in construction education. It has been successful for the instruction of disciplines having a similar dilemma of practice and theory, such as law (Redlich, 1914), business (Christensen, 1987), education (Silverman, Welty and Lyon, 1996), social work (Boud and Feletti, 1991); and nursing (Green and Holloway, 1996). It is well suited to a multi-perspective approach, since analyzing cases helps learners think clearly in the ambiguous or ill-structured situations of practice (Ashbaugh & Kasten, 1995).

Wasserman (1993) describes four common components of Case-Based teaching: a case report, study questions, small group work, and whole group discussion (debriefing).

A case report contains information necessary for the students to address the problem. Ertmer and Russell (1995) suggest the following organization for the case report:

- Case Overview: State the goal of the case (the supporting concepts and principles learners should pick up from the case).
- Case Objectives: Supporting concepts and principles students should use in analyzing the case issues.
- Case Background: problem scenario. It includes context, constraints and players.
- Relevant Data: facts, events, circumstances directly related to the case.
- Overall Description: Present a clear, concise, and complete description of all aspects of the situation. Present a realistic problem description (authentic, plausible, and technically valid).

Study questions are listed at the end of each case. Those questions are the key areas and issues which teachers want students to address. Study questions should be well prepared in order to achieve the best result.

A streamlined example of a case report containing the above elements is presented in the Appendix. It is based on an actual situation experienced by the author of this article. This example was introduced in the 1997 ASC Region IV meeting with the paper "Case-based instruction: a powerful alternative for construction education" (Senior, 1997).

Ertmer and Russell (1995) also suggest that "following the case presentation, students work individually or in groups to analyze the data, evaluate the nature of the problem(s), decide upon applicable principles, and recommend a solution or course of action. Small group work, in or out of class, gives students the opportunity to discuss cases and questions: with each other prior to the whole class discussion that follows. These sessions give students their first chance to examine the issues presented in the case study; ideas are tried out in the safest of contexts. Study groups engage students in thoughtful consideration of the case issues and primes them for the more demanding whole-class discussion that follows."

The final component, a whole class discussion or debriefing, is where the true value of case-based instruction is thought to reside. Christensen (1987) is eloquent on this aspect: "Each class provides an experience in learning to listen to the views of one's peers and in learning how to express one's self and perhaps to persuade others to one's point of view. The method provides a most invaluable opportunity to learn how far one can go by rigorous logical analysis on one or another judgment comes into play when many factors which have no common denomination must be weighed."

There are many benefits associated with Case-Based Instruction. Kirshman (1996) cites fifteen such advantages. From an educational perspective for Construction Management, some significant advantages are:

- Enhancing students' analytical and reflective skills. Case-Based Instruction teaching requires students to analyze all information in order to determine the problems. "In real world practice, problems do not present themselves to the practitioner as givens" (Schon, 1983).
- Improving students' ability to integrate all elements of knowledge as well as improving their problem solving skills. A case will present students with a complex situation which consists of several elements of knowledge. Students are required to analyze each element of knowledge and the interrelation among them, and eventually to integrate them into solutions.
- Allowing students' views and opinions to be expressed. After the presentation of the analysis, ideas and assumptions will be questioned and criticized by the other students. This also helps in reexamining each student's opinions and assumptions. It will improve students' communication skills. Each student is required to make a presentation. S/he will gradually learn how to arrange his/her thoughts, what was learned from the case, and present them to the class.

Case-Based Instruction classrooms have been described by Wasserman (1994) as being places "in which no single, correct answer is sought; where discussions are left, suspended, without closure; where students leave class with unanswered questions; where the frustration of not knowing for sure is allowed to ferment." Thus, some instructors and students feel uncomfortable with Case-Based Instruction because there is no room for the single, clear-cut answers so important for some learning styles. Preparing a subject for Case-Based Instruction is a very time consuming process, and instructors may feel that they lose some control over the class. Learning outcomes cannot be easily measured, and therefore instructors cannot be certain that students are learning all the contents of the subject compared with traditional lecturing. Some students also feel uncomfortable working with others, which is a basic component of this approach.

At Colorado State University, a combination of simulation and Case-Based Instruction has been attempted. The construction operations simulation training (COST) room provides an environment in which students can re-create an actual project's planning activities. For example, it is used to drill students for the ASC regional competition. The COST concept has proven to be difficult to implement due to its comprehensive nature, among other factors. Several improvements are planned to streamline its operation in the 1997-98 academic year.

Internships

While Simulation and Case-Based Instruction are classroom-based alternatives, internships immerse the student in an actual supervised professional situation. Internships are probably the oldest and most widely used format for experiential learning (Wolf, 1980). For centuries, professional education consisted mainly of an apprenticeship with relatively few collegiate requirements, and only in the last two centuries did classroom education gain the favor it now enjoys among educators. Gross (1981) defines an internship as "a practical experience outside the educational institution in an organization that deals with the line of work you hope to enter. More specifically, an internship is a relation you have with a company or organization in which you are treated as a quasi employee."

From a student's perspective, the internship experience is clearly positive. A survey of interns in the Media program at Loyola College (Ciofalo, 1992) found that:

- 85% agreed that the experience gave them a feeling for their profession.
- 77% found that their bosses treated them as entry-level professionals.
- 83% felt that their work as interns made a significant contribution to the company's mission.
- 74% agreed that their supervisors took the time to teach them on the job.
- Only 4% claimed that the attitudes of co-workers somewhat interfered with their effectiveness on the job.

The implementation of internships varies widely among institutions. An informal survey conducted by the author in 1996 among ASC faculty found that the need for an internship as part of the construction curriculum is almost universally supported by faculty across the country. The level of intervention is, however, quite different among colleges. At one end of the spectrum are programs like Purdue's Construction Engineering and Management, which make their internship a required component of the curriculum. Furthermore, Purdue has a full-time internship director, who recruits sponsors and is the liaison between them and their interns. The minimalist approach to internships, shared by several institutions, is to allow the campus Co-Op program to administer the internship. Students are responsible for contacting sponsors. The number of interns hired and their work conditions are totally discretionary to the sponsors.

The most important aspect of internship administration appears to be the assignment of relevant duties to interns, and the means for accountability from sponsors and interns. This is usually achieved by the explicitly defining college expectations, and by monitoring the performance of sponsors and interns via visits and periodic written reports.

Appropriate monitoring is one of the major problems in implementing internships. Interns can be supervised by individual faculty members in the department (each faculty is assigned several interns), by a full-time internship director, or by another college department (usually along the Co-Op program). Another problem faced by internships is establishing the physical framework for the internship. In most cases, the length of the internship is four to six months. Purdue's Construction Engineering and Management requires three 12-week periods. The available alternatives are to require students to work in the summer break, or extend the program's duration. Finally, but not least, there is the problem of how to give credit to the internship experience. In some programs, the internship is totally optional. In others, it is required but no academic credit is earned. In some others, like the one being implemented at Colorado State University, the internship is required and the student earns academic credit upon its completion. The real problem is how and if credit should be given to experienced and working students toward the completion of the internship. Policies vary from not counting previous experience to waiving the requirement.

Regardless of the implementation approach taken, internships are an increasingly popular method incorporating practice into the construction curriculum. Many of the problems faced by colleges instituting an internship program will be solved as more collective experience is accrued.

Other Approaches

Service-Learning

A powerful avenue for experiential learning is the inclusion of a service-learning component in the curriculum. Although the implementation details vary among disciplines and institutions, the basic philosophy of service-learning is the application of students' skills to solve a community-oriented project. Students are usually organized in groups, and their solutions many times are adopted for the project at hand. Projects are provided to students by the instructor. In turn, the instructor contacts community organizations to find out which projects are appropriate for the class. In the case of Colorado State University, the Office of Community Services simplifies this process.

An example of service-learning is the project to be implemented for the required course *Construction Project Scheduling and Cost Control* at Colorado State University. A small hotel has been donated to a local charity. It will be relocated about two miles from its current site, and rehabilitated. Students will have to develop the budget and schedule for this project, as well as investigate the administrative hurdles to overcome. They will also take part in the project implementation.

An important part of this approach is the reflection of the learning experience. Service-learning provides a valuable opportunity to ponder professional aspects which are, regrettably, frequently overlooked. Yet, service is at the heart of any profession. The American Society of Civil Engineers (1997), for example, succinctly defines profession as "the pursuit of a learned art in a spirit of public service."

Field visits

A very common way to include some practical component into course content is field visits. These visits can be very informative, but unless the experience is well designed, they can become glorified picnics. Field visits are important because the student encounters individuals in a practical work environment. They "see, hear and smell in an organizational and practical context" (Wolf, 1980).

A field visit should have:

- Background information about the project, company or location to be visited. Why is it relevant to the class? What are the special features to be observed?
- A significant tour of the facility. A qualified employee of the project, company or location should have been assigned to the visit. Otherwise, it is preferable to return on other date or discard the project.
- A report requirement. Students should have an incentive to pay attention.

Application papers

Another widely used approach to supplement theory is the requirement for a report about a topic requiring an external and direct contact from the student. Reports of this type have been well documented in the literature (for example, Wankat and Oreovicz, 1993; Borich, 1996; Barnet and Stubbs, 1986; Houp and Pearsall, 1977).

A special case of application papers are those requiring independent field research (Wolf, 1980). In this case, the research is substantially more demanding than in a simple paper. This is a common requirement for Masters degrees.

Conclusion

There is much consensus among construction educators for the need to include practical components into the construction curriculum. This paper has presented some of the most relevant and common approaches to include components of practice into a construction program. As indicated, some methods such as application papers and field trips require a minimum level of effort from an individual instructor, while others such as an internship are department-level enterprises of great complexity. Each one of these methods do not preclude the others, and the final mix depends on the preference and commitment of each construction program.

What seems clear is that more practice-oriented curricula will be the norm and not the exception in the future. The American Council for Construction Education guidelines for a self evaluation study (Form 102) explicitly lists field trips, summer job programs and similar practical experiences as part of its evaluated material. The author has had informal communication with faculty of several construction management programs. The majority have indicate that their industry advisory boards are demanding an internship. All these developments are the right thing to do. Practice is at the heart of construction education.

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Appendix

Case Study
Loading the Dice: Resource Loading a Project Schedule

B, a planning consultant, is called by Charlie, the contractor for the rehabilitation of a state-owned drainage channel system. He was referred to Charlie by Sam, the chief engineer of an international firm supervising this project for whom B has worked before.

The project is behind schedule, and B is requested to develop a recovery program. Even though he is retained by the contractor, it is Sam who has insisted on hiring him.

An initial look at the project makes clear to B that a major factor in the delay has been the unavailability of one imported dragline. The dragline is being held by the state's custom authorities, claiming that it must pay substantial custom duties. Charlie says that the equipment will be used on a temporary basis. However, he confides to B that he intends to keep the dragline at the end of the project.

Charlie thinks that the recovery schedule should be loaded with the dragline, to reflect the effect of any further delays in its release (delays that so far he considers to be the state's fault). Sam indicates that he will not accept the inclusion of the dragline as a resource, since other equipment can be used for the operation. Charlie insists that this alternative would not be cost effective, and he would be entitled to economic compensation. Sam's position is that if more time would have been allocated to the procurement of the dragline, the problem would not exist, and that therefore it is the contractor's responsibility.

B feels confused. Should he tell Sam about Charlie's plans to keep the dragline? After all, isn't Charlie just acting as a normal contractor? Should he advocate for including the dragline as a distinct resource in the schedule? Would it be possible to develop a schedule that is fair to both parties? Should he accept this project in the first place, given the circumstances?

Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 102-117

1522-8150/98/$3.00/Educational Practice Manuscript

Maintenance Management Concepts in Construction Equipment Curricula

Randy Rapp
Southern Illinois University at Edwardsville
Edwardsville, Illinois

Burl George
Bradley University
Peoria, Illinois

Any baccalaureate or graduate-level construction program offering a course in construction equipment management should impart instruction about maintenance management procedures and concerns, if the students are to gain the managerial perspectives that they will require upon graduation. Although the content of the instruction may vary, thorough discussions of maintenance management will comprise most of the suggested topics.

