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The *Journal of Construction Education* (ISSN 1522 8150) was founded in 1996 by the Associated Schools of Construction, an association of 105 international colleges and universities with construction education programs. The purpose of the *Journal* is to provide an important process necessary for the preservation and dissemination of manuscripts that report, synthesize, review, or analyze scholarly inquiry. The *Journal* is an important way of our focusing international attention on and contributing to the understanding of the issues, problems, and research associated with construction education and training. The recognition of scholarly work within the realms of curriculum information, contemporary educational practices, educational research and instructional application development within construction departments, schools and colleges, and industry are the reasons for the *Journal's* existence. The *Journal's* mission is to provide construction educators and practitioners with access to information, ideas, and materials for improving and updating their understanding of construction education and training. It is also intended to help its constituency become more effective in developing the talents of learners within construction programs. This *Journal* is not only a living textbook of construction education, but also a perpetual and dependable learning source for construction professionals whether they are within academia or within industry. The *Journal* will be published tri-annually (Spring, Summer, and Fall issues). The divisions of the *Journal* include invited and editorially reviewed Book Reviews and Teaching Profiles, and blind peer reviewed Educational Practice and Research Manuscripts.

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Editorial
Annual *Journal* Entries

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Annually, the following report provides the reader with an analysis of manuscripts submitted for review and publication. The *Journal* tracks those issue items that might indicate changes in the ways authors communicate bulk information to their readership. This is the sixth year of the Journal, and this review continues to include in the statistics addressed in the previous issues. This year the analysis includes statistics about the *Journal's* web page usage and a comparison between the *Journal* and its sister publications, The Annual Conference Proceedings and The American Professional Constructor.

Vital Statistics

Number of manuscripts accepted vs. rejection. There were fifteen manuscripts published during the past year. Twenty-six manuscripts were submitted for review, nine were rejected as not being acceptable for publication. This provides the Journal with a forty-five percent rejection rate. This is similar to that reported in previous five years (see Figure 1).

Average number of pages per published manuscript. There was a change in the number of pages per manuscript. The average was 8.87, which was a positive change of –2.22 from the previous year.

Average number of images, tables, and appendices. Within this volume, images averaged 3.07 images per manuscript that is 1.02 more than that of the prior year. Tables decreased -0.97 per manuscript to an average of 0.80. Attachments decreased from 0.45 per manuscript to 0.27. Figure 2 is a graph of the statistics from 1996 to 2001.

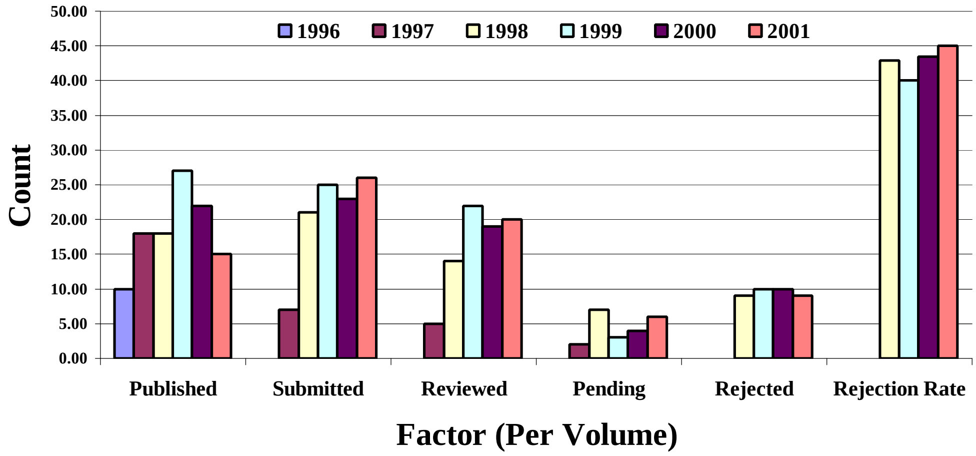

Figure 1. Publication and Submission Data

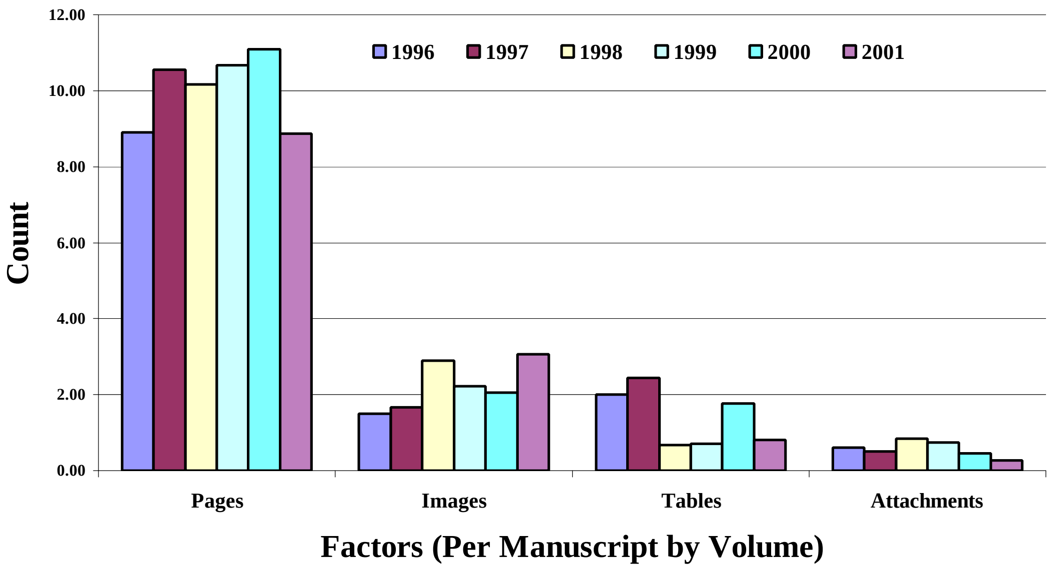

Figure 2. Manuscript Description Data

Figure 3 illustrates the hits received on the index page of the *Journal* for each month since April 2001. Prior data was not maintained in a usable format and therefore cannot be reported. The *Journal's* usage soars after each issue is published.

Figure 4 illustrates the where browsers are going within the *Journal* for the same time period. The manuscript archive received 42.22% of the browsing volume. This would indicate that the *Journal* is truly being used as an archival source by its readership. An interesting statistic is the 15% value for the reviewer-listing page. This indicates that readers are interested in the identity of our reviews. This should provide an effective argument for Review Board membership.

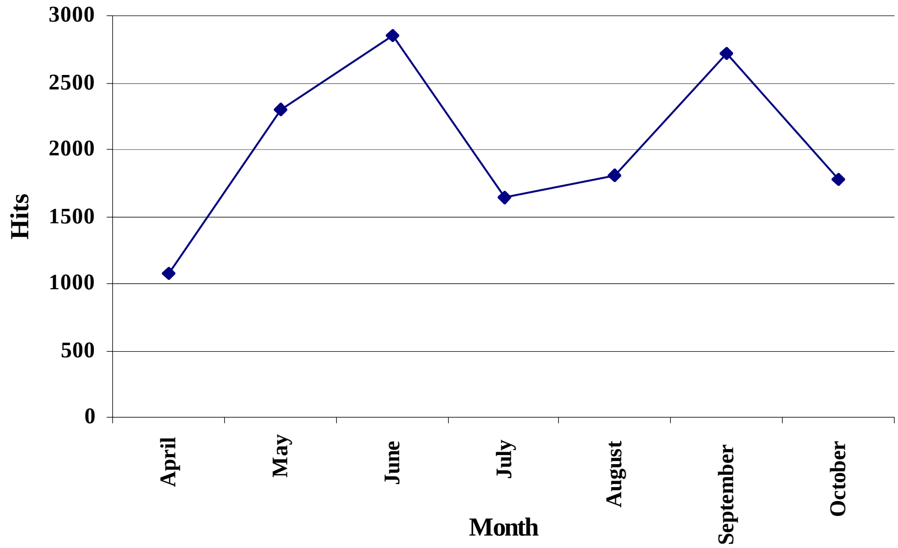

Figure 3. Journal Web Site Hits

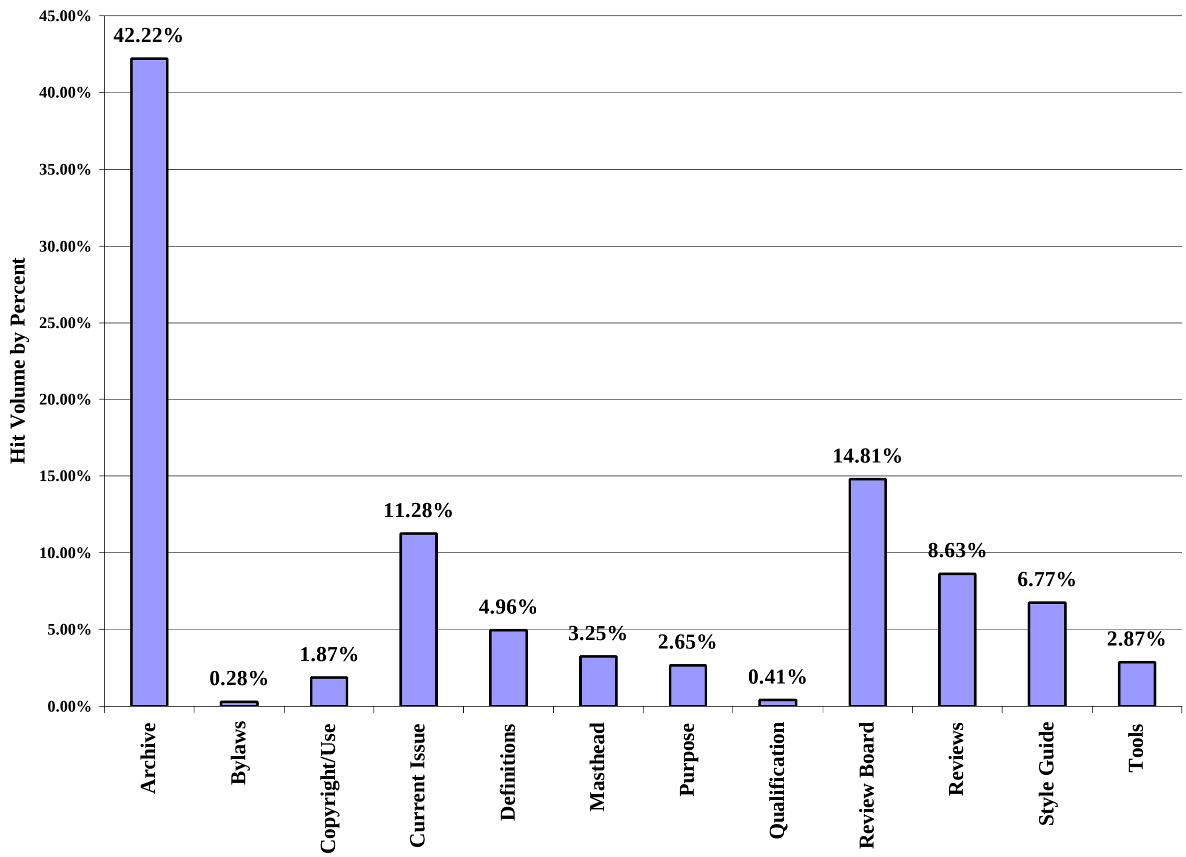

Figure 4. Hits by Page Category

Publication Comparisons

One of the concerns identified at the founding of the JCE was that its publication could seriously affect the AIC's journal while little concern was expressed for affect on the ASC proceedings publication. Three time periods are important to the reader. First is the period between 1973 and 1986, in which the AIC's journal "*The American Professional Constructor*" was the sole publication source for those closely aligned with the mission of the ASC. In 1986, academic pressures and the need of the ASC to record its annual conference proceedings formally lead to the publication of the "*Annual ASC Conference Proceedings*". Lastly, the period after 1996 represents the publication of the "*Journal of Construction Education*," as an enhanced response to academic pressures and a need for an education manuscript publication source.