Key Words: Construction Equipment, Preventive Maintenance Management, Cost Control

Introduction

An effective construction equipment preventive maintenance program might be characterized as the product of prudence, of the sentiment that "a stitch in time saves nine." Good maintenance programs and the efficient management systems behind them are essential for economically viable and operationally safe construction equipment. Unfortunately, this topic too often seems to draw more yawns than close attention. Perhaps part of the reason for this unwarranted indifference to this vital subject--even among constructors who should know better--is its lack of appropriate coverage in equipment management courses. The authors suggest that six lessons in any three semester-hour baccalaureate or graduate construction equipment management course be devoted to maintenance management procedures and concerns, if the students are to be well prepared for broad construction management responsibilities upon graduation.

Preventive equipment maintenance management implies a coherent and formal program of planned repair, component replacement, and servicing activities and the information management system surrounding them, all of which are implemented by an organization to maximize the availability of equipment for operational tasks. Compared to having no maintenance program at all, the allocable equipment maintenance costs may increase, but the value of improved equipment productivity should be even greater. Maintaining equipment productivity is essential to a firm’s long-term profitability. The program may depend on any of a number of strategies such as operate-to-failure or replace-before-failure, either of which incorporates elements of preventive maintenance to greater or lesser degrees. Whatever the organization concurs is appropriate for the equipment maintenance program--its goals and procedures--should be formally documented, and it should not be open to arbitrary changes or interpretations.

Since the maintenance management program is developed and resourced for maximum productivity and profitability in the long-term, it requires managers to seek continual improvement of the program resources and processes. As they would be for any purposeful organizational program, specific requirements for the program are determined. Managers then devise maintenance activities to satisfy the requirements, after which resources are allocated to match the workload and organized to most efficiently perform the necessary activities, such as equipment repairs and record keeping. Continual program assessment leads to improved performance and efficiency.

Lesson I: Significance of Preventive Equipment Maintenance

The particular project functions and concerns affected by a maintenance program include estimating, scheduling, safety, environment, and cost control. These functions are all interrelated, but the role of effective maintenance should be clarified separately for each to emphasize its significance.

Estimating

One of the main factors that needs to be taken into account in producing a realistic cost and productivity estimate is the production capacity of the equipment in question. This production capacity is in part dependent upon the quality of maintenance associated with the equipment. Therefore it is of extreme importance that the student understand that a machines' lack of maintenance or improper maintenance will adversely affect a contractor's ability to successfully bid on and complete projects within budgeted amounts. After all, making no allowance for variables such as unexpected breakdowns or scheduled idle time for maintenance procedures reduces the value of the estimate to less than the paper it is written on.

Inclusion of a preventive maintenance segment within broader course work, e.g., estimating and equipment usage, will allow the student to assess cost and production history when estimating true productivity and cost figures. The costs associated with increased operating expenditures, downtime, and production rates will become clear and those charges can then be assigned to the appropriate machine. The net result is a truer picture of equipment cost and productivity rates for the individual pieces of equipment.

Scheduling

The scheduling of a construction project is also affected by the absence or inclusion of a project-specific preventive maintenance program. To the beginning student or casual observer a piece of equipment is either working or it is not working. However, the more experienced a practitioner becomes, the more he/she understands that the time required to complete a project is adversely affected by a reduction in hourly production figures. Many factors affect the productivity of a machine, e.g., weather, operator efficiency, differing site conditions, etc. But possibly the most controllable factor is that of machine availability. Therefore, good management periodically schedules equipment downtime for programmed services and inspections, in order to identify and eliminate potentially catastrophic failures.

To this end, the inclusion of preventive maintenance information within the various curricula will allow the student to identify and incorporate into her scheduling talents those factors such as breakdown frequency and severity which would extend the duration of the project. In Figure 1 the components of maintenance time frame have been detailed to a much greater degree than those of the available time frame. This illustrates to students the potential time factor involved in the scheduling of maintenance and its effect upon the project schedule.

TIME						
TOTAL HOURS						
SCHEDULED HOURS (S)						
AVAILABLE (A)			MAINTENANCE (MT)			
OPERATION (OPT)			ONSITE		INHOUSE	
WORKING (WK)	DELAYED (DL)	IDLE (ID)	UNSCHED. (UM)	SCHED. (SM)	UNSCHED. (UM)	SCHED. (SM)
WORKING	FUEL	WEATHER	SERVICE TIME	SERVICE TIME	SERVICE TIME	SERVICE TIME
	OIL	SHIFT CHANGE	WAIT ON PARTS	WAIT ON PARTS	WAIT ON PARTS	WAIT ON PARTS
	FILTERS	NO OPERATOR	WAIT ON MECH.	WAIT ON MECH.	WAIT ON MECH.	WAIT ON MECH.
	WAIT ON EQ'PT	PERSONAL TIME	BREAKS	BREAKS	BREAKS	BREAKS
	MG'MT DELAYS	NOT NEEDED	PERSONAL	PERSONAL	PERSONAL	PERSONAL
	WAIT ON OPER.	BREAKS	DIAGNOSTIC	MODIFICATIONS	ACCIDENTS	MODIFICATIONS
			TEST	DIAGNOSTIC	LOGISTICS	DIAGNOSTIC
				TEST	DIAGNOSTIC	TEST
				INSPECTIONS	TEST	INSPECTIONS

Figure 1. Components of construction equipment scheduled time.

One factor that is not shown is the effect that delayed, improper or non-maintenance has on the hourly production of equipment. The great majority of schedulers and estimators for that matter, use production figures that assume full use of the machine for the duration of the work activity minus the typical job efficiency factors. This assumption of full use does not take into consideration the time needed for scheduled or unscheduled maintenance. Given the severity of operating conditions, scheduled maintenance alone may remove a machine from use 10 percent of the time. This 10 percent reduction in available time increases the duration of the project and the attendant costs.

Safety

A preventive maintenance curriculum must also address the issue of safety. Safety requirements impact system effectiveness, regulatory compliance, and personnel and equipment protection from injury or damage. The instruction should stress that the true professional never compromises safety, since poor procedures lead to higher insurance premiums, recall costs, accident and claim settlements, and legal fees, while reducing productivity and demanding that management spend much time with remedial matters. Students ought to learn that a competent project manager always ensures that all maintenance equipment and facilities comply with applicable design codes (NEC, ASME, API, etc.), construction codes, and government regulations (OSHA 29CFR1926 and 29CFR1910, EPA, etc.). In this way, potential costs associated with production working interruptions are minimized.

The instructor should emphasize procedures that ensure these safety program objectives:

- Safety actions are designed into operational procedures in a timely, cost effective manner.
- Potential hazards are anticipated, identified, evaluated, and eliminated.
- Historical safety data is routinely consulted and applied to ongoing operations.
- Necessary documentation always meets regulatory standards.
- Safety administration and procedures are incorporated into all organizational training.

Environment

Environmental management is related to safety management. Those concerns are everyone's responsibility. But as is true for the safety program, responsibility for the regulatory effectiveness of the program resides with the organization's managers. Delegating the authority for environmental audits and other aspects of the program's management is usually appropriate. Students should be introduced to some administrative aspects of environmental program management, particularly since the exposure can help maintenance managers avoid adjudicated penalties and reduced production time.

Cost Control

Project cost control is obviously affected by accurate estimating, tight scheduling, and minimization of safety and environmental violations, but there is more to it than that. As a capital asset, one of the worst conditions construction equipment can experience is inactivity when it could otherwise accomplish work and produce revenue. When unplanned equipment failures occur, the opportunity to earn is lost, even though ownership and operator labor expenses continue. Any measures that enable the construction organization to avoid lost production opportunities are therefore valuable. As noted before, good equipment maintenance programs allow managers to schedule well in advance any required maintenance periods, presumably when the equipment cannot be scheduled productively on the job. Good programs thus avoid the cost of lost revenues, even as they tend to reduce the average cost to repair or replace the less frequent component failures or potential failures.

Maintenance is a critical link between equipment ownership and operation costs, as Cliff Schexnayder, an Eminent Scholar at the Del E. Webb School of Construction, admonishes. Good maintenance management ensures that hourly operation costs are lower than they would be without an effective program. What is more, the value of well-maintained equipment when salvaged will be higher than it would be with a poor or non-existent program. Higher salvage value leads to lower depreciation costs. Since equipment depreciation for a heavy-highway construction enterprise may be second in annual expense only to management salaries, reducing the cost of depreciation may bolster the firm's bottom line. The nexus between ownership and operation costs further reinforces the significance of equipment maintenance management.

When an equipment manager makes a case for executive management to consider whether or not to implement or enhance a maintenance management program, it is not just the executives who must be convinced. Almost any successful maintenance program involves major portions of the firm or agency. A good program is very much a team effort, so all participants must be convinced of its value. The costs accruing to ineffective programs can perhaps be demonstrated by careful analysis of previous equipment utilization and expense data. One might estimate the costs of lost productivity due to unscheduled "down" time and the expenses of unscheduled repairs. By summing those two costs and comparing them to the cost for planned services or component replacement which would likely have prevented the unexpected breakage, the equipment manager can make a convincing case for a stronger maintenance management program. Students will see that construction equipment maintenance management does indeed have significance for them.

Lesson II: Equipment Management Responsibilities and Analysis

Equipment Manager

The person most critical to viable maintenance management is the equipment manager. In deliberately structured organizations, supervision of all equipment dispatching, maintenance operations, and repair versus replace decisions are among his or her responsibilities. The equipment manager should report to the chief operating officer or the vice-president for construction, in order that he may have adequate authority to work with construction project and operations managers, his internal customers. With this line of authority, occasional operation-maintenance scheduling disagreements between the parties can be resolved at the lowest possible level of supervision. The equipment manager needs the full support of upper management in order to best serve the organization. Certainly, the organization's equipment is purchased to provide project operational productivity, and good equipment managers never lose sight of that purpose. But both those who maintain and those who use construction equipment must learn how people and systems in the organization synergistically contribute to productivity.

Staffing

Recruiting qualified maintenance personnel can be difficult. At a minimum, hiring standards for mechanics should include that they have formal technical education in a field relating closely to the equipment they will service. They should understand the preventive maintenance process, in general--the methods, materials, and tools, as well as the relationships among maintenance-related activities of the typical construction equipment organization.

Training

All personnel who have any role in attaining high standards of equipment maintenance must be well-trained. Increasingly complex construction equipment demands more professional skill from labor. If mechanics lack equipment item-specific training, then their "repairs" may be ineffectual or, what is worse, may lead to yet more expensive premature failures. Likewise, equipment operators must understand how to obtain maximum efficiency and safety from their equipment, and this requires more deliberate instruction than the "learn as you go" approach sometimes relied upon. No matter where they obtain their knowledge, skills, and abilities (KSA)--whether from union locals, equipment dealers, or their employers--operators must prevent unnecessary, improper wear on their assigned equipment. Excessive speed or load weight on hauler bearings, for example, may drastically reduce equipment economic life and elevate ownership and operation costs far beyond any added revenues earned by applying higher speeds to the job.

Numerous human resources studies have demonstrated that good training programs lead to less personnel turbulence and higher morale. The costs avoided thereby are significant, and such cost savings are additive with expenses reduced or eliminated through the better maintenance programs which, in turn, also result from effective training. Thorough training of maintenance personnel substitutes for highly formalized procedural rules. Besides encouraging a greater sense of employee responsibility from job enlargement and enrichment, better-trained mechanics and foremen provide greater tasking flexibility and staffing depth for the organization. More employee skills equals more value to the agency or firm.

Teamwork and Partnership

Operational and maintenance managers together share some required KSA. It makes good sense for them to share maintenance management training, to enhance their teamwork through better understanding of each other's concerns and resources. The authors' experiences with maintenance management programs have been that the "us-them" mentality between project and maintenance managers must be eradicated before significant maintenance improvements result. For that matter, some instruction combining both management and labor may be appropriate. All organization members holding equipment-related positions need to know what the new maintenance technologies are capable of doing. But the best technological and systemic enhancements available yield minimal returns when the people involved are not motivated to work in a spirit of partnership. This mutually supportive philosophy is essential to building a strong, ongoing maintenance training program. Ideally, students will carry this attitude with them as they work into construction management positions.

Program Requirements Analysis

Critical to the development of an appropriate equipment maintenance plan is the company's or agency's scheme of field operation and the details of the construction projects. If the project scope, duration, and location make it appropriate, managers will probably seek specific maintenance assets to be exclusively assigned to the project for its duration. If the support package is adequate in capability, the responsiveness of the project-specific maintenance effort will surpass what it might when resources are provided only on a job order by job order basis. This may be very costly, however, if there are periods of minimal maintenance work at the project when completion of job orders is delayed elsewhere. If project-specific maintenance resourcing is unaffordable, then contact maintenance teams which travel, e.g., with wreckers and tool trucks, among the organization's job sites can often be advantageous. They might be able to satisfy a job order on site, saving the expense of evacuating equipment back to the main shop for repair. While not as immediately responsive as project-specific service and repair teams, they may afford an optimal compromise between reduced non-available time and low maintenance cost-per-hour.

Students should note that the maintenance organizational structure devised by management and its level of resourcing should be supportive of field maintenance requirements. One may organize a team for project-specific service and repair support over an extended duration, but with what effect on other projects' maintenance requirements? If an analysis makes management conclude that routinely employing contact maintenance teams will best contain costs, then a team-based structure might be implied for the main shop.

Contracted Out-Sourcing

Heretofore, this paper tacitly implies that the firm or agency will perform its own maintenance. Students should learn, however, that maintenance can be out-sourced, whereby any or all required effort can be obtained through contract, perhaps with an equipment dealer. Reduction of fixed costs such as those incurred by maintenance shops allows organizations to be more flexible and better able to react to changing competitive environments. On the other hand, organizations with well-established and efficient internal maintenance capability may find out-sourcing to be a poor alternative. The competitive differentiation that a good shop provides can contribute to winning work and enhancing profit margins.

Those organizations that do not already have shops of their own may want to avoid the significant start-up costs of building internal service and repair capability. Even though the contracted maintenance cost-per-hour may be higher than that for a well-run shop of its own, a company may opt for out-sourcing with its known costs, since it removes an element of risk from the project cost equation. Some companies may find that contracting nearby for scheduled services while repairing unscheduled failures themselves is the lowest-cost alternative. In that case, retaining some degree of maintenance response in the organization and not becoming fully dependent on outsiders mitigates some risk. Analyses involved in making decisions such as these may be complex, but they are essential for cost-optimization and competitiveness. Future construction managers should appreciate the sorts of alternatives from which they may one day select.

Lesson III: Maintenance Strategy and Techniques

Preventive maintenance procedures are established by the organization to best meet project operational demands, and one may even track their origin to the competitive strategy of the firm. The operate-to-failure (OTF) strategy, simplest to implement, demands that manufacturer-specified services be performed. Students should recognize that no equipment organization can remain profitable even in the short-term if minimal preventive maintenance activities--lubrication, fluid and filter replacement, and pressure and alignment adjustments--are not timely accomplished. Besides those procedures, nothing is done in OTF to determine the maintenance condition of the equipment, until the item cannot produce as it ought due to component failure.

At the other extreme, a fixed-time maintenance (FTM) strategy causes equipment components to be replaced at rigorously specified times, established on a statistical basis developed from design and historical data. One of two replace-before-failure strategies, FTM may cause parts to be "swapped out" although they are nowhere near failure. Unneeded downtime and component replacement may lead to equipment operation costs not much reduced from those of OTF. The optimal approach would seem to lie between FTM and OTF. A condition-based maintenance (CBM) strategy seeks to proactively replace components before they fail, like FTM. However, the components are replaced only when there is clear indication that they are near failure. This stretches their lives and reduces operation costs below FTM levels. The increased maintenance expenses of CBM above those of OTF are justified by the non-availability costs avoided by scheduling maintenance when the equipment is not required on the job. Although total maintenance expenses may escalate with the CBM strategy, the equipment operating cost per hour drops. Essential for CBM to be effective is a predictive capability.

Predictive Maintenance

The primary predictive maintenance procedure which many construction equipment maintenance organizations deem sufficiently reliable for integration into their preventive maintenance programs is oil analysis. The sample is at least analyzed to determine when the lubricant might need to be changed due to breakdown. While this knowledge allows managers to eliminate expenses from premature replacement of oil and filters, the greatest value of oil analysis may come from ferrographic or spectrographic analysis of the contaminants in the oil. These permit laboratory personnel to measure the wear on the component, and ferrographic comparisons may reveal the reason for the wear. This affords a meaningful predictive capability. In the years ahead, today’s students will certainly see even better predictive maintenance capabilities routinely imbedded in equipment they manage. Extensive component and system condition warning systems, including on-board computerized vibration analysis, will become commonplace and afford very accurate estimates of time to component failure.

The benefits of maintenance prediction are not always obvious to organizational "beancounters." The costs averted from breakdowns that never happened (probably because more resources are devoted to maintenance activities) often go unrecognized. This leads to doubts about the elevated level of resources allocated to predictive maintenance of equipment. So as budgets get tighter, maintenance shops may be the first elements of the organization to suffer cutbacks. By the time the longer-term effects of such cutbacks are manifest, productivity and profitability may be reduced. Overcoming inertia to get the program back to a more proactive stance is then difficult. Students should appreciate that such longer-term perspectives are necessary for profitability.

Some Recommended Techniques

No matter the maintenance strategy an organization applies, daily pre- and post-operative checks of the equipment should be routine. This activity is often a critical interface between operation and maintenance. Equipment manufacturers provide complete inspection checklists. Managers should provide such lists and related documentation to any equipment personnel who have need of them. Especially in the case of more proactive maintenance management strategies, frequent cleaning of the entire item is necessary to thoroughly inspect for damage and incipient failures.

Proper painting adds to equipment value by protecting surfaces from corrosion. Thorough cleaning and proper painting also lead to pride of operation and enhance the public image of the firm or agency, and it is good for morale. Component or system deficiencies--especially if they involve safety--and imminent failures must be repaired before operating the equipment again. Lesser shortcomings may often be deferred until the next scheduled maintenance period. Effective operators know their equipment well enough that they can often tell, by its behavior, if it has or soon will have a mechanical problem. This bolsters the argument that equipment should have an assigned operator and maybe an assistant, who except for emergencies, should be the only persons permitted to drive or operate their assigned items. This may not always be an achievable arrangement, but students should appreciate the benefits of assigning the same operator to designated equipment, if possible.

Lesson IV: Maintenance Organizational Structure and Facilities

The organizational aspects of maintenance programs require that company resources be combined to fulfill specific performance objectives as efficiently as possible. These resources involve groups of individuals of varying expertise blended into an organizational structure to accomplish a variety of functions. Among other determinants, the structures vary with the broad goals and objectives of the organization; the specific functions to be performed; the resources available for maintenance; and the working relationships of the maintenance participants.

The successful implementation of total preventive maintenance (TPM) requires both an understanding of system-level requirements and organizational interaction. To appreciate this, students must be introduced to organizational responsibilities that may not be discussed in some construction curricula. Human resource concepts such as position management and personnel training demand attention. Effective maintenance organizations are deliberately planned and staffed. Inevitable changes in equipment design, its operating environment, and maintenance techniques and resources mean that structures which prove efficient today may nevertheless demand a new configuration tomorrow.

Equipment Organizational Grouping and Structure

Students should become acquainted with organization structural models to better appreciate how formalized working relationships can enhance productivity. Three basic structural groupings are commonly denoted as *functional*, *product*, and *matrix*. A functional construction organization groups individuals with the same general types of expertise and job requirements. All equipment-related functions, including that maintenance, are placed under the direction of an equipment manager in one division or department of the construction organization. Equipment is dispatched to projects as needed, is returned when not actively used, and the equipment manager maintains control of all items. A smaller firm performing local work might find this arrangement to be most efficient. Within the maintenance section itself, the structure would be described as being *simple*. If the firm's or agency's equipment requirements expand, then the equipment department or division will expand and maybe sectionalize internally on a functional basis.

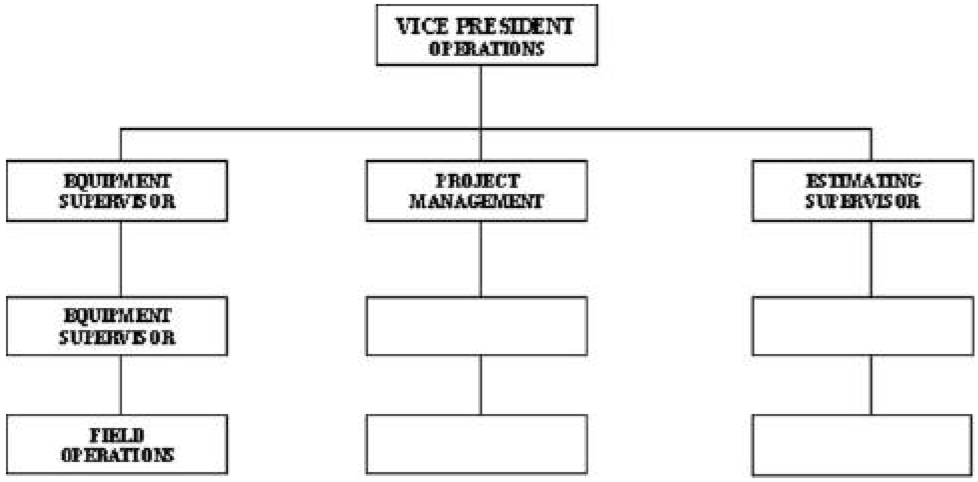

Figure 2. Function-Grouped construction organization.

As companies grow and expand into new areas of technical expertise and specialize in products or geographic regions, a divisionalized structure may evolve. Divisions are analogous to smaller and comparatively autonomous specialized firms subordinate to the main company. A company might restrict itself to excavation and concrete projects, establishing separate divisions for each product. Another possibility could be two geographically differentiated divisions, both doing excavation and concrete, but in different regions. Company equipment could be divided appropriately between the divisions, and each division would establish independent internal mechanisms to manage the equipment and maintenance, perhaps entrusting it to divisional equipment managers. The preventive maintenance procedures employed by the divisions may differ to better match their respective productivity needs, so details of their respective maintenance organizational structures may not be the same either.

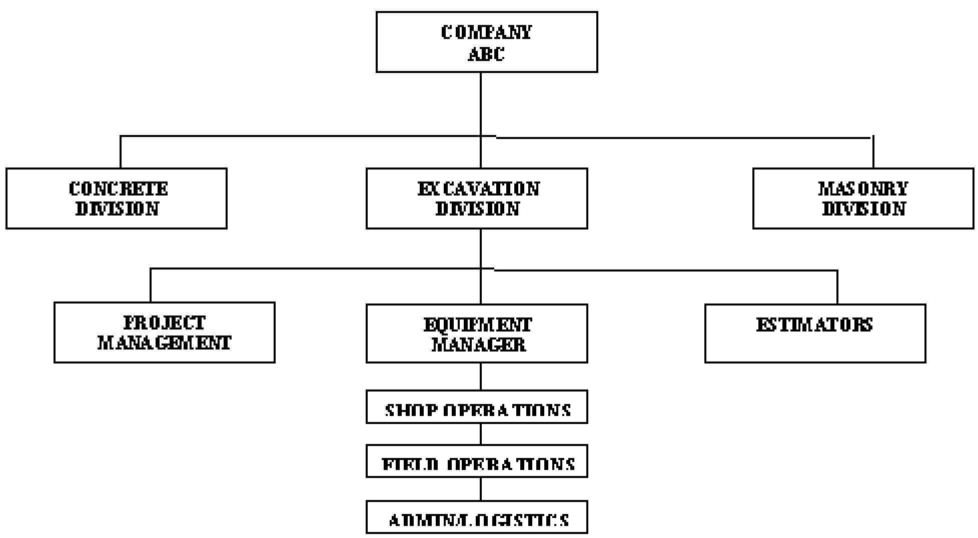

Figure 3. Product-Grouped construction organization.