The ASC Board of Directors was first presented with a proposal for the JCE in 1990. In 1992, they requested a survey be conducted within the ASC membership to determine if there was faculty support for a journal. The following year a report was provided to the Board that indicated that 82% of the membership's faculty wanted an education journal. At that time, the AIC journal was not publishing education manuscripts with pedagogy content and most academic programs accepted the ASC proceedings as equal to a journal publication. The ASC Board voted not to proceed with an ASC journal and elected to work with the AIC by encouraging it to publish pedagogy works. In 1994, the AIC agreed to dedicate one issue per volume of its publication to educational manuscripts, however this was never truly embraced or acted upon by the AIC. The analysis of publications within the AIC's journal indicates that within the three time periods the publication of educational manuscripts has never exceeded 11% of total publication. The membership and publication emphasis of the AIC is directed toward industry professionals and not toward the academic educator. As a result, in 1996 the JCE became a reality responding to years of academic efforts and needs within the academic community.

In response to the initial ASC Board concerns, a comparison between the *Journal* publication and its sister publications has been provided. Data for the following illustration was gathered from prior ASC proceedings, AIC journals, and the JCE database (see Figure 5).

The data indicates that the AIC journal is responsive to the actions of the ASC publication efforts. Before the ASC proceeding publication, the AIC journal was having difficulties in attracting authors. Dramatically in 1986, its number of publications increased proportionally mirroring that of the ASC proceedings. Of interest to this analysis is the effect of the JCE upon its sister publications. The first effect with the least significance is between the proceedings and the JCE. There has been an observable minor negative effect upon publication within the proceedings, however as always, there are probably confounding non-identified variables at play. The overall authorship within the ASC proceedings continues to increase which has cause difficulties in physical publication efforts. In response to this the ASC proceedings Editor/Publisher has reduced the page count from 15 to 10.

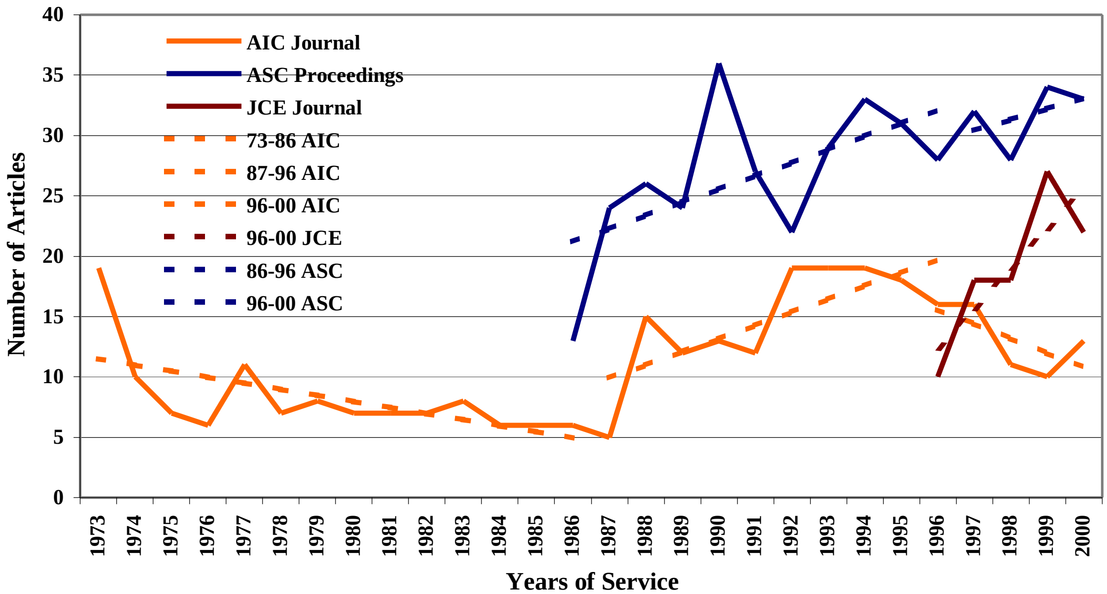

Figure 5. Interaction Effects between Selected Publications by Period of Activity

The final effect to be discussed is the interaction between the AIC journal and the JCE. The JCE has had a significant effect upon publications within the AIC journal. This was not an effect intended by the ASC Board or the JCE. The question that begs to be answered is why. The answer could be that the JCE has published both practice and pedagogy manuscripts at the direction of the ASC Board an activity which is counter to the mission of the JCE. By ASC Board vote, the ASC proceedings for the years 1996 and 1997 were grand fathered into the JCE. This immediately responded to those faculty that needed to publish at the highest level of publication, a journal. As a result, ASC member faculty did not continue to submit their works to a journal outside of the ASC. This is probably the result of association and membership. Few of the ASC member faculty are members of the AIC and therefore may wish to publish and inform their academic associates of their works. Academia within construction education has continued to evolve to match that of the remaining academic body, which requires journal publication for tenure and promotion.

The response of the JCE has been to cease accepting practice manuscript submissions, as of this issue, and to abide by its stated mission and purpose of pedagogy publications at the direction of its Advisory Board. However, does this action meet the needs of the ASC member faculty? Is the AIC's journal the publication outlet for these works that are intended to communicate practice issues to academia? In that few ASC faculty have membership or access to the AIC journal it would be ludicrous to expect such a result. If the ASC membership has the desire to inform its academic community of practice issues then it must do so through an ASC practice journal and not within the AIC's journal which has an industry readership. It is also the responsibility and duty of the ASC and the JCE to ensure that the AIC's journal remains a viable publication true to its industry mission while responding to the academic and pedagogical needs of our ASC membership and JCE authors and readers.

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1522-8150/01/$3.00/Educational Practice Manuscript

Internet-Based Interactive Construction Management Learning System

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Incorporation of classroom tasks that improve the abilities of students to manage the complex dynamics, pressures, and demands of construction sites is becoming critical to meet the demands of the construction industry. These goals are, however, difficult to incorporate using traditional educational tools. This paper describes the work being performed as part of a three-year project that has been funded by the National Science Foundation (NSF). The goal of the project is to enhance the undergraduate construction engineering and management education by incorporating practical content into the construction engineering and management curricula, thus bridging the gap between the classroom and the construction site. These enhancements are accomplished by developing: 1) an Internet-based Interactive Construction Management Learning System (ICMLS) and 2) an advising and mentorship program that enhances practitioner-involvement. ICMLS uses Internet-based interactive and adaptive learning environments to train students in the areas of construction methods, equipment and processes. This system is being developed using multimedia, Internet-based computing, databases, discrete-event simulation, and Virtual Reality Modeling Language (VRML).

Key Words: Construction, Education, Interactive Learning, Internet-Based Computing, Virtual Reality Modeling Language (VRML), Discrete Event Simulation

Introduction and Background

Construction is a very large and diverse business and is a significant employer, cash generator, and contributor to the economy. Growth and the replacement of people leaving the labor force will add more than 68,000 new positions for civil engineers by the year 2005, according to a recent forecast of employment trends (ASCE, 1996). Attracting talented high school graduates and imparting the best possible civil and construction engineering education is critical to the future of the U.S. construction industry.

In the early 1980's, the construction industry faced increased national and international competition, stringent governmental regulations, and an environmentally conscious populace. The industry also encountered issues such as organized labor, challenges of new technologies and new materials, and construction of complex projects. These forces emphasized the value of strong engineering and management skills required for delivering high quality constructed facilities. That, in turn, added a new dimension to the profession and led to the evolution of a group of professionals among civil engineers who practice construction management.
As a direct response to the needs of the construction industry, universities around the nation started undergraduate and graduate curricula in civil and construction engineering that provide more emphasis on construction engineering and management (Oglesby, 1982 and Tatum, 1987).

Construction Education – Current Status

Over the past few years' national organizations such as American Society of Civil Engineers (ASCE), American Society of Engineering Education (ASEE), National Science Foundation (NSF), and National Research Council (NRC) have sponsored numerous studies to gauge the current status of undergraduate engineering education and to develop an agenda for improvement. These studies have identified a number of major issues such as: 1) faculty development; 2) practitioner involvement; 3) development of integrated curriculum; 4) focus on diversity; 5) new approaches to assessment of faculty, students, courses, and curricula; 6) broader and flexible curricula; and 7) utilization of active learning approaches (ASCE, 1995 and NSF, 1995). These initiatives have brought new impetus aimed at the continuous improvement of undergraduate engineering education.

Similar studies have also been undertaken on the civil and construction engineering education front. A study conducted by the Institution of Structural Engineers in the UK reveals that civil engineering education should include practicality and feel for construction engineering (Walker, 1981 and Shaw, 1981). In reality, many civil and construction undergraduate programs fail to provide students with an arena where they can acquire the skills and experience necessary to successful professional practice and on-site performance (Hadipriono and Sierakowski, 1986 and Fruchter, 1997)). Most civil engineers need to spend many years in the field in order to assimilate an adequate knowledge about actual construction performance. Therefore, it is imperative for civil engineering (and construction engineering and management) educators to promote these education enhancement factors to undergraduate students in the classroom (Hadipriono, 1985; Hadipriono and Larew, 1985; and Echeverry, 1996).

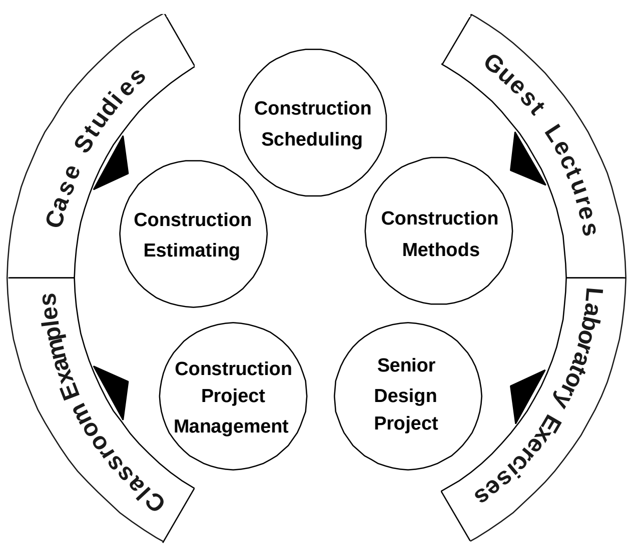

Figure 1. Current Construction Engineering and Management Education.

Figure 1 explains the status of the current civil and construction engineering and management curricula. Students complete key courses such as construction materials and methods, estimating, scheduling, and project management before undertaking the senior design project. Instructors use case studies, classroom examples, guest lectures, and laboratory exercises to explain the application of classroom knowledge in solving real problems. However, the current approach is often inadequate in preparing students for the on-site construction processes. This is evident from the sudden "jump" the students experience when starting their senior design project. The reasons for this "jump" are: 1) lack of adequate experience in the dynamics and complexity of the construction site; and 2) lack of guidance and interaction with construction experts. The senior design project—normally one semester in duration—does not completely accomplish its objective due to this missing link in the current curriculum.