The matrix organizational structure combines functional and product organizational strengths while reducing their weaknesses. Matrix structure typically requires personnel to respond to two authorities, their functional supervisors and their project managers. Some employees may be assigned to multiple projects simultaneously. Depending on the degree of autonomy that a project manager must command in order to perform effectively, not only the productive equipment, but also some maintenance assets, may be designated for his exclusive use. This scheme would probably prove necessary when a company secures a project far away from its normal area of operations. The structure demands more professionalism and teamwork from members than do simple or divisionalized structures. If the employees of an organization have had little autonomy and seldom established effective informal working relationships, then evolving to this sort of structure may engender more trouble than it is worth. Many public and private sector entities have employed this scheme with varying degrees of success within the past decade, however.

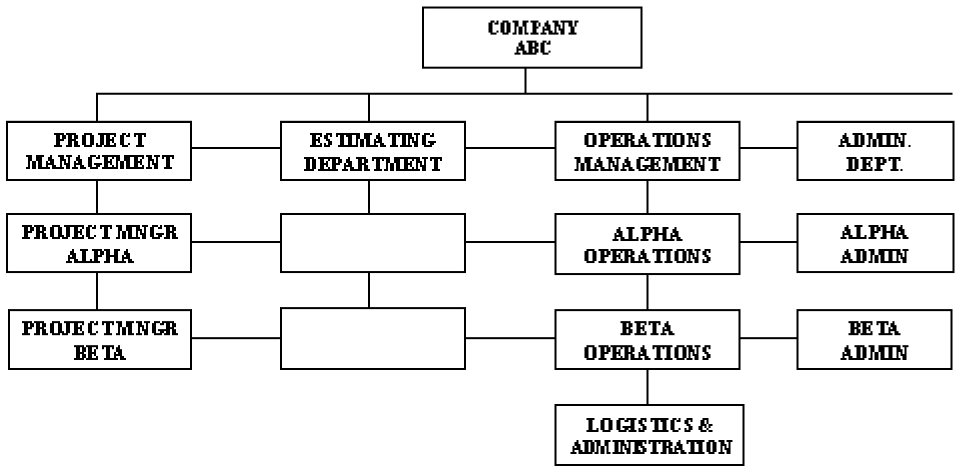

Figure 4. Matrix-Structured construction organization.

No matter the particular structure imposed, someone must know that he or she is directly responsible for monitoring and controlling the equipment and its maintenance. The manager must have immediate access to the resources needed to effect necessary maintenance activities.

Facility Design

From the organization structure and subsequent characteristics, the required maintenance facilities can be determined. The increasing complexity and size of equipment demands larger and better designed maintenance buildings to enhance productivity. Construction program graduates may become involved with decisions to extend or rebuild existing maintenance facilities. They should be made aware of parameters that control such designs.

Four factors most control the design of the maintenance area: floor area, workshop bay height, workshop bay width, and layout. The total floor area required must include all equipment workshop bays, gangways, storage areas for such items as tool rooms and repair parts stores, and offices. Identifying the requirement for the latter three types of areas is a relatively simple proposition, but determining the workshop bay area is more tedious. Three methods may be employed to perform the more complicated calculation: scaling dimensions to meet the equipment fleet’s biggest machine; providing bays for the number of mechanics employed; applying a repair time-area formula.

$$\text{Total Maintenance Bay Area} = \sum [(N\ T\ A) \div (50 \text{ weeks/year})]$$

where N = total number of equipment items of one type and size
T = average time (weeks) each type-size is in shop each year
A = bay area required for each type-size

Project requirements may compel the equipment manager to perform many repairs with on-site maintenance contact teams. If it is logical to expect that condition to continue, then the formula T factor for each type-size will remain small, and the total bay area will be less. This reduces the organization’s investment and operational expenses for fixed facilities, to compensate for contact team expenses.

A shop ceiling height of 16 to 18 feet is adequate for most equipment owned by small- to medium-sized construction organizations. Maintenance personnel working on equipment in excess of that height should plan to service and repair the items in an open-air facility. The width of the workshop must allow for the angling of the bays and their length. A bay in most shops should be 35 to 45 feet wide. If the length of the work area is excessive, then the contractor should consider "stacking" the bays with a walkway between them. The layout of the area should take into consideration the number of craft specializations and their repair tool requirements, proximity and security of any tool rooms and repair parts stores, ample number and capacity of electrical outlets, and safety and environmental security needs. The work area design requires flexibility to be reconfigured to accommodate inevitable changes in equipment design. Of course, other architectural criteria for efficient industrial operations remain valid. Attention to detail in the facility design stage costs little compared to unnecessary facility overhead expenses.

Lessons V and VI: Maintenance Evaluation and Control

Statistical Measures

If maintenance organizational structure, facilities, and other resources are tailored to the maintenance strategy and procedures that best serve job site productivity, the entire maintenance operation will probably be effective. Among the most critical measures by which to gauge maintenance organizational effectiveness are the mean time to repair (MTTR) or the speed of repair, the mean time between failures (MTBF) or the frequency of repair, and the maintenance ratio (MR). These can be determined for equipment components and systems, for an equipment item, and for entire categories of equipment.

$$\text{MTTR} = \text{Unscheduled Maintenance Hours} \div \text{Number of Failures} \leq 6 \text{ Hours/Failure}$$

It includes the time to evacuate to shop or to bring a contact team to the item, to get a mechanic, to inspect equipment and find the failure, to obtain repair parts, to make the repair, and to operationally test the repair. Repair should normally be performed in well under one day. Poor quality which results in redo work is anathema to quick equipment return to production and low maintenance costs.

$$\text{MTBF} = \text{Operating Hours} \div \text{Number of Failures} \geq 100 \text{ Hours/Failure}$$

This is a function of equipment design, intensity and skill of operation, and accurate and timely maintenance. As a rule of thumb, if items are properly repaired, they should operate at least 100 hours before failing for some other reason.

$$MR = \text{Maintenance Hours} \div \text{Operating Hours} \leq 0.25$$

Good maintenance systems should result in at least four hours of operation per hour of maintenance.

$$\text{Availability} = \text{Available Hours} \div \text{Scheduled Hours} \geq 90\%$$

Naturally, 90 percent is a rule of thumb which may vary with such factors as equipment age and type and with intensity and type of application. Rules of thumb require care in application, but they afford students points of reference for evaluating equipment maintenance programs.

Information Systems

Only by measuring and recording maintenance program data can managers determine their effectiveness. Manual maintenance management data systems--some of them rather primitive and reflective of the minimal maintenance techniques formerly in vogue--have existed for generations. Nowadays, automated information management systems facilitate compilation and analysis of equipment-related data. The automated systems often capture the same information as the traditional manual systems, but they afford more efficient data sharing and manipulation. They make it easier to record expenditures by equipment component or system, e.g., structural frame, power train, engine, or hydraulics. Whether the system is designed by the organization itself utilizing generic spreadsheet or database software or purchased from vendors offering commercially available programs, it must provide the sort of information managers require to make critical equipment maintenance-related decisions.

For Equipment Item:

operator name(s); purchase price; depreciation; salvage value; job orders applied; historical ownership and operation costs; historical utilization and non-available time; current location; current availability status; next programmed maintenance; results of most recent diagnostic activity; currently deferred maintenance shortcomings.

For Equipment Category:

mobilization costs; utilization estimates; cost estimates; MTTR; MTBF; projects worked.

On Job Orders:

mechanic name(s); dates and times maintenance begun and completed; parts and components used; labor by craft, versus standard time; maintenance delays.
Estimating, accounting, and maintenance databases should share data.
This implies flexible units of time: hours, days, etc.

Figure 5. Useful equipment and maintenance information system data

Organizational structures and leadership philosophies naturally play a role in determining what information will be made available to whom. As wise managers move their organizations to greater employee empowerment, the architecture of the information management system that they purchase or devise should be adaptable to the new internal working relationships and expectations. For example, allowing a mechanic to readily query the recorded data associated not only with the particular item on which he is working, but also with consolidated data pertaining to the equipment category, may enable him to detect component failure trends no one else sees. The level of data detail should be structured not only for current application, but also for possible future analysis. Compiling meaningful data demands management's close attention, and other system users or potential users should contribute to the system needs analysis, too. What sort of data will be included and how much of it are not small matters, since data entry adds up to consequential labor costs, and insufficient data can impede well-informed decisions. Devoting adequate time to devising a worthwhile architecture usually pays big dividends in the long run. Upon implementation a properly constructed and readily accessible database demands some control, since "garbage in equals garbage out."

Students should learn that the compiled data is often applied to many significant management decision processes, so it must be complete and accurate. Whether manual or automated, the job order is almost always the primary means of monitoring and controlling what is done for service or repair, by whom, and at what cost in labor and materials. In most cases, the documentation for maintenance job orders is manually gathered on the shop floor. Key shop administrators should be specifically trained to review the manual documentation before entering the information into the computerized database. Some fields of an automated database may be linked to yet other management and financial information systems, for such compilations as the equipment expense ledgers or the repair parts store inventory.

Operators should be kept informed of such things as minor equipment shortcomings which they have noted and which have been deferred for repair until the next scheduled maintenance period. Operators must be tied into the flow of information, if their sense of ownership is to be cultivated as it should be. Construction site foremen and field engineers must realize how important their daily or weekly production reports are to the accuracy of the system data. Equipment operation-maintenance team cohesion and mutual ownership improve with information flow and integration of this nature. Future managers thus see how to effect meaningful systemic improvements for minimal cost by adjusting information processes.

Cost Accounting

The equipment cost accounting system, which includes the ledger for equipment maintenance expenses, serves two primary functions: (1) to collect the data for internal rental rate calculations, and (2) to control costs against project and general overhead budgets. As a result, among other characteristics, the accounting system must be able to summarize labor and materials costs by specific equipment item (e.g., D-8 bulldozer #4, serial #999) or by general item type (e.g., all large bulldozers), as well as by costs allocable to specific projects.

Repair or Replace

One of the equipment manager's most critical duties is determining whether to repair or replace a piece of construction equipment. Since contractors seek profit maximization, productivity enhancements built into new equipment might cause a manager to procure the new and the dispose of the old. This may occur even if maintenance is managed efficiently and the productivity of the old equipment is relatively high while its operation costs are comparatively low. Maintenance management and its effect play a significant role in the eventual decision, since the remaining value of the currently owned equipment derives from how it has been operated and the effectiveness of maintenance. Critical to the decision is good information by which to evaluate the likely future performance of the old item. This is yet another justification for a thorough equipment information management system.

Repair Parts

The maintenance organization must establish procedures for supplying repair parts and components to fix equipment. The procedures will derive from the maintenance flexibility and response the various jobs demand and the order-ship time, i.e., the time lag between a part being ordered by a mechanic and the part being delivered for installation. There are few equipment repair delays as frustrating as long waits for repair parts, so shops have strong motivation to provide for rapid delivery of a wide assortment of repair parts. The overhead associated with properly storing many repair parts can be costly, however, so managers must determine optimal levels of repair parts stockage, if management decides to supply parts by internal stores. Besides the order-ship time, demand history--which parts were needed and how frequently--determines what and how many repair parts should be stocked. Also important to that determination are the equipment manufacturers' recommendations, the maintenance strategy, and risk to the project costs if the components fail and cannot be quickly replaced.

Future maintenance managers must learn to be cautious of mechanics hoarding parts that they believe will be difficult to obtain quickly. If the parts are needed often and not readily available, then stockage procedures are not synchronized with demand history, and the repair parts store must correct its historical data or revise its inventory model to begin stocking the parts. Mechanics' caches of repair parts often grow when the internal parts store seeks to reduce costs by making demand stockage criteria more stringent. Ironically, what begins as an effort to reduce costs may not accomplish its purpose, as it delays job order completion. Students should see that all of the factors affecting stockage levels must be weighed to ensure proper results.

Conclusion

Expanding the above material and the ideas it provokes into five or six lectures of a construction equipment course will provide future construction managers with detailed managerial perspectives not always developed in construction curricula. Many articles in recent years have reiterated noticeable trends or repeated the possible merits of broad concepts to create certain competitive advantages in the construction industry, but they usually lack specifics that can be readily grasped and applied. These equipment maintenance management concepts are more specific, offering a direct opportunity for profitability enhancement. Students who gain such exposure are of immediate value on the job site or in the office to their future employers.

The authors invite collaboration with other construction equipment management faculty to elaborate upon these lesson ideas with a view to jointly publishing detailed, integrated construction equipment maintenance management lesson plans. They might be offered for the asking to any Associated Schools of Construction institutions who would care to employ them. No doubt other concepts besides those of this paper would merit inclusion. The increasing legitimacy of construction program and individual constructor certification processes implies that the body of knowledge pertaining to subjects of this nature should become more standardized. Lesson plans and course syllabi, which include the KSA that academic and industry consensus indicates are necessary for competent construction managers, will contribute to greater construction productivity and professionalism.

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Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 118-130

1522-8150/98/$3.00/Educational Research Manuscript

Construction Management Curriculum Reform and Integration with a Broader Discipline: A Case Study

Allan J. Hauck
Colorado State University
Fort Collins, Colorado

The Construction Management (CM) curriculum reform process at Colorado State University is described through a review of the history of the program, the problems facing the program at the beginning of the reform, the process used to reform the curriculum, the results of this process, and the future of curriculum upgrades in this program. Curriculum reform on this campus resulted in a Departmental Core providing the foundational skills for three different majors. To that core, the CM program has structured upper division coursework in engineering science, general business, construction systems and techniques, and construction management practices. The need for the integration of CM programs with a broader discipline which provides a larger theoretical framework is also discussed. The curriculum reform process described here resulted in a stronger integration of this CM program with the larger discipline of technology management rather than the traditional association with the design disciplines of engineering and architecture.

Key Words: Curriculum, Curriculum Development, Construction Curriculum, Technology Management, Undergraduate Construction Education

Introduction

Construction management (CM) programs historically have emerged from and/or have been affiliated with programs representing other disciplines - predominately engineering and architecture. It is fair to say that the field has frequently struggled to find an identity of its own. Rounds (1992) recognized this struggle in an analysis of the history of construction programs during the 1970’s. During this time period, "the academic discipline of construction gained even greater acceptance when programs at the Departmental level emerged, demonstrating the viability of construction as a distinct and independent academic area which could stand on its own beside its progenitors in Agriculture, Industrial Arts, Architecture, Engineering and Business" (Rounds, 1992, p.146).

However, partly as an outgrowth of this emerging independence of construction as a separate discipline, an unusual paradox has developed. It is generally believed that the strength of an individual CM program is positively correlated with its level of autonomy from other departments or disciplines, but that degree of independence leaves those autonomous programs targets in the struggle for limited resources and university recognition. Perhaps more importantly, a high level of autonomy robs a CM program of the benefits of a larger theoretical framework in which to operate. This move toward autonomy has been evident in the curricular changes at many CM programs in recent history. As an example, Virginia Tech has recently introduced a substantial reorganization of its Building Construction program (Mills, et. al., 1996) which appears to move the curriculum further away from its roots in Architecture. This may well lead to a broader association with the National Science Foundation supported "Synthesis Coalition" which is working to reform engineering education. The mission of the Coalition is to "develop a multidisciplinary ‘Bridging of the Architectural/Engineering/Construction Gap’ curricular sequence" (Mills, et. al., 1996, p.20). If successful, this association might provide an example of the larger theoretical framework referenced above.

The American Council for Construction Education (ACCE), the national accrediting body, does not require or expect an administrative affiliation with any other discipline. Consequently, there are many such affiliations with engineering, architecture, technology, and business. The question program leaders and department heads must address is, "Which is the appropriate association?" Currently, many seem to be answering this question by indicating that no affiliation is best; the more autonomy the better.

The following case study relates one program’s attempt to address this issue through a major curriculum reform which integrates the CM curriculum with a larger discipline. The argument is made that the larger discipline in this case - that of technology management - may provide more appropriate opportunities for integration than either of the design professions of engineering and architecture.

The History

At Colorado State University (CSU), the Construction Management program has a long history. Now celebrating its 50th Anniversary, the program started as "Light Construction and Marketing" in the General and Industrial Arts Engineering Department which was then located in the Division of Engineering. The department and the CM program was transferred to the College of Sciences and Arts in 1957. The program name was changed to Industrial Construction Management in 1959. The program was first accredited by ACCE in 1985 and the name was changed to Construction Management in 1986. CM now supports about 350 undergraduates, a Master’s degree, and a joint Ph.D. program with the School of Education. The CM program applies the study of the management of technology to the construction industry.

The department changed its name to Industrial Sciences in 1970 and inaugurated a program in Industrial Technology Management (ITM) one year later. ITM applies the same emphasis on the management of technology to the manufacturing industry. The historical mission of the department - teacher education - is still seen in the third program in the department, now representing about 10% of the undergraduate population. To reflect an additional emphasis on the preparation of professional industrial trainers, this program recently changed its name to Technology Education and Training (TET).

The Department of Industrial Sciences moved to a new College of Professional Studies in 1975 and then to a consolidated College of Applied Human Sciences in 1986. After much discussion about the changed mission of the department over the last two decades, the department name was changed again in 1996 to Manufacturing Technology and Construction Management (MTCM).

About 550 students are declared majors in one of the three programs supported by the department.

During this history, these three programs had developed into completely autonomous entities sharing virtually no resources and no common courses. The only curricular overlap was in one half of one safety course required by all three programs and courses in statics and mechanics of materials required by CM and ITM and taught in the College of Engineering. The department was criticized as appearing to house three small departments which happened to be in the same building. During their respective histories, each of these programs, and the resources they represented, had been "targets of acquisition" by other departments and colleges. While program curricula had experienced minor changes and the content of courses had been modified to reflect new technology such as software applications, the fundamental base of the curricula had not been modified in many years.

The Problem

At the start of the curriculum reform process, a number of significant problems related to the historical development of the programs were noted:

- no recognition of the commonalities among disciplines represented by the three departmental programs
- no recognition of the distinct features of these commonalities which would make the department distinct from other units in the university
- a current need to support a large number of separate and diverse courses
- inadequate staffing to support this diverse base of courses and the faculty desire for an expanded emphasis on graduate programs and research.

In addition to the above, which were deemed faculty or administrative problems, a number of challenges related to student performance were also noted:

- a significant number of early, uninformed career decisions resulting from the vast majority of departmental students being internal and external transfers - creating a desire to "get on with" their new major rather than exploring other options
- inconsistent "basic skills" preparation for upper level coursework (e.g., taking a required course in Technical Writing during a student’s last semester of Senior year)
- lack of training in teamwork and group problem solving: despite the preponderance of group projects in upper level courses, students were never taught how to solve problems as a team
- lack of a required work experience (internship) as suggested by industry.

These two sets of problems - related to administrative/faculty needs and student performance - led the faculty to commit to a major curriculum reform process in 1995.

The Process

The first step in the department-wide curriculum reform was to establish a consolidated departmental mission statement which recognized the central themes of all three programs. This statement was designed to recognize the commonalities among the programs while identifying the unique features which distinguish this department from other related disciplines. First established early in 1995 as part of a strategic planning report, this departmental mission now reads as follows:

> In keeping with the land grant tradition, the Department of Manufacturing Technology and Construction Management engages in teaching, scholarly, and outreach activities to promote the development of knowledge and skills related to management, teaching, and training in manufacturing and construction. The department addresses complex issues related to the linkages between these two industries, such as: management of technical applications; materials development and market feasibility; operations and process development and improvement; design processes; environmental issues; technology transfer; human needs and resource issues; and effective pedagogical strategies.

The first major steps toward a new curriculum were taken at three days of faculty meetings in January 1996. The faculty developed and considered long lists of desired "Program Outcomes" for each of the three majors with the intent of identifying those outcomes which were common to all three. From this discussion, the following list of "key phrases of common purpose" resulted which described elements of an inclusive departmental curriculum base:

- Integration of resources
- People management
- Built environment
- Managing processes
- Graphic communication
- Regulatory agencies
- Safety
- Team/Group dynamics
- Problem solving
- Ergonomics
- Career options
- Adaptability/Flexibility
- Applied technical skills
- Cultural diversity
- Materials processing
- Scheduling
- Legal issues
- Understanding applied math and science
- Global considerations
- Environmental solutions
- Project management
- Strategic/Business planning

After much discussion and review, it was proposed that the only way to address the problems cited above and to accommodate the objective of emphasizing the "common purposes" noted for all three programs was to establish a common core of departmental requirements. (See Figure 1) This core of common coursework - primarily encompassing the Freshman and Sophomore years and providing the fundamental skills in technology management - was initially established according to the following motions passed by departmental faculty:

1. That a common core with a "gateway" (implying that pre-"gateway" students would not declare a program major) be implemented in the department.

2. That a common core should include university requirements and departmental and non-departmental coursework totaling 45-60 credit hours.
3. That part of the "internal core" should be established with departmental prefixes (9 credit hours minimum).
4. That curriculum enhancement would be achieved without jeopardizing existing program quality.
5. That the common core should not be limited to "pre-gateway" coursework alone.

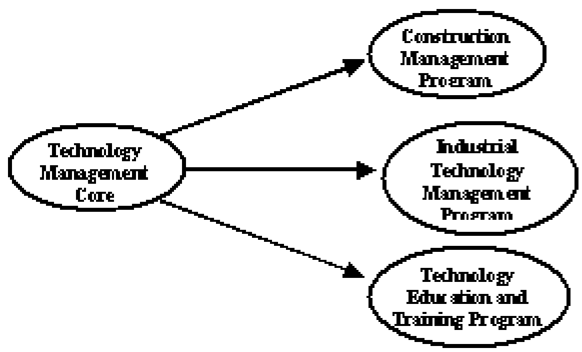

Figure 1. Relationship of the common core to the three departmental majors.

After the decision to accept the concept of a technology management core, nine areas of potential coursework were identified by the faculty which contained topics required by majors in all three programs. These curricular areas included:

1. Electronic Information Systems/Applications (Computer Literacy)
2. Electrical/Electronics/Power and Energy/Controls
3. Leadership, Motivation, and Team/Group Skills
4. Occupational Awareness
5. Materials and Basic Processes
6. Graphic Communications
7. Safety/Environment
8. Problem Solving
9. Management

Faculty discussion shifted to identify the desired outcomes/objectives to be attained in each of these areas. Two or three faculty members volunteered to work on each curricular area to further define objectives and to identify whether the outcomes for each content area could be achieved through existing coursework in other departments or whether a new departmental course(s) should be developed. Faculty in each major also worked as a group to examine the impact of a core on each program and to identify what other upper division coursework might need to be modified to attain the goals established above.

The Results

Following the January 1996 meetings at which the above decisions were made, many additional meetings were held to finalize the content and structure of the departmental core requirements.