It is clear from these studies that the current civil and construction engineering curricula are often inadequate in preparing students for the complex process of construction. Weaknesses include a fragmented curriculum that does not permit the inclusion of issues of importance to construction, the limited access to construction practitioners and hands-on experience, and limited use of advanced computing tools to improve student learning.

Problem Statement

The traditional teaching methods are often not fully capable of providing students with all the skills necessary to solve the real-world problems encountered in construction (AbouRizk and Sawhney, 1994) or conveying complex engineering knowledge effectively. The instruction methods used to convey this engineering knowledge in the majority of construction engineering and management curricula rely, for the most part, on traditional methods such as exposing students to applied science courses. Also, curricula often convey this knowledge in fragments in a series of courses (Fruchter, 1996 and Fruchter, 1997) and do not provide enough opportunities for students to interact with construction professionals or to pool the knowledge acquired in several courses to solve real-world problems.

Ideally, visits to construction sites or site training would constantly complement the more conventional classroom instructional tools. However, there are various complicating issues that make it impossible to rely on the sites. Foremost, the instructor cannot control the availability of a project at the necessary stage of completion. Also, visits of larger groups to construction sites may not be welcome, involve risk, and are unpractical (Echeverry, 1996). Finally, the high cost of site training is a further impediment to its extensive use for construction education (AbouRizk, 1993 and AbouRizk and Sawhney, 1994). General computing and information technologies, and simulation in particular, have the potential to complement construction engineering and management education. The authors, motivated by this, have undertaken this research project to address the above-mentioned issues through the development of an integrated educational framework that will expose the civil and construction engineering students to the complexities of the construction site.

State of the Art

Numerous innovative tools have been used to enhance the learning of civil and construction engineering students. Some common examples are site-visits, use of construction site-videos, computer simulation and gaming, internship, and summer training.

The idea of construction games can be traced back to Au and Parti (1969) who suggested that computerized heuristic games could be used for the education of engineers and planners engaged in the construction industry. Scott and Cullingford (1973) described a scheduling game for construction industry training. Halpin (1976) presented a model for the project gaming system CONSTRUCTO that allows students to plan, monitor, and control hypothetical projects. Harris and Evans (1977) developed a road construction simulation game for site managers focussing on the planning and control of linear construction projects. Herbsman (1986) explained the use of civil engineering project management games at theUniversity of Florida where each player was required to participate in the design and execution phase of an assigned actual project being constructed near the university. Rounds et al. (1986) described a construction game that simulates the progress and project reporting structure of an industrial construction project. Dudziak and Hendrickson (1988) developed a simulation game for contract negotiations. Vehosky and Egbers (1991) explained the development and use of a game for simulation of management of a design and construction project. AbouRizk (1993) and AbouRizk and Sawhney (1994) described the development and deployment of a construction bidding game that provides the undergraduate students of civil and construction engineering a thorough understanding of the components and methods of construction bidding. Fruchter and Krawinkler (1995) described the development and testing of a new and innovative computer integrated Architecture Engineering Construction (AEC) teaching environment.

From the above summary it can be observed that a number active learning systems aimed at training students in different aspects of construction management, have been designed and implemented. Most of the systems mentioned above are either manual or have been developed with limited use of advanced computing tools. They are not geared towards the dissemination of knowledge related to construction processes, methods, equipment, and decision-making factors related to site execution of construction processes. Active participation of construction practitioners is also not utilized in these systems. This research project derives its motivation from the systems described above and demonstrates the effectiveness of utilizing active learning concepts to enhance classroom instruction.

Overview of the Research Project

The research project is based on the development of an Internet-based Construction Management Learning System (ICMLS) that utilizes: 1) active learning approaches to bridge the gap between the classroom and the actual construction site; 2) advanced Internet-based computing technologies to bring the complexities of the construction site to the classroom; and 3) knowledge and expertise of construction professionals through an advising and mentorship program. Figure 2 depicts ICMLS and the mentorship program in the context of construction engineering and management education. The system is used as an instructional tool for the key courses identified in the figure to introduce practical construction management concepts. The project advisory committee consisting of regional construction practitioners is guiding the development of the ICMLS. During the testing and final utilization of the system members of the advisory committee will act as student mentors. This strategy helps the students gain: 1) adequate experience in the dynamics and complexity of the construction site; and 2) guidance and interaction with construction experts.

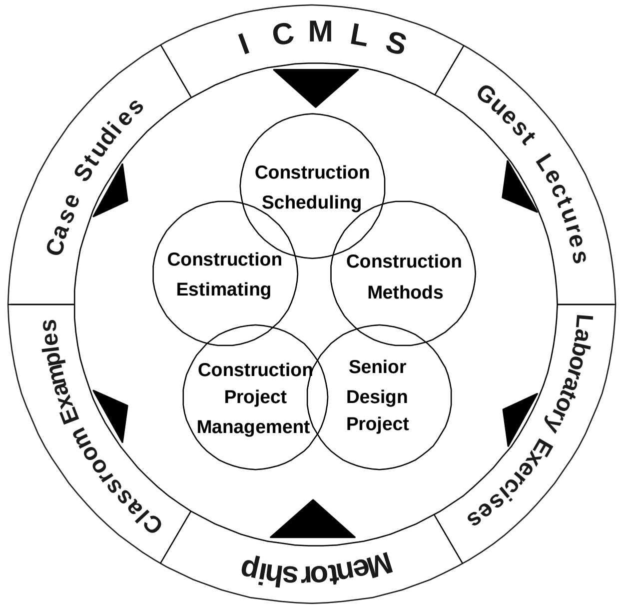

Figure 2. ICMLS and the Mentorship Program in Construction Engineering and Management Education.

What is ICMLS?

The Internet-based Interactive Construction Management Learning System (ICMLS) is a simple tool that students can utilize to gain practical knowledge of construction equipment and construction processes. The key features of the ICMLS are its use of the Internet as its launching medium, and its use of multimedia databases, hypertext, 3-D modeling, and simulation to provide students with an interesting and realistic view of the selected construction processes and construction equipment. ICMLS uses an interactive and adaptive learning environment to improve students' learning in the area of planning of construction processes and equipment. The system is process-oriented and mimics the challenges faced by a construction manager on a real life construction project. It allows students to apply their knowledge of construction materials and methods, estimating, scheduling, resource allocation and utilization, fleet size determination, productivity and cost calculations, and decision-making in relation to construction processes in a holistic, non-fragmented way. Discrete event simulation, 3D modeling, and mentoring by construction professionals bring practical content to the curriculum.

Challenges Addressed by ICMLS

The challenges of education/instruction are manifold and range from issues related to the enhancement of the learning abilities of students to curricula integration and the inclusion in the curricula of hands-on, real-world experiences. The following paragraphs describe some of these challenges as well as some potential solutions to shortcomings:

1. The improvement of the learning abilities of students: Generally, one of the most important findings of research efforts directed at identifying features that enhance student learning, is that students learn more effectively and permanently when they can actively participate in the learning process (Chi et al., 1989). It is thus important to provide possibilities for the students to actively use and explore the new concepts asthey learn them. Computing technologies such as course material on floppy disks or CD-ROM and the Internet can be helpful in complementing the instruction. Further, computerized (simulation) games that can respond to the user's actions allow for a learning experience to take place (AbouRizk and Sawhney, 1994).
2. Knowledge fragmentation: Current curricula do not give students a holistic view of their field of study. A typical undergraduate program in civil engineering includes curricular components such as mathematics and basic sciences, humanities and social sciences, engineering sciences, civil engineering design, and civil engineering core courses (ABET, 1993). The conventional civil engineering curriculum, implemented at most U.S. Universities, focuses on unlinked and independent core and support courses that convey knowledge in fragments. Often students neither retain nor are able to utilize knowledge acquired in previous courses (Bertz and Baker, 1996). To address these shortcomings, there is the need to develop curricular instruments that will require students to pool their knowledge to solve authentic real-world problems. Project-based learning, where learning evolves around real-world projects that span various disciplines, can also be implemented to address these shortcomings.
3. Providing hands-on experience: The incorporation of a practical element in construction engineering and management is of foremost importance. However, as discussed above, several factors complicate or even prevent the use of extensive site training. Computer-based games that simulate the environment of construction, with all its complex and dynamic relationships between different factors, can, however, bridge the gap between the classroom and the construction site by allowing the students to take actions and learn from the responses to these actions.

The research being conducted by the authors addresses these issues and incorporates strategies to meet the challenges identified above.

Internal Components of ICMLS

The internal structure of ICMLS is shown in Figure 3. Internally, ICMLS consists of a number of components that are described in the following sub-sections.

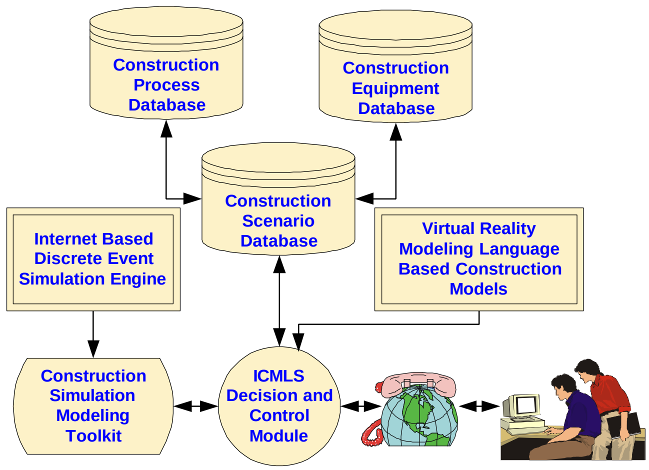

Figure 3. Internal Components of ICMLS.

Construction Equipment Database

This component contains information pertaining to equipment specifications, productivity, operation, use, and manufacturers. The construction equipment has been divided into eleven categories with approximately 70 different pieces of equipment being identified in those categories. Over 200 construction equipment manufacturers have been contacted to collect information. Figure 4 shows the actual screen of ICMLS from where construction equipment information can be accessed by the student.

Figure 4. Construction Equipment Database.

Construction Process Database

This repository contains a number of construction processes from residential, building, heavy engineering, and industrial construction. Visual as well as textual explanations of the processes are supplemented with multimedia elements. The construction process database has been divided into two broad categories that include building construction and heavy construction. Figure 5 shows the construction process database screen in ICMLS.

Figure 5. Construction Process Database.

Construction Scenario Database

The construction scenario database contains a number of real world scenarios that are used in the interactive mode of ICMLS. Figure 6 shows a sample from the construction scenario database. This database is internally linked to the construction process database so as to synchronize the two databases. Students use this component of ICMLS to study the interactions between construction equipment and construction activities in a construction process. The interactivity in this component is further enhanced by the Virtual Reality Modeling Language (VRML)-Based Construction Models and Internet-Based Discrete Event Simulation component of ICMLS.

Figure 6. Construction Scenario Database.

Virtual Reality Modeling Language-Based Construction Models

The Virtual Reality Modeling Language (VRML) is a three-dimensional (3-D) modeling language that can be used for describing 3-D shapes and scenery (also called a virtual world) on the World Wide Web (WWW) (Ames et al., 1996 and Hartman et al., 1996). VRML can be defined as a 3-D analogue to Hypertext Markup Language (Lea et al., 1996).