The Departmental Core incorporates all of the faculty initiatives outlined in the previous section. Some of the features of this Core, in its current form, include the following:

- A department core requirement including six courses (16 credit hours) incorporating the common introductory knowledge required for all three program majors.
- A computer literacy requirement incorporating an examination of prerequisite computer skills given during the first semester of departmental registration. This is a two level examination: Part One measures a student's proficiency in Basic File Management and will serve as a prerequisite to some Core courses and Part Two will test End User Software proficiency and will be a prerequisite to application for a program major (beyond the "gate"). If necessary, an introductory computer course will be recommended to complete a university requirement (Logic and Critical Thinking) and to prepare for this exam.
- A verbal communication requirement including Composition, Speech, and Technical Writing which exceeds the university requirement for this area.
- A mathematics requirement including Logarithmic and Exponential Functions, Numerical Trigonometry, and Analytic Trigonometry which exceeds the university requirement for this area; if needed, College Algebra I and II will be taken in place of elective hours in the Core.
- A natural science requirement including Chemistry and a second natural science course to meet the university requirement for this area. At least one of these two courses must include a lab.
- A social science requirement including General Psychology and a second social science course to meet the university requirement for this area.

Program specific requirements scheduled for the last semester of the Sophomore year including Calculus for CM and ITM applicants and Schooling in the United States for TET applicants. Students having completed less than 60 credit hours will be registered as Manufacturing Technology and Construction Management majors without reference to a program major. When students have met all requirements of the Departmental Core (including current enrollment), they complete an application process to one or more of the three programs.

Depending on articulation agreements, transfer students with over 60 credit hours may be admitted directly into a program major, after review by the department, while they complete remaining Core requirements. Upon completion of the Core, these transfer students will have the opportunity to reconsider their selection of major.

The recommended sequence of courses in the Departmental Core is illustrated in Appendix A. Recognizing that most students in the department will continue to be transfers from other majors or from other institutions, there is no course sequence in the Core longer than two semesters. In other words, students transferring at the beginning of their Sophomore year after completing most of the general university requirements should be able to complete the Core and matriculate to the major of their choice on schedule.

There are six new courses in the Departmental Core addressing many of those areas of "common purpose" identified by the faculty. Those new courses are briefly described as follows:

MC 110 (2 Credit Hours) - Team Problem Solving and Leadership. This course explores the roles of leadership and teams in modern organizations. A combination of individual and group experiences will be utilized to give students direct experience with current and emerging tools, skills, and techniques for team based problem solving and leadership.

MC 151 (3 Credit Hours) - Introduction to Manufacturing and Construction. This course introduces the student to a wide variety of construction and manufacturing materials, processes, and systems. A combination of individual and group experiences will be applied in laboratory activities resulting in the construction of foundation, floor, wall, and roof systems commonly found in wood framed structures and the mass production of a manufactured product.

MC 251 (3 Credit Hours) - Materials Testing and Processing (Prerequisites: MC 151 and Chemistry). Students are exposed to various manufacturing and construction materials and processes through a systems approach. Separating, forming, conditioning, and joining are the focus for student laboratory experiences. A variety of research-based materials testing problems complements the laboratory component with hands-on activities related to common manufacturing and construction materials and applications.

MC 141 (2 Credit Hours) - Trends in Energy and Transportation. This course explores the ways in which our natural resources are converted into forms of energy used for transportation and environmental control and modification. Laboratory activities will be used to evaluate alternative energy sources and conservation techniques and their short- and long-term environmental ramifications.

MC 241 (3 Credit Hours) - Energy Control Systems (Prerequisites: MC 141 and Computer Literacy Examination - Part 1). This course studies the selection, application, and evaluation of electronics and fluidics based systems and devices for energy control.

MC 131 (3 Credit Hours) - Graphic Communications/Computer Aided Design (Prerequisites: MC 151 and Computer Literacy Examination - Part 1). This course emphasizes the importance of graphic communications in the visualization, design, fabrication, and construction of assemblies. Reading technical drawings, manual drafting techniques, reprographic technologies, and computer aided design applications are introduced.

The impact of this new Departmental Core on the last two years of the CM program is illustrated in Appendix B. The program builds on the Core content areas of materials and methods, energy and controls, leadership skills, and graphic communications - as well as other requirements in computer literacy, verbal communications, mathematics, and natural and social sciences - to create a course of study meeting all requirements for ongoing ACCE accreditation. (See Figure 2) A major change in the CM program which paralleled the development of the core requirements was the establishment of a required internship. The requirement is for six months of structured work experience. Many industry supporters of this program have expressed a strong preference for a minimum of six months of contiguous internship experience (e.g., January to July or June to December). To allow for this, the program requirement permits the student to complete either two three-month internships or one six-month placement. In either case, the student must complete the internship requirement before enrolling in his or her last semester of coursework.

DEPARTMENTAL CORE

Core Content Areas (16 Credits):
Leadership Skills
Materials and Methods
Energy and Controls
Graphic Communications
Computer Literacy

Verbal Communications (9 Credits):
Composition
Public Speaking
Technical Writing

Mathematics (3 Credits):

Trigonometry
Natural Sciences (7 Credits):
Chemistry
Other Nat. Science(Student Choice)

Social Sciences (6 Credits):
Psychology
Other Soc. Science (Student Choice)

Program Requirements (3 Credits):
Calculus (for CM and ITM majors)
Schooling in U.S. (for TET majors)

Other Univ Requirements (11 Credits)

Electives (6 Credits)
TOTAL - 61 Credit Hours

"GATE"

CONSTRUCTION MANAGEMENT

Engineering Sciences (18 Credits):
Statics
Mechanics of Materials
Structural Design
Design of Wood Structures
Properties of Construction Mat'ls
Soil Engineering
General Business (12 Credits):
Management Fundamentals
Accounting
Business Law

Labor Relations

Construction Systems/Techniques
(18 Credits):
Architectural Planning
Construction Surveying
Construction Equipment
Mechanical Systems in Buildings
Safety Management
Advanced Construction Systems

Constr. Management (19 Credits):
Construction Contracts
Quantity Surveying
Construction Estimating
Project Scheduling
Project Administration
Internship
TOTAL - 67 Credit Hours

PROGRAM TOTAL - 128 Credit Hours

Figure 2. Conceptual relationship between departmental core and construction management program.

The Future

The faculty of the Manufacturing Technology and Construction Management Department considered many alternatives while working on this curriculum reform package. While many of these alternatives were included in the final proposal, other ideas were tabled for future development and consideration. Some do not need formal course changes as much as a shift in emphasis in existing courses. A list of some of these future plans for curriculum updates is presented below:

- Module based courses in which course content might be taught in interchangeable five-week modules for one credit hour each.
- An emphasis on a communications core which would go beyond the university requirements and which would formalize an oral and written communications component

in every departmental course. This would address a major concern expressed by our industry advisory committees.

- Formalize the role of industry internships in the department. While this will be required for CM majors and is being considered by ITM, many policy decisions are necessary to make this an integral part of the curriculum.
- An infusion of the study of human factors throughout most of the courses in the curriculum which emphasizes the management of people in addition to the management of technology.
- Increase the number of "after the gate" core courses to be taken by all or most departmental students in areas of commonality among all program majors (e.g., a joint scheduling course for ITM and CM majors).
- Review the capstone courses currently offered by each of the programs to ensure that they meet the University goals and requirements for such capstone courses.

Conclusions

Mills, et. al. (1996) have noted that the "cornerstone of building a strong construction education curriculum is balancing practical experienced based knowledge with academic inquiry. To accomplish this goal our graduates must possess technical strength combined with the people and communication skills necessary to be successful in the global construction industry of the Twenty-First Century."

This balancing of practical knowledge with academic inquiry - and of technical skills with people and communications skills - is fundamental to the definition of technology management as a discipline. This discipline of technology management provides an excellent theoretical framework in which CM programs can operate. Construction Management programs (or programs by any other names meeting ACCE accreditation standards) have never "fit" neatly within the other disciplines which have provided these programs an administrative home. CM programs share a similar technology knowledge base with the design professions of engineering and architecture, but the net result is something different. These programs also share a common management knowledge base with the disciplines represented by colleges of business, but the curricular outcome is different. Again, it is in the "balancing act" among engineering, architecture, and business that the discipline of technology management finds a home.

The faculty at CSU believe they have strengthened the CM program by establishing a Departmental Core of courses designed provide a strong foundation in the understanding of people, communications, basic materials and methods, mathematics, and science. On that foundation, upper division coursework builds a solid background in the engineering sciences, general business, construction systems and techniques, and construction management practices. To this base in "academic inquiry" the CM program adds "practical experienced based knowledge" through the requirement for six months of industry internship.

The outcome of this curriculum reform process is the integration of the CM program with the broader discipline of technology management. When examining the needs of CM graduates and the industry they serve, few writers have suggested that what is needed is a stronger background in the design disciplines of engineering and architecture. Instead, one reads of the need for more personnel skills, better communication, stronger leadership, and a better understanding of basic business principles. Recent research completed by Mead and Gehrig (1995) attempted to identify the key skills required of constructors in the 21st century. The top three "skills" identified by this research were communication, business management, and leadership. Their "study indicates that communication, management and control, and leadership will be the pivotal skills required of future constructors. Tomorrow's marketplace will reward individuals who can manage people and paper, set and meet objectives, and lead their projects to success." (Mead and Gehrig, 1995, p. 27) How should these findings impact the future development of CM curricula? The authors encourage faculty to "emphasize people skills in construction programs. Develop specific courses or curricula at the graduate and undergraduate level which help professionals develop and strengthen these key skills. Expand role playing, simulated meetings, presentations, and team projects to foster leadership and people management. Emphasize technical writing in all courses." (Mead and Gehrig, 1995, p. 27)

These needs describe the expanding discipline of technology management rather than the traditional design disciplines associated with CM programs. Regardless of administrative affiliation on their respective campuses, construction education programs would do well to look to technology management as the broader theoretical framework in which to find a place. This association with an appropriate broader discipline beyond the construction industry itself will strengthen the position of these programs when seeking university recognition and support.

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Appendix A
DEPARTMENTAL CORE

CORE	FRESHMAN		SOPHOMORE	
	1ST SEMESTER	2ND SEMESTER	1ST SEMESTER	2ND SEMESTER
Department Core Requirements	*MC 110 (2) – Team Problem Solving and Leadership*	*MC 151 (3) - Intro. to Manufacturing and Construction*	*MC141 (2) – Energy & Transportation* *MC 251 (3) - Mat'ls Testing/Processing (prereq. - MC 151 & C 103)*	*MC241 (3) – Energy Control Systems (prereq. - MC 141 & Comp. Lit.-Pt 1)* *MC 131(3)-Graphic Comm. & CAD (prereq. - MC 151 & Comp. Lit.-Pt 1)*
Mathematics/Science	USP Cat. I.c. (3) (BD 140/1 rec. if comp. literacy test not passed) M120/1(2) –Algebra I/II (if needed)	M 124 (1) - Log. & Exp. Functions M 125 (1) -Number. Trigonometry M 126 (1) –Analytic Trigonometry C103(3 or 4 w/ Lab) Chemistry & Society	Natural Sci. elec. (3 or 4 w/ Lab)	
General	Social Sci. elec. (3) Humanities elec. (3) Physical Educ. (1) Elective (3 or 1 if M120/1 is taken)	CO 150 (3) –College Composition Elective (3)	SP 200 (3) – Public Speaking & Disc. Humanities elec. (3) Physical Educ. (1)	JT 300 or 301 (3) - Technical Writing PY100 (3) – General Psychology
Program Requirements				M 141 (3) –Calculus in Mgmt. Sciences (for ITM and CM) - OR - ED310 (3) – School in U.S. (for TET)
Credit Hours by Semester	15	15 - 16	15 -16	15
TOTAL CORE - 61 Credit Hours				

Requirements to apply for a program major at end of Sophomore year (including current enrollment):

- completion of all USP requirements (33 hours minimum including CO 150, SP 200, M 124 and 125 and 126, C 103, and PY 100)
- completion of the 16 required hours of MC core courses
- completion of Parts One and Two of the department's computer literacy examination
- completion of Cross-Cultural Awareness requirement
- completion of JT 300 or 301
- completion of M 141 (for CM and ITM applicants)
- completion of ED 310 (for TET applicants)