VRML files are text files that contain information regarding the objects and linkages between the objects in a virtual world. It can be applied to a number of areas including web-based entertainment, 3-D user interfaces to remote web resources, 3-D collaborative environments, and interactive simulations for education, virtual museums, virtual retail spaces, and more. The ability to animate, play sound and video within the virtual world allows users to interact with the virtual world. The control and enhancement of the virtual world with scripts allows the development of dynamic and sensory-rich virtual environments on the Internet (Cosmo Software, 1997). These features of VRML can be beneficially utilized to build teaching aids that supplement classroom instruction. As part of ICMLS, the authors are using VRML to develop these innovative and accessible teaching aids. The authors have developed interactive 3-D simulations that are being used to teach construction processes. Figure 7 and 8 show an Internet based 3-D model of steps involved in residential construction that have been implemented as part of ICMLS. Students can access this 3-D model through a web browser that is equipped with a VRML plug-in.

Figure 7. VRML-based Animation of Residential Construction.

Figure 8. VRML-based Animation of Residential Construction.

Internet-Based Discrete Event Simulation

One of the key components that adds interactivity to ICMLS is discrete-event simulation. Traditionally, simulation has been defined as a tool that can be used to mimic reality and provide responses of a system under consideration to external and internal factors. Simulation has been applied in the design and analysis of construction processes by researchers and by some large construction organizations (Halpin and Riggs, 1992). In addition to industrial uses, simulation can also be used for educational purposes, especially for civil and construction engineering education. This is based on the hypothesis that “simulated environments” can act as excellent catalysts in the learning process. In a recent study, Suda (1993) reported that “simulation can be a powerful trigger to learning of project management principles.”

With the advancement of computing technology and widespread adoption of the Java programming language as a standard for Internet-based computing, application of simulation in education is becoming a reality. Tools are now available to allow development of "simulated environments" that are accessible to students over the Internet. In ICMLS, the authors have utilized Java-based simulation to allow students to interactively manage construction processes in a simulated environment. This development is based on the Silk environment (Healy and Kilgore, 1997 and Healy and Kilgore, 1998).

The Java-based simulation component of ICMLS allows users to model common construction processes. Students select a problem scenario from an existing list displayed by the system. For example, students can select a scenario in which they are required to supervise the moving of 234,000 units of earth for a canal project. Students can then utilize Java-based simulation to study the earthmoving process. They can use the session to: 1) select a fleet of equipment—in this case front end loaders and dump trucks—to accomplish the earthmoving; 2) determine total productivity; 3) determine total project cost; and 4) determine total duration of the earthmoving process. Figure 9 shows a sample screen of ICMLS for the simulation of the earthmoving process.

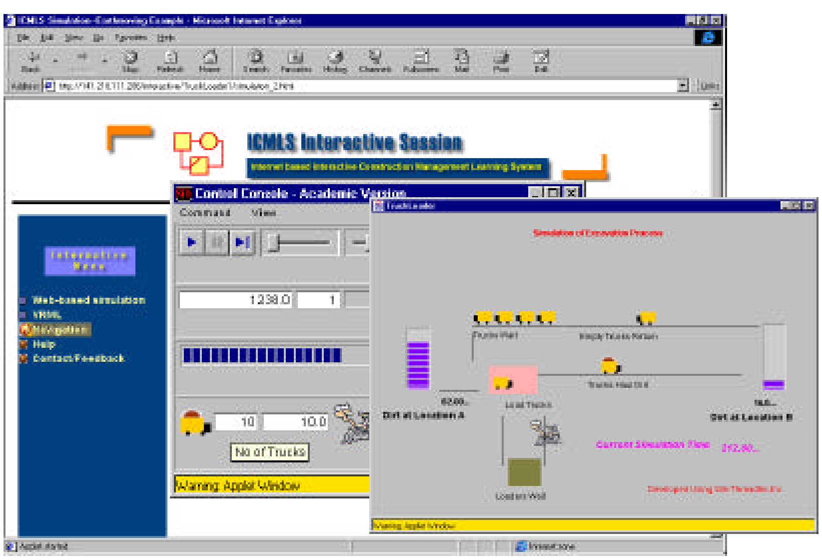

Figure 9. ICMLS Simulation.

Student Interaction with ICMLS

The critical factor in the success of the ICMLS is the clear identification of student interaction with the system. The system is design for utilization in the construction materials and methods, construction estimating, construction scheduling, and construction project management courses. The students utilize the system in consultation with an industry mentor. In addition, the system can be utilized in other civil engineering courses, introductory preengineering courses, and for demonstrations to prospective transfer students. Figure 10 shows the student interaction process.

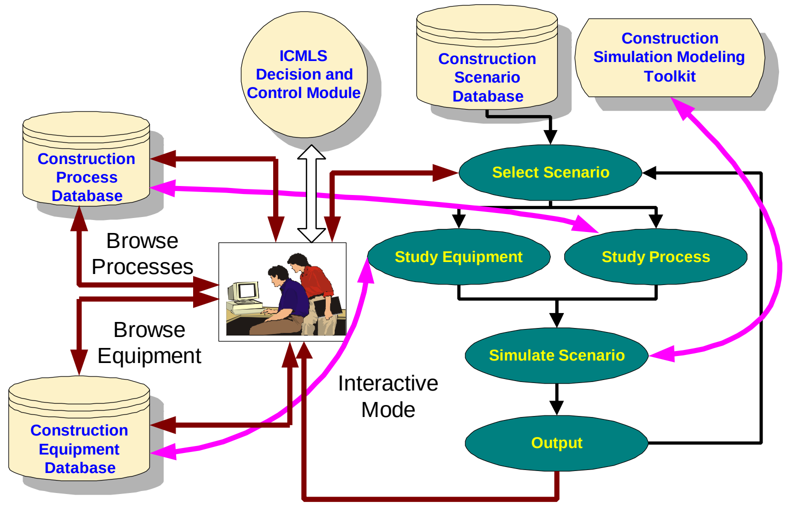

Figure 10. Student Interaction Process.

The students can utilize the Interactive Learning System in the following three modes:

1. In the first mode, a student can browse through the "electronic" database of construction processes. This gives students an idea of construction site operations. For example, a student can select the slurry wall construction process and obtain textual, graphical, and multimedia explanation for the process. In this mode, the student learns about the construction technology, construction method, equipment usage, material usage, and underlying work tasks and their sequencing.
2. In the second mode, a student can select the "electronic" database option and browse through the available construction equipment. For example, the student can select a vibratory pile driver and obtain information about the general description of the equipment and performance factors such as amplitude, eccentric moment, frequency, vibrating weight, and non-vibrating weight of the vibratory pile driver. This database also utilizes text, graphics, and multimedia to provide the students with the information related to equipment characteristics, equipment usage, and technology involved.
3. In the third mode, the system is used as an interactive simulation and gaming environment that presents students with real life construction problem scenarios and allows them to develop a solution, implement the solution, visually study the response of the system to the solution, and then iteratively improve the solution. This allows students to learn subtle and complex interactions between construction costs and time. The actual solution is presented to the system by the development of a simulation model. The students

formulate the following inputs: 1) study the underlying construction method and technology; 2) develop an appropriate simulation model; 3) select equipment and allocate them to the developed simulation model; and 4) select duration for the work tasks identified as part of the simulation model.

Integration of ICMLS into the Curriculum

Successful utilization of ICMLS requires effective strategies to integrate it into the curriculum of the following disciplines:

1. Civil Engineering—both at the lower and upper level of the undergraduate curriculum
2. Construction Engineering and Management—both at the lower and upper level of the undergraduate curriculum
3. Two-year Transfer Degree Programs in civil and construction engineering

Table 1 provides a listing of student experiments and projects that result from the usage of ICMLS. ICMLS is scheduled to be beta-tested in some of the courses listed below, starting in the fall of 2001.

Table
Interactive Learning System-based Student Experiments and Projects

Course Description	Student Activity	Faculty Advisor	Industry Mentor
Introduction to Construction	Use of Interactive Learning System in the demonstration and browse mode	Required	Optional
Introduction to Engineering Design	Demonstration of the Interactive Learning System	Required	Optional
Construction Materials and Methods	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Scheduling	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Estimating and Bidding	Use of Interactive Learning System in the interactive mode	Required	Optional
Construction Project Management	Use of Interactive Learning System in the interactive mode	Required	Required
Senior Design Project	Use of Interactive Learning System in the interactive mode	Required	Required

Conclusions

The authors envision that the successful completion of this project will provide an instructional tool that clearly caters to the needs of civil engineering education in general and construction engineering and management education in particular. A number of benefits arise from the development of ICMLS. These include graduates that are better prepared to manage the complex dynamics, pressures, and demands of construction sites. The availability of "job-ready" graduates is becoming crucial in trying to meet the demands of the construction industry today. The enhanced practitioner involvement and construction industry input, increases practical content and can provide students with increased familiarity with the construction industry. The improved recruitment, retention, and program completion for the construction engineering and management program are of benefit to the university. As can be seen, ultimately all parties involved, universities, students, and the construction industry, can benefit from ICMLS. The university will generate more importance and interest as an educational institution through improved recruitment and better graduates, while the students will benefit from a better education that will ultimately also benefit the construction industry.

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Correlates of Student Performance in Environmental Control Systems Courses at an Undergraduate Level

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The purpose of this study was to examine the correlates of student performance in Environmental Control Systems courses offered by the Department of Construction Science at a large South Central University. It is indicated by a number of studies that student performance is affected the class size. Some other studies suggest that student characteristics, teaching effectiveness, student satisfaction with a course, and overall academic ability of a student are also correlated with student performance in a course. The study population consisted of the students who attended Environmental Control Systems courses in Summer Semesters of 1997 and 1998, Fall Semester of 1997, and Spring Semester of 1998. Relevant data related to these factors were collected using a survey instrument. Sample size of the study was 223 students. The data was analyzed using correlation and multiple regression analyses. The findings generated from the analyses of the data indicated that student performance in Environmental Control Systems courses, offered by the Department of Construction Science at a large South Central University, are not correlated with class size. Personal characteristic variables such as gender and academic classification are inversely related to student performance. Overall academic ability of a student is positively correlated with student performance.

Key Words: Undergraduate Education, Construction Science, Environmental Control Systems, Class Size, Gender Difference

Statement of the Problem

The question of class size is probably one of the first problems of education approached by research. Studies conducted at both school and college levels indicate that students learn more where there are fewer of them in the class (Pate-Bain, et al., 1992; Toby, 1993). Glass et al. (1982) report that the relationship between class and student performance is very strong. However, there are some other studies that contradict these findings (Hanushek, 1998; Siegfried and Kennedy, 1995).

Student population in the Department of Construction Science (COSC) at a large South Central University is over 600 and is expected to be higher in the coming years. The Strategic Plan of the Department does not envisage any market reason to put a cap on student enrollment (COSC, 1996). The construction industry requires about 7,000 Construction Science graduates every year, whereas the total output of such graduates from all university programs in the United States is about 2,000 per year (COSC, 1996). As a result of this increasing number of students, class sizes are gradually becoming bigger.

The primary mission of the Department as stated in the Strategic Plan (COSC, 1996) is to "prepare students for successful careers in construction and construction-related industries" (p.4). The Plan also emphasizes that "in order to accomplish this mission, the Department must create an environment conducive to academic excellence" (p.4). Effective classroom teaching is one of the factors to achieve this goal. This effectiveness is likely to be affected, among other factors, by the size of classes.