Legend:
Existing Courses
New Courses (Italics)
Revised Courses (Bold)

Appendix B
IMPACT OF COMMON CORE ON CONSTRUCTION MANAGEMENT PROGRAM

Given the Departmental Core described above, the faculty restructured the Junior and Senior year requirements for a degree in Construction Management (CM) as follows:

CM	JUNIOR		SENIOR		
	1ST SEMESTER	2ND SEMESTER	1ST SEMESTER	INTERN	2ND SEMESTER
Construction	MC 232(4) -Arch & Const. Planning MC366 (3) - Const.Equip & Methods MC361 (3) -Mech. Systems in Bldgs.	MC261 (3) - Const. Surveying MC 362 (2) - Const. Contracts *MC363(2) –Quantity Surveying* MC 364 (3) - Adv. Construct. Systems	MC 317 (2) –Safety Management MC365 (3) -Const. Estimating	MC487a (6) - Internship	MC461 (3) - Const. Project Scheduling & Cost Control MC464 (3) - Const. Proj. Administration (Capstone Course)
Science/ Engineering	CE 256 (3) - Statics for Non-Engineers	CE358(3) -Mech. of Mat'ls for Non-Eng.	CE350(3) -Soil Eng for Non-Engineers CE 370 (4) - Elem. Structural Design		CE364(2)-Properties of Const. Materials F 432 (3) - Design of Wood Structures
Business and Management	BG 260 (3) – Legal Envir. of Business	BN 300 (3) -Mgmt. Fundamentals	A 210 (3) - Financial Accounting		BP471(3)-Labor Rel. & Collect Bargaining
Credit Hours by Semester	16	16	15	6	14
TOTAL FOR MAJOR - 128 Credit Hours					

Note on Required Internship:

The CM program requirement is for six credit hours of MC 487a (Internship) which will be equivalent to six months of structured work experience. Many industry supporters have expressed a strong interest in and preference for a minimum of six months of contiguous internship experience (e.g., January to July or June to December). To allow for this valuable experience, the program requirement allows the student to complete either two three-month internships or one six-month internship. The Internship Director will help advise students on options available for three- and six-month placements. Please reference the Construction Management Internship Policies manual for more details on this requirement.

<u>Legend:</u>
Existing Courses
New Courses (Italics)
Revised Courses (Bold)

Journal of Construction Education
Summer 1998, Vol. 3, No. 2, pp. 131-140

1522-8150/98/$3.00/General Manuscript

The Use of Recycled Polymer Fibers as Secondary Reinforcement in Concrete Structures

Flynn L. Auchey
The Virginia Tech Polytechnic University
Blacksburg, Virginia

This paper presents the results of a feasibility study undertaken to identify the potential for using recycled high-density polyethylene (RHDPE) fiber as secondary reinforcement in Portland cement concrete structures. This study demonstrated that: 1) It is feasible to use recycled high density polyethylene fibers as secondary reinforcement for temperature and shrinkage influences in Portland cement concrete structures, 2) RHDPE fibers appear to be able to be produced more economically than virgin polypropylene fibers, 3) RHDPE fibers appear to overcome several of the negatives presented by the virgin polypropylene fibers, including floating to the surface and impact on slump, and 4) Shrinkage crack propagation was controlled as effectively by the RHDPE fibers as by the virgin polypropylene fibers. Four very important concerns relative to the use of RHDPE that were reserved for later study subject to the success of this study are: 1) the potential challenge of the alkaline reaction of the RHDPE material, 2) RHPD's performance under extreme temperature cycling, water migration rate studies, 3) its performance under extreme temperature cycling, and 4) the impact of long-term plastic shrinkage.

Key Words: Polymer Fibers, Secondary Reinforcement, Concrete, Recycling, Portland Cement

Introduction

Waste is one of the main challenges of our times. Since l950, the total waste in landfills has increased 500% (Bilwatsch, 1991). The three primary sources of plastics that end up in solid waste are the resin producer, the processor and fabricator, and the consumer. Four primary alternatives exist for dealing with plastic waste: landfill, ultraviolet degradation, incineration, and recycling. Of these alternatives, recycling holds the greatest promise for returning the resins to service at a high economic level on the material value scale.

Of all these plastic wastes, high density polyethylene (HDPE) is used in a greater percentage of the products that are destined for short term highly visible packaging, i.e. bottles for bleach, motor oil, toiletries, milk containers, etc.

Therefore, these recycled containers become an excellent candidate for reuse in secondary recycled applications (Modern Plastics, 1988). In order to reduce this municipal solid waste growth, additional demand for recycled HDPE must be generated from industries, including construction (Wilkinson, l990). Indeed, construction is projected to rank second only to packaging in the use of recycled plastics. Much of this demand can be accomplished by diverting the construction industry away from the use of virgin polymers as secondary reinforcement, wherever possible, to the use of recycled polymers.

Virgin polypropylene fibers have been used successfully in the construction industry for over eighteen years as secondary reinforcement. They offer the construction industry an option to the standard welded wire fabric (WWF). Welded wire fabric has many advantages; however, it is subject to tremendous cost fluctuations because of world steel market influences. Also, it rarely ends up in the exact physical location in the slab that the designer intended because of the physical process of field placement. In addition, it does not readily adapt to the evolving technologies which use equipment that must travel over the area normally occupied by the WWF. For these reasons, more designers are going to the polymer type fiber (PF) as secondary reinforcement. Many of the major construction industry companies like J. A. Jones, The Bechtel Corp. and The Parsons-Main Co. have completed major projects using PF type secondary reinforcement successfully. Many major construction projects, like the new Denver airport, have incorporated PF type reinforcement. The PF industry claims that it has enjoyed double-digit growth in product volume sales each year for the past thirteen years (Fibermesh, 1994).

Polypropylene fibers have gained wide acceptance in spite of several shortcomings:

1. Raw material cost fluctuates wildly with the cost of petroleum,
2. Many designers perceive that the percentage of material actually required to provide the necessary reinforcement exceeds the amount recommended by the suppliers
3. The fibers 'float up' to the surface of the concrete matrix during finishing causing additional time and work to finish the slabs properly
4. The addition of the fibers to the concrete matrix decreases the 'slump', making placement more difficult thus requiring the addition of more water, which degrades the concrete strength, or plasticizer which adds to the basic cost.

Goals and Objectives of this Research

The primary purposes of this investigation were to determine:

1. If it was feasible to use recycled high density polyethylene (RHDPE) as a replacement material for welded wire fabric (Zolo and Hays, 1991) as temperature and shrinkage reinforcement in Portland cement concrete structures.
2. If RHDPE that has been sorted from municipal waste, properly cleaned and mechanically 'shaved' into multi-dimensional fibers, would economically fulfill the performance criteria presently being met by virgin polypropylene products.
3. If RHDPE fibers can be used successfully structurally and economically while overcoming some of negatives associated with the virgin polypropylene products.

This study was undertaken to identify the potential for success of the RHDPE fibers as a partial replacement for the virgin polymers. The study was limited to specific structural and performance tests, which provided an indication of the validity of using the RHDPE as a structural material.

Four very important concerns relative to the use of RHDPE were reserved for later study subject to the success of this study:

1. The potential challenge of the alkaline reaction of the RHDPE material,
2. Its performance under extreme temperature cycling,
3. Water migration rate studies, and
4. Long-term plastic shrinkage.

This study was a jointly sponsored by The University of North Carolina at Charlotte, DOW Chemical Company and the LAW Engineering Company.

The Material

The polymer fibers used in the tests were of two different compositions. Fibers in test specimens marked 'FIBER MIX' (FM) were obtained from commercial stock supplied by the ready-mix company that supplied the concrete. This fiber was made from virgin polypropylene. The fiber mixed into the test specimens marked RHDPE were sheared in random lengths from clear plastic milk containers selected from waste stock. This material was cleaned with dishwashing detergent and rinsed in clear water prior to being sheared into fibers. The fiber dimensions varied in length from 19.05 mm (.75 in.) to 38.1 mm (1.5 in.) long by approximately 1.587 mm (.00625 in.) wide by 1 mm thick. The tensile strength of the FM fibers was quoted in manufacturer specifications as 44.81 N/mm^2 (6,500 psi).

The tensile strength of the RHDPE fiber as tested by LAW Engineering was 33.61 N/mm^2 (4,875 psi) based on an average of four "dog bone" specimens tested using ASTM **D882** as a general reference. The concrete supplied by Concrete Supply Company of Charlotte, N.C. was specified as Mix Code # 3700. Mix specifications (per cubic yard) were: strength, 27.58 N/mm^2 (4000 psi) cement: 517 pounds, coarse aggregate: 2000 pounds, fine aggregate: 1341 pounds, water: 325 pounds and design slump: 4 inches.

Experimental Procedure

The concrete was poured close to noon when the temperature was 21^{0}C, (70^{0}F). The pouring was concluded at 12:25 p.m. and the temperature was 23^{0}C, (74^{0}F). Thirty nine - 152.4 mm., (6 in.) diameter by 304.8 mm, (12 in.) high cylinders and twelve beams 152.4 mm x 304.8 mm) were poured by LAW Engineering laboratory technicians assisted by seven senior Civil Engineering Technology students from UNCC.

The cylinders were separated into lots containing a) no fiber, b) 0.1% fiber (by volume, 1.5 #/cu. yard) and c) 0.2% fiber (3.0 #/cu. yard). The ready-mix concrete was measured and placed into a portable mixer. The appropriate fiber quantity was then blended into the concrete matrix and thoroughly mixed by motorized drum mixer for five minutes to get uniform distribution of the fiber.

The concrete was then checked for unit weight, slump and air content, per ASTM C-173, and poured into the test cylinders and beams; they were then cured according to ASTM Designation C 192-90a. The specimens were tested on the seventh and twenty-eighth days per ASTM designations:

1. C-39 Compressive Strength
2. C-496 Splitting Tensile Strength
3. C-78 Flexural Strength

It was noted that in both the 0.1% and the 0.2% test specimens more than 100 FM fibers floated to the top and presented a 'fuzzy' appearance. Less than 5 RHDPE fibers were observed to float to the surface of their respective specimens.

Results and Discussion

Field Measurements

The following initial data were recorded while the specimens were being poured:

Table 1

Effect Of % of Fiber Content on Slump

SPECIMEN TYPE	% FIBER	SLUMP	AIR CONTENT
CONTROL	0.0%	4.75"	2%
RHDPE	0.1%	4"	2%
RHDPE	0.2%	3.5"	2%
FM	0.1%	3"	2%
FM	0.2%	2"	2%

These data suggest that the RHDPE fibers had less negative effect on the slump of the concrete as compared to the FM type fiber. This result may have important strength, productivity and cost related impacts; however, more testing will have to be done to statistically verify the real strength and economic impact of this variable.

Appendix 'A' shows the Summary of Laboratory results of the compressive strength tests, splitting tensile strength tests, and the flexural strength of the specimens at 7 days and 28 days for the control specimens with no (0%) fiber content (CONTROL), fibrillated (FIBER MIX) fiber specimens and the recycled high density polyethylene (RHPDE) specimens.

Summary of Laboratory Test Results

Compression Strength Results

In compression, the RHDPE specimens showed only moderate advantage over the CONTROL and FIBER MIX specimens at 7 days (6% over CONTROL and 3% over FIBER MIX); however, at 28 days, the RHDPE with 0.1% fiber shows an average of 5% greater compressive strength over the control and 10% over the FIBER MIX specimens. It should be noted in Appendix 'A' that the compressive strength of the RHDPE with 0.2% fiber dropped back to a 3% advantage over FIBER MIX. Note also that the average of the FIBER MIX specimens with 0.1% fiber content had not yet reached the design strength of the mix.

Flexural Strength Results

Flexural strength tests were run using only the CONTROL concrete beams and the 2% RHDPE reinforced beams. The results indicate that the RHDPE did increase the flexural strength of the beam.