Effective classroom teaching leads to better student performance (McKeachie, 1980). Apart from classroom sizes, factors such as personal characteristics, student attitude, interest, motivation, and satisfaction are also assumed to have an effect on student performance. In view of the evidence provided by the results of the studies conducted in other disciplines, it is hypothesized that student performance in Construction Science students is affected, apart from classroom size, by the following factors related to the students:

1. Personal characteristics (academic classification and sex),
2. Interest and enthusiasm for class work,
3. Participation in discussions,
4. General feelings towards the course,
5. Perceived understanding of the materials taught,
6. Overall course satisfaction, and
7. Academic ability.

Methodology

Study Population

The study population consists of the students who registered for and actually attended Environmental Control Systems I and II courses offered by the Department of Construction Science, Texas A& M University, in the following semesters:

1. Summer I and II, 1997
2. Fall, 1997
3. Spring, 1998
4. Summer I and II, 1998.

Number of students in the classes ranged from a minimum of 25 to maximum of 80. The sample size was 223. The entities under study are the students who attended these classes. The unit of analysis is the student.

Data Collection Procedure

A survey instrument was prepared to collect the data related to personal characteristics of the student, feelings of the student toward the course, teaching effectiveness, and the student's current grade point average (*GPA*). The instrument was administered in the classrooms at the end of the semesters. The sample size of the study was 223.

Variables and their Operationalization

Student Performance (GRADE)

Student performance is the actual academic performance of the student in the class. It was measured by the percentage of total numerical grade obtained by the student in the course.

Class Size (CLSIZE)

It is the size of the class in terms of the number of students. It was measured by the number of students who actually attended the class.

Semester (SEMESTER)

Semester is an academic term during which the student attended the course. It was categorized into two groups: 1) regular semesters consisting of fall and spring semesters and 2) summer semesters or terms. The regular semesters have duration of 15 weeks each, while the summer terms have a shorter duration of 5 weeks each. This variable was included to measure the effect of semesters on student performance. It is a dummy variable, which took on a value of 1 for a regular semester and 0 for a summer semester.

Sex (SEX)

Sex is the gender identification of a student. It is a dummy variable, which took on a value of 1 for a female and 0 for a male.

Level (LEVEL)

Level indicates the academic classification of a student. As per University regulations, only students classified as juniors and seniors are eligible for enrollment in Environmental Control Systems courses. A student classified as a senior was coded 1 and a student classified as a junior was coded 0.

Teaching Effectiveness

The following variables were used to measure teaching effectiveness:

1. *Interest and Enthusiasm for Class Work (INSPIRE)*: It is the reported level of interest and enthusiasm of the student for doing the assigned class work. It was operationalized using a single-item measure on a five-point Leikert-scale.
2. *Feelings toward the Course (FEELING)*: It is the reported level of perceived self-directiveness achieved by the student as a result of taking the course. It was operationalized using a single-item measure on a five-point Leikert-scale.
3. *Perceived Level of Understanding of the Materials Taught (UNDSTAND)*: It is the reported level of understanding of the course materials by the student. It was operationalized using a single-item measure on a five-point Leikert-scale.

4. *Overall Course Satisfaction (SATISFY)*: It is the reported level of satisfaction of the student with the course. It was operationalized using a single-item measure on a five-point Leikert-scale.

Grade Point Average (GPA): It is the reported overall grade point average of the student. It ranges from 0 to 4.

Analysis and Interpretation

Results

A correlation analysis was used to measure the strength of relationship between class size (*CLSIZE*) and student performance (*GRADE*). A correlation of 0 between two variables indicates that each variable has no linear predictive ability for each other. A correlation coefficient of close to |1| means that the two variables have a perfectly linear connection. The product-moment correlation obtained from the test was not found to be statistically significant at the 0.10 level ($Rho = 0.06$, $p>|Rho| = 0.35$). The results indicated that class size did not have any statistically significant effect on student performance in Environmental Control Systems courses under study.

A multiple regression analysis was performed in order to ascertain whether the student's personal characteristics, overall course satisfaction, overall academic ability, and teaching effectiveness had an effect on student performance (*GRADE*). The following model was used for the analysis:

$$GRADE = ?_0 + ?_1 CLSIZE + ?_2 SEMESTER + ?_3 SEX + ?_4 LEVEL + ?_5 INSPIRE + ?_6 FEELING + ?_7 CONTRIB + ?_8 UNDSTAND + ?_9 SATISFY + ?_{10} GPA + e \qquad (1)$$

where $?_0$ = intercept,
$?_1$, $?_2$, etc = regression coefficients, and
e = error term.

Results of the analysis are shown in Table 1.

Based on the results of the analysis, the regression equation can be written as follows:

$$GRADE = 62.48 + 0.05*CLSIZE + 0.95*SEMESTER - 2.04*SEX - 2.3*LEVEL + 0.64*INSPIRE + 0.24*FEELING - 0.93*CONTRIB + 0.21*UNDSTAND + 0.5*SATISFY + 5.36*GPA \qquad (2)$$

The *F*-value of the model used for multiple regression analysis was found to be statistically significant at the 0.0001 level. However, the predictive efficacy of the model was not found to be very high with an R^2 of 0.37 and an adjusted R^2 of 0.34. But such values are considered to be satisfactory related to empirical studies in social sciences (Freund and Wilson, 1991).

Table 1

Multiple Regression Analysis of GRADE Using Class Size, Personal Characteristics, Overall Course Satisfaction, Overall Academic Ability, and Teaching Effectiveness.

Variable	**Intercept**	**Regression Coefficient**	***T***	***p*>|*T*|**	**Critical Value of |*T*|**
Intercept	62.48	---	12.89	0.0001	1.65
CLSIZE	---	0.05	1.52	0.13	
SEMESTER	---	0.95	0.72	0.43	
SEX	---	-2.04	-1.71	0.09	
LEVEL	---	-2.30	-1.79	0.07	
INSPIRE	---	0.64	0.71	0.48	
FEELING	---	0.24	0.57	0.57	
CONTRIB	---	-0.93	-1.51	0.13	
UNDSTAND	---	0.21	0.27	0.79	
SATISFY	---	0.50	0.52	0.60	
GPA	---	5.36	9.34	0.0001	
Model F (1,222) = 12.62	$p>F = 0.0001$	Critical Value of F = 2.73	Model $R^2 = 0.37$	Adjusted Model $R^2 = 0.34$	

Class size (*CLSIZE*) was not found to have any statistically significant effect on student performance in Environmental Control Systems courses offered by the Department of Construction Science at a large South Central University. It confirmed the results obtained earlier using correlation analysis.

The results indicated that there was a gender difference in student performance. Sex was negatively related to student performance at 0.10 level of significance. The male students obtained higher grades than the female students did.

Student classification (*LEVEL*) was also negatively related to student performance at the 0.10 level of significance. It indicated that students with junior classification performed better than did the seniors.

It was intriguing that none of the teaching effectiveness variables appeared to have any statistically significant effect on student performance. Overall satisfaction with the course was also not found to be related to student performance.

The most important correlate of student performance was found to be the student's overall Grade Point Average (*GPA*). It was statistically significant at the 0.0001 level.

Discussion

Gender difference (*SEX*) was found to be a statistically significant predictor of student performance at the 0.10 level. Coleman and Gotch (1998) report a similar finding with respect to spatial perception skills of chemistry students. However, the results should be viewed with caution. It requires further investigation.

Student classification (*LEVEL*) is another variable that was found to have a statistically significant effect on student performance at the 0.10 level. It is possibly due to the fact that some mathematical skills are required for the Environmental Control Systems courses. In case of seniors, these skills are not likely to remain fresh in mind because they would have taken the mathematics-related courses in their freshmen and sophomore years.

The most statistically significant predictor of student performance was found to be the academic ability of student, measured by the student's overall grade point average (*GPA*). Studies on education indicate that student performance in any particular course is positively correlated with overall grade point average. Findings by Seymour et al. (1994) reveal that most significant factor in predicting success in a business microcomputer course is the overall grade point average of a student. Similar findings have been reported by Rose et al. (1996) in a study of student performance in an introductory psychology course. It was, therefore, likely to find a positive relationship between student performance in Environmental Control System courses and overall grade point average.

The study indicated that student performance in Environmental Control Systems courses, offered by the Department of Construction Science at a large South Central University, is not correlated with the size of a class (*CLSIZE*). A study conducted by Siegfried and Kennedy (1995) reported similar findings related to economics courses and class size. A recent study by Hanushek (1998) states, "the enormous amount of research devoted to studying class size has failed to make a very convincing case that reducing class size is likely to improve student performance" (p.1). However, this finding should not be generalized to other Construction Science courses. A logical extension of this study would be to conduct studies on the effect of class size on student performance in other courses.

The study was based on the same teaching methods for all classes. They included lectures with the help of audio-visual aids, presentation of the course materials and relevant literature using personal web page, individual design of systems, and homework problems. Jamison (1982) indicates that a reduction of class size may not be necessary to alleviate student achievement if an effective and relevant teaching method is adopted to teach a course. For future studies, it may be worthwhile to use teaching method as a predictor of student performance in construction science courses.

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Fire Resistance and Performance of Alternative Concrete Wall Systems

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Insulating Concrete Forms (ICFs), also known as stay-in-place concrete forms, and Autoclaved Aerated Concrete (AAC), have become more recognized as alternative concrete wall systems over the past few years. Both residential and commercial construction designs can benefit from these systems. ICFs and AAC systems provide a high R-factor, reduce thermal conductivity, and provide insulated thermal mass to a structure. The fire resistance of ICFs and AAC barrier walls is another benefit of these alternative concrete wall types. A 200- mm thick AAC wall can withstand 4 hours of direct exposure to fire without experiencing any structural damage, and 100-mm units are fire resistance rated for 2 hours. Also, non-loadbearing AAC products can resist fire for approximately 1-hour per 25-mm of thickness. These partitions minimize the risk of fire and make containment easier. This makes AAC suitable for use in shaft walls, area separation walls, and other critical fire-resistance applications. As advantages for ICFs and AAC products become better understood, demand will increase, production processes will improve, and material costs will go down. The cost and benefits of ICFs and AAC products should be analyzed prior to design because of the advantages of these new construction materials.

Key Words: Insulated Concrete Forms, Autoclaved Aerated Concrete, Fire Resistance

Introduction

Statistics from the American Insurance Association show that the largest source of disaster damage to homes is fire. Wind causes the second and earthquakes cause the third most damage to homes. Historically, damage from fires has been many times that from either wind or earthquakes (Vanderwerf, 1995).

Of all construction materials, concrete is one of the most resistant to heat and fire. Experience shows that concrete structures are more likely to remain standing through fire than are structures of other materials. Unlike wood, concrete does not burn and unlike steel, it does not yield or bend. Concrete does not break down until it is exposed to approximately 1000 degrees C, which is far more than is present in a typical house fire (Harmathy, 1986).

Insurance statistics confirm that concrete walls have a higher fire survival rate than wood frame walls. Exterior walls have the ability to remain standing through a fire, rather than collapsing. In most areas of the country, occupants get a reduction in the fire portion of their homeowners insurance if the house has concrete walls, amounting to about $40-$50 per year for a standard 2000 square foot house (Nielsen, 1998).

Background

There are a variety of materials used in the manufacturing and installation of Insulating Concrete Forms (ICFs). These systems combine polystyrene, reinforcing steel, and concrete to provide the insulation and structure in a building system. The types of polystyrene used include expanded polystyrene foam, extruded polystyrene foam, and recycled foam. While polystyrene has not traditionally been used in structural applications, polystyrene forms function as the formwork for the concrete placed within the form's core (Munsell, 1995). In addition to these primary components, polyurethane foam sealants are also important ingredients used in the assemblage of ICF systems. Polyurethane foam sealants keep the forms together until the concrete is placed. As the concrete cures, the ICF systems interlock with the unique shape of the placed concrete. The major difference in ICF systems is in the interior cavity that determines the shape of the concrete. ICF systems are classified according to two characteristics. One is the form of the ICF unit, and the other is the form of the concrete in the finished wall. The units exist in a variety of forms, which are grouped into panel, plank, and block. The differences are their size, method of interconnection, and point of assembly (Nielsen, 1998). Figure 1 illustrates the distinctive features of each.

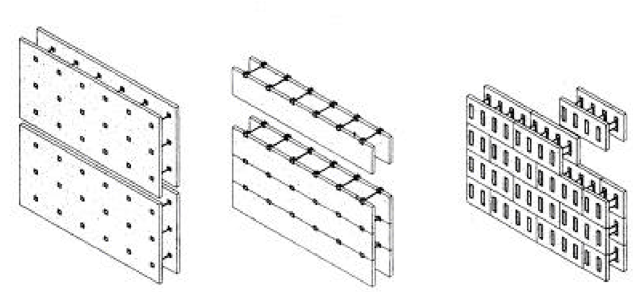

Figure 1. Panel, Plank, and Block systems

Autoclaved Aerated Concrete, AAC, is manufactured by various processes. AAC is comprised of silica sand, cement, lime, gypsum, water, and an expansion agent (usually aluminum powder), which forms a porous microstructure in the concrete (Barnett and Nelson, 1997). The major ingredients go into a mold, filling it approximately one-third, and the expansion agent is then mixed in. Once the "cake" has risen, it is placed in an autoclave to complete drying. This process creates a product that is 70-80 percent air by volume, and with a design weight ranging from 500 kg/m3 to 750 kg/m3. AAC systems are significantly lighter than conventional concrete systems, and therefore require fewer raw materials are needed to produce an equal amount of building volume.

Design flexibility and compatibility with other building systems are requirements of any new building system. AAC standard panels can be combined with light gauge metal, fiberglass, wood, and glass. Many creative designs can be achieved by combining these materials without any loss of functionality. Wall treatments can range from smooth or textured paintable surfaces to wallpapers and tiles.

Fire Testing

Different wall systems withstand disasters in different ways. The most common way to measure resistance to fire is with the fire wall test, described in ASTM E119, "Fire Tests of Building Construction And Materials." These methods are applicable to assemblies of masonry units; composite assemblies of structural materials of buildings; including bearing or other walls and partitions; columns, girders, beams, and composite slabs; and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units that constitute permanent integral parts of a finished building. Test results are expressed in hourly ratings. This test is performed under laboratory conditions, whereby a gas fire burns at a controlled temperature on one side of a wall until the cool side overheats past certain temperature limits. If the wall maintains its structural integrity, the wall gets a fire wall rating equal to the length of time it was subjected to the flames. However, if the wall fails structurally, i.e. collapse, during the heating, it gets a fire resistance rating instead, indicating the wall might prevent fire from spreading for the length of time it stayed below the temperature limits, but may change composition or deform.

Standard test methods for fire tests of building construction and materials measure the fire resistive properties of the assemblage materials when subjected to a standard fire exposure, and provides for a relative measure of the ability of the assemblage to prevent the spread of fire. After the assemblage is subjected to the standard fire exposure, it is subjected to a standard fire hose stream of water, intended to simulate the effects of fire fighting efforts. The assemblage must successfully pass both portions of the test in order to achieve a certain fire rating.

A test furnace is used to determine the fire resistance ratings of construction assemblies, and a standard time-temperature curve is used to control the fire exposure of materials under fire testing. Building constructions are exposed to heat in a test furnace under a 44 kg/m2 fire load. The quantity of combustible material per square foot of floor area is commonly referred to as the "fire load." A 44 kg/m2 fire load corresponds to a 7-hour fire temperature duration. Cotton waste is placed on the cool side of the material. Time is measured until gases seep through, cotton ignites, and the temperature reaches 120 degrees C above its original temperature, or failure under a water-stream test occurs.

Fire Rating

The fire resistance of concrete masonry units is based on the "equivalent thickness" it would have if it were solid. A 200-mm thick, standard, hollow concrete masonry unit, CMU, is about 55% solid if one subtracts the area of the voids from the total area. The fire resistance of the unit is based its thickness and aggregate type used to produce the CMU. Graded by the ability of the aggregate to resist high temperatures, Grade A concrete is made with calcareous gravel, trap rock, blast furnace slag and other heat resistant stones for coarse aggregate. The course aggregate in Grade B concrete is quartz, granite, or sandstone, having more volatile matter and combustible material than Grade A aggregate.

Most 200-mm CMU block walls are fire wall rated at two hours or more. Although they rarely fail structurally, i.e. collapse, after that time, they overheat on the cool side. As a frame of reference, a 50-mm x 100-mm wood frame wall with sheetrock on one side and wood siding on the other is generally rated at one hour for fire resistance, after that the wall fails.

Among its numerous benefits, AAC's fire resistance is perhaps its most valuable quality. In load-bearing applications, 150-mm block walls offer a 4-hour fire rating, while 200-mm block offers a 6-hour fire rating, and a 100-mm non-loadbearing interior wall panel achieves a 3-hour fire rating. AAC blocks and panels also meet the most stringent building code requirements. Testing was performed on two AAC walls, one constructed of 100-mm wall panels and the other of 200-mm block. The walls were approximately 300-cm wide and 330-cm tall. The 100-mm panels performed satisfactorily for a Fire Resistance Rating of 3-hours and 10-minutes, while the 200-mm block wall performed satisfactorily for a Fire Resistance Rating of 6-hours and 6-minutes.

Fire test wall temperatures for the 200-mm wall are illustrated in Figure 2. The furnace temperature and the interior wall surface temperature are nearly the same, however the ability of heat to transfer to the opposite side of the wall is minimized from approximately 980 degrees C to 38 degrees C after one hour. Even after 6-hours of elevated temperatures at the interior wall surface, the temperature on the opposite side never reaches 120 degrees C.

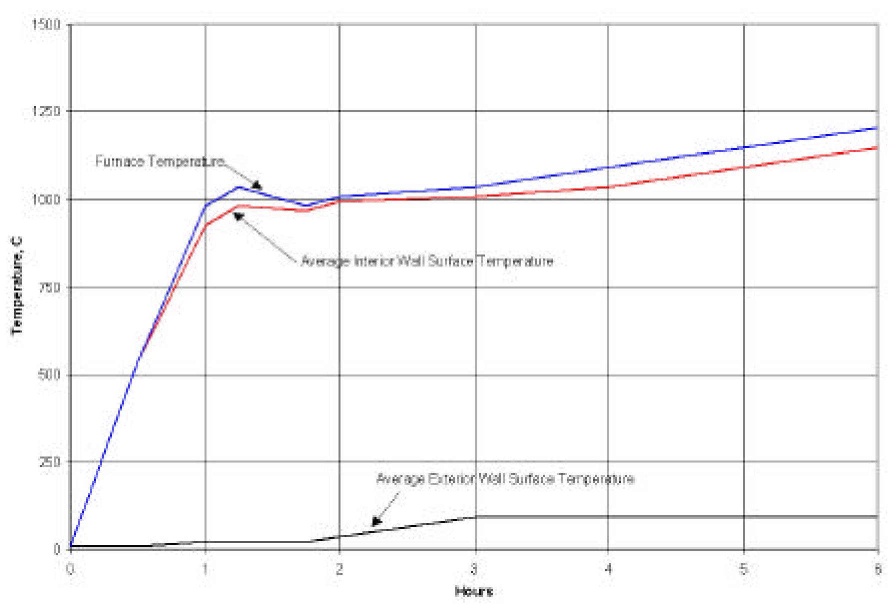

Figure 2. Fire Test Wall Temperatures for 200 mm AAC Panels

When a fire occurs, the low thermal conductivity of AAC also reduces the rise in temperature of the embedded steel reinforcement. The combination of a low thermal conductivity and a low coefficient of thermal expansion are beneficial when AAC is exposed to fire. Water in crystalline form within the material acts as a heat sink. The internal structure of AAC allows steam to escape without causing surface spalling (Wittmann, 1983). The temperature is lower in

AAC than in dense concrete, not only on the non-exposed side but also on the side that is exposed to the fire. The temperature on the exposed side is important because it affects protection of the reinforcing steel in AAC panels.

The practical experience obtained with AAC in fires has shown that the structural parts of AAC are able to continue to serve with minor repairs, which considerably reduce the cost of damage caused by fire. AAC can also be used as a cladding to protect other materials such as steel structures or to increase the fire rating of concrete walls. AAC is non-combustible and due to its low thermal conductivity, heat migration takes place at a slow rate giving AAC excellent fire resistance. Table 1 provides fire ratings for AAC panels and AAC block (Barnett and Nelson, 1997).

Table 1

Fire Ratings for AAC

AAC Block Size		
Height x Length	**Available Width**	**Fire Rating**
20 cm x 60 cm	100 mm	4 hours
20 cm x 60 cm	150 mm	6 hours
20 cm x 60 cm	200 mm	8 hours
20 cm x 60 cm	250 mm	8 hours
20 cm x 60 cm	300 mm	8 hours
60 cm x 100 cm	100 mm	4 hours
60 cm x 100 cm	150 mm	6 hours
60 cm x 100 cm	200 mm	8 hours
60 cm x 100 cm	250 mm	8 hours
60 cm x 100 cm	300 mm	8 hours

When compared to concrete masonry unit construction, all core spaces of a 200 mm CMU wall must be filled to achieve a 4-hour fire rating. Material such as loose dry expanded slag, burned clay or shale can be used to fill the cells. When compared to metal stud construction, four layers of gypsum wallboard are required to achieve a 4-hour fire rating.

Superior ratings are possible because unlike conventional block, AAC is an aerated product. Within each block and panel, air is trapped in tiny cells, so the flame is unable to spread from one cell to another. Also, the ease of construction helps to ensure a monolithic, highly fire-resistant wall. AAC provides benefits to multi-family housing units, hotels, self-storage facilities and malls, which have many rooms in a building. Storage facilities must be compartmentalized, thereby meeting firewall requirements set by Florida building departments.

Insulating Concrete Forms

Concrete walls have proven resistant to allowing fire to pass from one side of the wall to the other. This is especially of interest in areas with brush fires that could spread indoors. “Fire wall” tests of ICF walls prove that walls can be subjected to continuous gas flames and temperatures of up to 1100 degrees C for as long as 4-hours. None of the ICF walls ever failed structurally, i.e. collapsed. ICFs tested were of the “flat” or “uninterrupted grid” type, having no significant breaks in the concrete layer. Part of the test also measures how well the wall slows the passage of heat and fire from the side with the flame to the other cool side. During these tests, the ICF walls did not allow flames to pass directly through. They also did not allow enough heat through to start a fire on the cool side for 2- to 4- hours. In contrast, wood frame walls typically allow both flame and fire-starting heat through in an hour or less and typically collapse.

Both AAC and ICFs require covering the inside face of exterior walls with plaster or stucco, which can also aid as a fire-resistant coating. Concrete exterior walls probably won't make a fire fighter's job any easier since most fires start within the house however, knowing it can contain the fire and be structurally sound may be of great benefit.