Splitting Tensile Strength Results

The RHDPE specimens at 0.1% again showed the most interesting results at the 28-day test for splitting tensile strength. They out-performed the control specimens and they exceeded the capacity of the FIBER MIX specimens by 2.6%.

Fiber Distribution

No statistical analysis was made of the distribution of either the FM fibers or the RHDPE fibers in any of the specimens; however, physical observation with the naked eye indicated that distribution of both fiber types in all specimens was reasonable uniform.

Shrinkage Crack Mitigation

Two separate flat panel tests were performed to compare the abilities of the two different polymer fibers to resist shrinkage cracking. No ASTM specification was available for this test so actual field construction conditions were simulated as closely as possible. Both tests were conducted using the four thousand-pound concrete mix referenced above. The concrete was placed into wood forms measuring 76 mm thick by 609.6 mm wide by 914.0 mm long. Three of these test panels were used: panel ones mix contained 0.1% of 'FM' fiber, panel two mix contained 0.1% of RHDPE, panel three contained no (0%) shrinkage reinforcement. All panels were underlain with a polyethylene vapor barrier to minimize base surface drag. Test number one was poured under job conditions: 23^0C, (74^0 F), with a controlled wind velocity of 10 to 15 mph. The relative humidity was 70 percent. Test two was performed when the temperature varied between 29^0C (84^0 F). and 31^0C (89^0 F), with a relative humidity of 64% and an average controlled wind velocity of 32 K/hr. (20 mph) to 41 K/hr. (25 mph) Neither test produced micro-cracking in any of the samples. This test will be run again under more extreme drying conditions.

Cost Comparisons

Cost comparisons of the RHDPE material with the FM material were most difficult to correlate. The retail cost of the FM was quoted at between two dollars and sixty-six cents ($2.66) per pound ($5.91/kg.) to as much as four dollars and sixty-six cents ($4.66) per pound ($10.35/kg.). The RHDPE material was obtained from a contract recycler in bailed (not clean) condition for eight cents ($.08) per pound ($.17/kg.). This price was for clear milk bottles. (The fiber used in the tests were from clear stock). Colored bottles were quoted at four cents ($.04) per pound ($.09/kg.). In addition to this cost, we added cleaning, handling, cutting and packaging costs of approximately twenty-four ($.24) to thirty two cents ($.32) per pound ($.71/kg.), giving us a total of thirty two cents ($.32) to forty cents ($.40) per pound ($.89/kg.). No profit or overhead allowances have been added. Further, as stated, RHDPE was not available commercially; therefore, best estimates from commercial suppliers were used.

These relative costs would suggest that the RHPD material could enjoy a significant pricing advantage. This apparent pricing advantage is due primarily to the following factors: (a) the initial raw material cost is lower for the RHDPE and (b) the cost of production is lower because it involves only the cleaning and shearing process. The melting, pelletizing, extrusion, and shaping of the FM fiber is eliminated. All other costs associated with getting the material to the marketplace should be similar for both materials.

The most difficult part of validating the actual recycled material cost was with regard to the variation in raw material cost due to possible increased demand for RHDPE and the 'social contribution' cost of the municipal collection process. That is, as new markets are developed for this material and municipalities adjust their cost sharing for the collection process, the raw material cost will likely increase. In addition, since the original patents on the FM material have expired, more competition has entered the marketing arena and this may create a downward pressure on the retail pricing structure of the virgin polymer material. However, given the obvious differential between the combined production costs of the RHDPE and retail cost of the FM materials, there exists potential advantage for the RHDPE materials.

Summary and Conclusions

Experiments were conducted on specimens made of four thousand pound (4,000 psi.) concrete, which contained varying amounts of polymer fiber reinforcement. The control specimens contained no fiber reinforcement. The other specimens contained either one or two tenths percent (by volume) of virgin polypropylene fiber reinforcement (FM) or one or two-tenths percent (by volume) of recycled high density polyethylene fiber reinforcement (RHDPE). Slump, compressive strength, splitting tensile strength and flexural strength tests were performed by LAW Engineering laboratory personnel on these specimens in accordance with appropriate ASTM testing guidelines. It should be noted that sufficient tests were made to develop an average, not a statistically based result.

On the basis of the test results and physical observations, the following conclusions have been made:

1. It may be feasible to use recycled high density polyethylene fibers as secondary reinforcement for temperature and shrinkage influences in Portland cement concrete structures, i.e. all of the tests indicated that the RHDPE fiber specimens provided a higher strength than did the specimens with the FM material.

2. RHDPE fibers appear to be able to be produced more economically than virgin polypropylene fibers. It can be concluded that about twice as much RHDPE fiber can be provided in a concrete mix using RHDPE as can be provided at the same cost using FM. In addition, there are additional savings in secondary costs associated with the reduction in municipal landfill site volume requirements.

3. RDPE fibers appear to overcome several of the negatives presented by the virgin polypropylene fibers, e.g. the RHDPE fibers do not appear to float to the surface as readily as do the FM fibers. This will cause a reduction in finishing time and costs as well as an improvement in concrete slab surface appearance. The slump of the concrete mix does not appear to be effected as negatively by the RHDPE fibers as by the FM fibers. This will allow the pouring of concrete mixes with lower percentage of water, which not only increases the basic concrete mix strength without negatively effecting the ease of pouring but also reduces the need for addition of plasticizers to enhance concrete workability. This results in additional cost savings.

4. Shrinkage crack propagation was controlled as effectively by the RHDPE fibers as by the FM fibers.

5. The flexural strength of the beam specimens was improved significantly; however, additional testing needs to be performed to get a more accurate statistical comparison.

The results of this feasibility study favor the use of RHDPE fibers as secondary reinforcing in Portland cement concrete structures. Additional study is being performed including sufficient specimens to provide statistically significant results.

Recommendations For Further Study

The tests performed in this study were primarily designed to provide an indication of relative advantages and disadvantages of the RHDPE fibers over the control as well as the FM specimens. This information will now be used to design further statistically significant research testing of the RHDPE fibers and other co-mingled waste polymers.

Additional testing to be performed will include:

1. The impact of alkaline reaction in Portland cement concrete on recycled polymers,
2. Water migration studies,
3. The reaction of Recycled Co-Mingled Polymer (RCP) fibers to extreme freeze-thaw conditions (Now underway with The Army Corp. of Engineers CRREL Laboratory),
4. The response of RCP fiber reinforced concrete to corrosive and caustic atmospheres
5. The damping effect of varying percentages of RCP in structures subjected to dynamic and/or vibration loading conditions,
6. The cost effectiveness of using RCP in different types of reinforced concrete structures,
7. The most effective methods for producing RCP fibers,
8. The response performance (in-service) of various configurations of RCP fiber,
9. The true effect of RCP fibers at varying concentrations on slump, concrete strength and workability.

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Appendix A

SUMMARY OF TENSILE STRENGTH AND ELONGATION
UNCC RHDPE Research Project

Specimen Number	Thickness, Inches	Width, Inches	Test Speed	Elongation, Percent
1	0.0210	0.250	2"/min.	952
2	0.0245	0.250	20"/min.	3.7
3	0.0205	0.250	20"/min.	5.5
4	0.0213	0.250	2"/min.	1005
		Tensile Strength in psi		
1		4950		
2		3410		
3		3510		
4		4880		

Appendix B

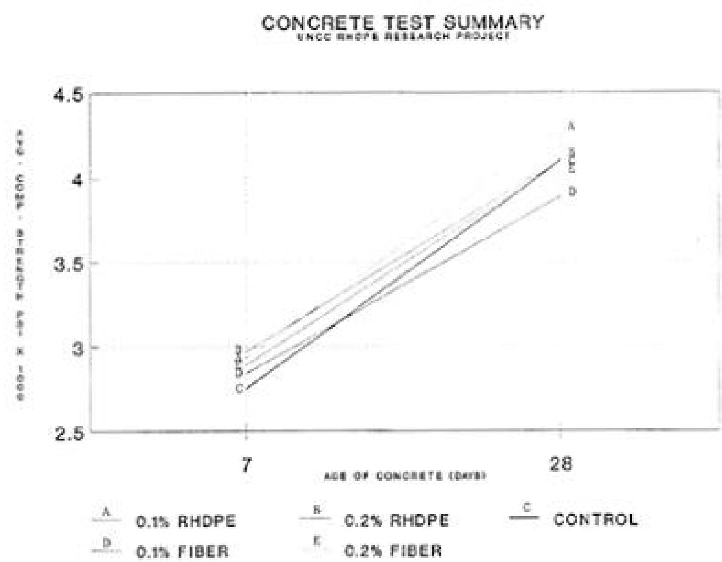

Figure 1. Compressive Strength Comparison

Appendix C

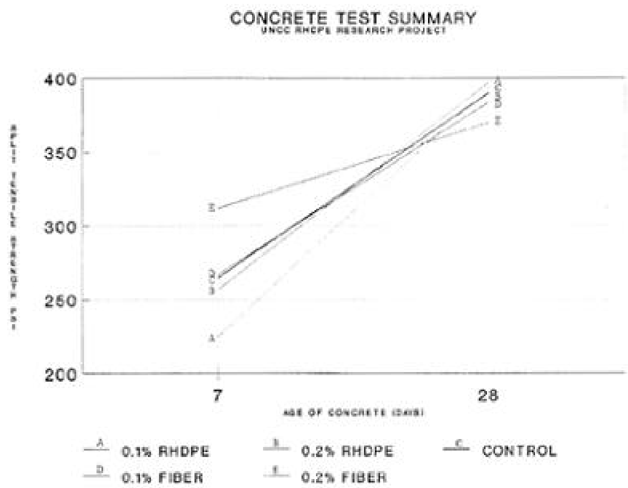

Figure 3. Splitting Tensile Strength Comparison

Appendix D

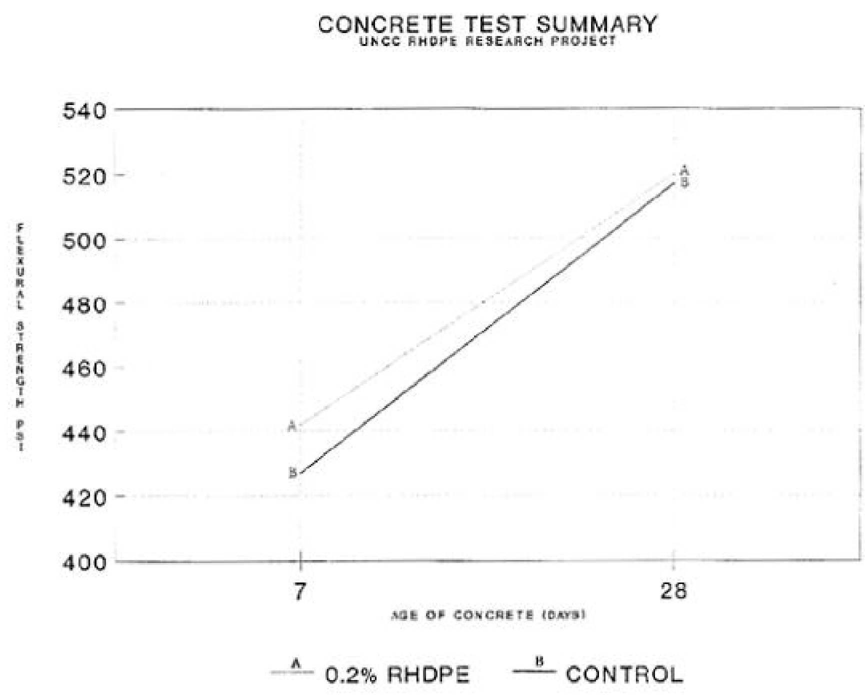

Figure 2. Flexural Strength Comparison

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Acknowledgement

The Editor wishes to thank the Department of Construction Science and the College of Architecture of Texas A&M University for their support of the *Journal* creation and operations. Thanks are also due to the Editorial Advisory Board whose names appear on the second page; and to those serving on the Review Board listed above.

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