Toxicity

Any organic material, be it wood or plastic, gives off emissions when it is subjected to intense heat or flame. The Southwest Research Institute reviewed the numerous existing studies of fire emissions and concluded that the emissions from polystyrene foams are "no more toxic" than wood (Janssens and Orvis, 1999). Unlike ICFs, AAC is not made of organic materials and has no toxicity associated with burning of the product.

Toxicity test results compare the total sum of toxicity factors (carbon monoxide, carbon dioxide, and poisonous chemicals) found in the smoke of burning materials as compared to the smoke from burning red oak. During a fire, no toxic gases or vapors are ever emitted from AAC. Since sand, water, and lime make up a large part of AAC's composition, AAC is also environmentally friendly. Table 2 compares ICFs to other building materials.

Table 2

Sum of Toxicity Factors for ICFs, AAC, and Other Construction Materials

Material	Sum of Toxicity Factors
Red Oak (the standard)	100
AAC	0
ICF	20
White Pine	50
PVC (poly vinyl chloride)	360
ABS (plastic pipe)	280
Urethane (rigid)	290

Note: US Testing Co Report No 03298

At low concentrations, the eyes and skin can be irritated. At high concentrations, death is probable. The inhalation of toxic gases, usually carbon monoxide, and smoke is a major cause of death in fires.

Flame Spread

Flame spread is the tendency of fire to spread along a surface, usually regarding finish materials. The rate of fire spread in a building is greatly influenced by the surface characteristics of building materials. A vertical flame spread helped by convection is usually greater than horizontal flame spread on walls and floor. Nevertheless, a tunnel is used to test flame spread over the surface of building materials. Figure 3 and Figure 4 illustrate vertical flame spread and "Steiner Tunnel" horizontal flame spread tests respectively.

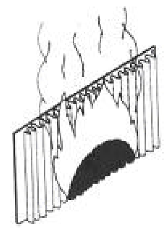

Figure 3. Vertical Flame Spread Helped by Convection

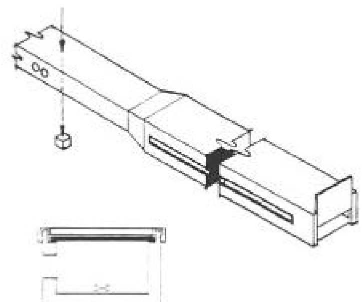

Figure 4. Steiner Tunnel Test

Cellular or foamed plastics are generally not permitted by code to be used in load bearing applications. There are extensive code requirements to be met for the safe use of these materials. However, the foams in ICFs are manufactured with flame retardant additives. If you hold a match to the material, it will melt away. Of course, in a house fire the foam may be subjected to constant flame from other materials burning nearby (wooden floors and fabrics). The "Steiner Tunnel Test," described in ASTM E84, "Surface Burning Characteristics of Building Materials," or more commonly referred to as Underwriters Laboratory Tunnel Test, determines the flame spread, fuel contributed, and smoke developed of building materials when compared to Asbestos Cement Board (rated as 0, 0, 0), and uncoated Red Oak (rated as 100, 100, 100). Test samples used are 50 cm wide by 7.5 m long. This test also measures how much a material carries fire from an outside source. In the test, a tunnel is lined with the test material, a fire is run at one end, then the distance the flame spreads is then measured. The flames travel about one-fifth as far down a tunnel lined with ICF foams as they spread down a tunnel lined with wood. The distance flame spreads from the igniting flame during a 10-minute fire exposure under controlled test conditions in a test tunnel is pertinent to flame spread. The results of the test are compared to the flame spread on asbestos-cement board and the flame spread on an untreated red oak floor under similar fire exposure. Table 3 indicates the results of tests.

Smoke Development

Smoke limits visibility and harms breathing. The inhalation of toxic gases, usually carbon monoxide, and smoke is a major cause of death in fires. The smoke release rate is smoke

Table 3

Flame Spread of ICFs, AAC, and Other Construction Materials.

Material	Flame Spread
Asbestos-cement board	0
AAC	0
ICF	3m
Untreated red oak flooring	30 m
Maximum accepted by Building Codes	23 m

Note: US Testing Co Report No 03298

produced by burning the test material. It normally applies to finish materials and furnishings; however, the smoke development from ICFs is rise for concern.

Because ICFs are flammable, quantifying the amount of smoke that results in the burning of the form is important. Building codes set standards for smoke development, and ICF manufacturers have met such requirements. The amount of smoke developed during a standardized burning test in a test tunnel are compared to the smoke developed by burning an asbestos-cement board and the smoke developed by burning a red oak floor under similar fire conditions during a 10-minute period. The amount of smoke development is determined by the light absorption percentage of the smoke using a photoelectric circuit operating across the test furnace flue pipe.

Smoke development from Asbestos cement board is zero because the product is fireproof. However, because asbestos is carcinogenic, other considerations for fire resistance must be met. Insulating Concrete Forms have more smoke development than untreated red oak flooring, but still meet the maximum accepted by building codes, as Table 5 makes this comparison.

Table 5

Smoke Development of ICFs, AAC, and Other Construction Materials

Material	Smoke Development
Asbestos-cement board	0
Untreated red oak flooring	100
AAC	0
ICF	Less than 300
Maximum accepted by Building Codes	450

Note: US Testing Co Report No 03298

Conclusions

- Alternative concrete wall systems such as AAC load bearing walls, AAC non-load bearing walls, and IFC load bearing walls offer improved fire resistance as compared to conventional CMUs and wood frame wall construction.

- 200 mm thick AAC units can withstand direct exposure to fire without experiencing any structural damage for over 6 hours, and 100 mm AAC units are fire resistance rated for over 3 hours.

- Also, non-load bearing AAC products are fire rated for approximately 1 hour per 25 mm of thickness.

- Other important factors to consider when selecting materials include toxicity, smoke development, and flame spread. Both AAC and ICF wall types meet these standards established by the National Fire Protection Association, NFPA.

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Developing Benchmarks for Construction Information Flows

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Recent research suggests that the efficient movement of information between project stakeholders is a critical factor in the success or failure of a construction project. Unfortunately, little effort has been made to understand which information flows are important, or to understand how quickly critical information components can be processed. This paper identifies key construction information components, and outlines a means for developing benchmarks for specific information flows. Benchmarking is a well-known system that uses a given standard to improve the efficiency of individual processes. Using historical data from recent construction projects, information process cycles were analyzed to develop a benchmark for a single information flow: the construction submittal process. This benchmark can be used to measure and improve the processing speed of a construction submittal package. More importantly, when benchmarking is applied to other critical information flows, this system can be used to improve the efficiency of the construction communication process.

Key Words: Information Systems, Project Management, Information Benchmarking, Information Flow, Information Speed

Background

The design and construction of a building project is an information driven business. From the birth of a project to its final completion, ideas are developed, decisions are made, and thousands of pieces of information are transferred between people and firms. These information flows include the design and technical data, the contractual details, and the management facts needed to administer and control the project. Given the advent of high speed internet communications, these information flows are being transmitted, received, and acted upon in increasingly compressed time frames.

More importantly, research has shown that the smooth and efficient movement of that information is one of the keys to managing successful construction projects. In a recent study by the Construction Industry Institute, the authors note that, "Throughout the entire life cycle of a project, there exists a need to identify, compile, and accurately disseminate relevant information among team members. Project performance can be enhanced through the implementation of effective project communications, and projects can fail if hindered by poor communications" (CII, 1997).

Unfortunately, the process of moving construction information is becoming increasingly complex. In many cases, onerous contracts and growing litigation have made project teams adversaries instead of allies (Pietroforte 1993). Decreasing product life cycles and growing capital costs are compressing the time needed to design and construct complicated facilities. At the same time, increasing technological complexity is shifting project control away from the design and contract team toward specialized subcontractors (Kubal 1995). These market forces have fostered an explosion of information, inundating project managers in a sea of letters, memos, logs, and other project communications (Deloite and Touche, 1996).

While most experts agree that information flow is critical to a construction project's success, little effort has been made to develop benchmarks that describe the time it takes to process individual information components. This paper provides an overview of the benchmarking process, identifies key construction information components, and outlines a means for analyzing specific information flows. Using historical data from recent construction projects, information process cycles were analyzed to develop benchmarks for a single information flow: the construction submittal process. While submittal review and approval is only one function of the construction management process, the methodology outlined here can be used to measure other critical information components. In turn, this information can be used to monitor and improve the efficiency of the vital construction communication process.

Benchmarking Basics

Benchmarking is a method that has been used widely by manufacturing companies to improve their business processes, reduce waste, and increase customer satisfaction. The Xerox organization introduced the concept of benchmarking to American corporations in 1979, and other major companies quickly embraced their techniques. In response to increased competition by the foreign firms, Xerox began collecting data on the best practices of other organizations. When firms apply these practices to their own organizations, they reduce production costs, minimize inventory, and dramatically increase their market share (Patterson, 1996).

The essence of benchmarking is measuring individual processes against a given standard or benchmark. Benchmarks can be developed in several ways: First, internal benchmarks can be developed within organizations, and these measurements can be used to set production standards for individual processes. A second approach is competitive benchmarking, where similar firms share production data on their products or processes. A third approach is collaborative benchmarking, which involves an exchange of information from a consortium of companies.

Benchmarking theory can also be applied to project communications, by measuring the process cycle times of specific information flows. Cycle time can be defined as, "the time required to complete one cycle of an operation" (Womack & Jones, 1996). Cycle time analysis has its roots in modern manufacturing, and the work of Frederick W. Taylor. As early as 1895, Taylor advocated the precise measurement of typical manufacturing processes as a way of determining how much work a person could accomplish in a "full days work" (Taylor, 1895). Taylor's work was revolutionary in that he applied scientific methods to business practice through the precise monitoring of specific events, and Henry Ford later refined the practice during the development of the modern assembly line. Today, cycle time measurement is one of the cornerstones of modern manufacturing practice. This data is used widely in business process reengineering

(BPR) and in manufacturing quality control as a measure of business performance (Davis, 1995; Hammer, 1993; Naisbett, 1985; Prasad, 1996; Ohno, 1988).

Cycle time thinking can be also be applied to the measurement of the construction communication process. Once critical information components are identified, cycle times can be used to develop averages or benchmarks for specific information flows. In turn, these benchmarks can be used as a basis for measuring and improving the speed of critical project communications.

Construction Information Components

In its broadest sense, information can be defined as the data and messages that are transmitted between people within a communications network. In his book on organizational structure and information technology, Harrington (1991) contends that information can be considered in two ways. The classic "resource" view says that information can be created, transmitted, stored, and received by an organization much like the production components on an assembly line. Like the work on an assembly line, many of these information flows can be measured in terms of time, quantity, and quality.

Much of the information generated during the course of a construction project fits this resource or production based view. For example, once a project moves beyond the design stage, its working drawings, specifications, and budgets remain relatively static for the duration of the project. As such, this information can be used effectively by multiple parties.

Unlike the resource view, the "perception" driven view sees information as more than processed data. Here, information is dynamic and constantly evolving, and is often interpreted differently by different parties. For instance, a change request initiated by the design team may be seen by the owner in terms of cost, while the contractor looks at the same request as a schedule impact. According to Harrington (1991) these varying "perceptions" impact the way people handle information, and these differing perceptions can cause confusion and uncertainty. These informal information flows are much more difficult to measure.

While the resource and perception views provide a theoretical framework for understanding information flows, construction information can be classified more narrowly in terms of three categories: technical information, commercial information, and management and control information (BT, 1995).

- Technical Information: This category includes designs and technical evaluations that describe a building. Examples might include drawings, specifications, details, and design clarifications.

- Commercial Information: includes the contract details, which establish responsibilities for the delivery of a project. Includes delivery schedules, costs, prices, payment schedules, terms and conditions.

- Management and Control Information: includes the project management information needed to control the project and generate reports. This category includes information which is developed by the project manager including: Meeting Minutes, Submittals and Shop Drawings, Change Order Status Log, As-Built Drawings, Requests for Information, Contract Status Log, Safety Information, Daily Logs and Project Schedules.

Because the Management and Control information is used to regulate the construction process, the timely flow of this information often has a direct impact on the duration of a project. For instance, many long lead items require the review and approval of the design team, the construction team, and the owner before they can be fabricated. If the flow of approval information between the parties is interrupted or delayed, then the item's delivery will be postponed accordingly. Individual material delays often result in larger project delays. Requests for information, change order approvals, dispute resolutions, submittal and shop drawing approvals review, payment applications are examples of information flows that can impact the schedule performance of a project.

In addition to timely information, project participants also have specific information needs. Tenah (1986) identified several construction information components, when he researched the information needs of specific construction personnel. His study found a wide array of functions within construction organizations and that “information needs” are often “inextricably linked” to the management responsibilities of each member of the project team. Information includes the timely and relevant facts needed to make decisions about the cost and performance of an individual project. These facts include key information on the cost, duration, procurement status, and performance aspects of the project. Tenah analyzed construction information by analyzing the needs of individual personnel. Hence a company president had a need for project cost and schedule summaries, progress forecasts, financial reports, business development info, and corporate strategic plans, while a project superintendent has a different set of information needs.

Using this original data (1986), the author re-sorted the information needs by information variable. By prioritizing these variables based on their frequency, a schedule of information needs was developed. This prioritized schedule is depicted in table 1.0.

Benchmarking a Specific Information Flow

An example of a specific information component is a project's shop drawing and submittal review process. According to the American Institute of Architects, the purpose of submittals is to "demonstrate... the way the contractor proposes to conform to the information given and expressed in the contract documents" (AIA, 1987). The design team uses the submittal process to ensure that the materials and methods that are proposed by the construction team will meet the quality intent of the design. According to Hinze, "Typically, this is done through the submission of the relevant information for the owner's approval. The information must be sufficiently detailed so that the owner can make an informed decision about the adequacy of the item in question" (Hinze, 1993).

Table 1

Prioritized Schedule of Construction Information Needs, (Adapted from Tenah, 1986)

Information Need	President	VP Finance	VP Operations	VP Administration	Procurement Director	Chief Accountant	Operations Manager	Chief Estimator	Division Engineer	Procurement Manager	Construction Manager	Labor Relations Manage	Project Manager	Project Engineer	Assistant Estimator	Planning & Scheduling	Cost Engineer	Estimator	Purchasing Agent	Accountant	Safety Engineer	Field Engineer	General Superintendent	Superintendent	Foreman	Totals
Project Cost Summaries	1	1	1		1	1	1	1	1	1	1		1	1	1		1	1		1		1				17
Project Schedule Summaries	1		1		1		1	1	1	1	1		1	1	1	1	1	1		1		1				16
Project Progress Forecasts	1		1		1	1	1	1	1	1	1			1	1	1			1	1						14
Contract Documents								1					1	1	1	1	1	1	1		1	1	1	1	1	13
Project Financial Reports	1		1		1	1	1		1	1	1		1	1	1					1						12
Government Regulations		1	1	1	1					1		1									1		1	1	1	10
Detailed Project Budgets					1					1			1				1	1	1	1		1	1	1		10
Procurment Status					1		1	1		1			1	1			1			1		1				9
Union & Labor Agreements		1		1		1						1	1	1							1		1	1		9
Vendor & Sub Lists					1					1	1		1		1				1			1	1			8
Detailed Project Schedules											1			1	1				1			1	1	1	1	8
Safety Regulations				1	1					1											1		1	1	1	7
Construction Forecasts		1	1	1	1		1				1															6
Job Staffing Requirements				1			1		1			1	1										1			6
Field Labor Costs				1		1														1			1	1	1	6
Construction & Engineering Methods								1	1					1	1		1	1								6
Contracts					1					1			1				1		1				1			6
Vendor Performance Reports															1		1	1	1				1	1		6
Subcontract Perfomance Reports															1		1	1	1				1	1		6
Historical Cost /Performance Data															1	1	1	1				1		1		6
Production Reports																1	1					1	1	1	1	6
Value Engineering								1						1	1		1	1								5
Bid Results					1			1		1								1	1							5
Critical Item Status													1	1					1			1	1			5
Project Scopes													1	1		1							1	1		5
Quality Control & Testing Reports														1								1	1	1	1	5
Wage & Tax Requaltions				1								1		1						1						4
Experience Data								1	1						1	1										4
Material Purchase Orders										1									1	1			1			4
Construction Legislation			1				1				1															3
Drawing Status													1	1					1							3
Inovice Approvals										1										1			1			3
Back Charges																				1			1	1		3
Change Orders																				1			1	1		3
Submittals & Shop Drawing Status																						1	1		1	3
Business Development Info	1								1																	2
Volume of Work				1					1																	2
Health & Welfare Information				1																	1					2
Training Programs				1			1																			2

Generally, the specifications outline the submittals required for each project. Submittals packages may include a combination of shop drawings, samples, or product data. These documents take the form of "submittal packages" which are developed by the subcontractor and are then forwarded to contractor and subsequently to the design team for review (Fisk, 1988). Because key building components like elevators, mechanical systems, and electronics cannot be ordered until their individual submittal packages have been reviewed and approved, the submittal process is critical to the timely delivery of materials. Figure 1 illustrates the flow of information during the submittal process (Mincks & Johnson, 1998).

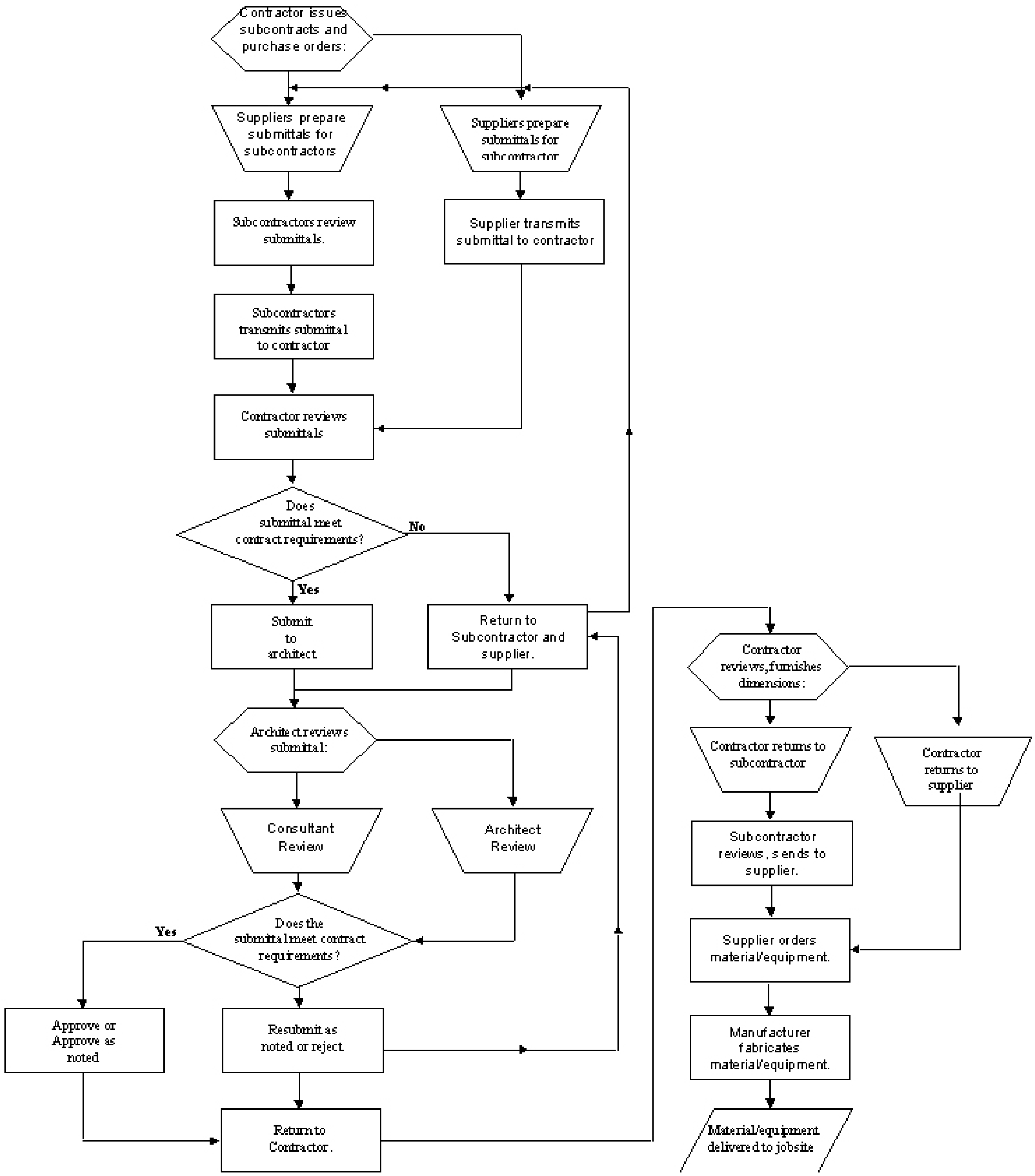


Figure 1. Submittal Process Flow Chart (Mincks & Johnson, 1998)

While other data and information flows can be measured, the submittal proces was chosen for several reasons. First, the submittal process requires information transfer and processing between many members of a project team. For instance, a temperature control device submission will be developed by a vendor, submitted to a mechanical subcontractor for review and approval, then submitted to a general contractor for submission and approval. Once approved by the contractor, the submittal is routed through the design team for review approval. When all parties have approved the submission, the information is transferred back through the team members to the originator. If any party rejects the submittal, then the process starts over again. As such, the submittal process is a good example of an information flow that extends through the entire breadth of the project management system.

Secondly, the submittal process is a standard requirement of AIA (American Institute of Architects) contracts. Because most projects in the United States are governed by AIA contracts, the submittal process is well defined. The contract and specifications outline exactly how a piece of information (the submittal) will be generated, transmitted, approved, and re-transmitted. This framework provides an information flow that is standard to most construction projects, and this flow can be measured.

Finally, because submittal review is well defined, project management systems have been established to monitor and control the process. This control device is known as a submittal log, and it tracks key dates during the life of the submittal. For instance, a submittal log will typically note when a submittal is required, and when it was transmitted to approving members of the project team. Given the critical path nature of material approvals, most large-scale construction projects keep detailed submittal logs. Unlike many other construction information components, these logs provide a well-documented record of a specific information flows that are standard to most construction projects. While individual submittals will vary widely from job to job, a statistical analysis of several construction projects can be used to measure the speed of a particular information flow.

Benchmarking the Submittal Process

Submittal data was collected from ten construction contractors that were chosen at random from the register of Associated General Contractors of America. These contractors submitted historical data from 20 projects completed over the last five years. To insure replication these projects met the following criteria:

- Projects were selected from a random sample
- Projects were building construction projects
- Project size was 5 million dollars or larger

After screening, logs from twenty projects were selected and approximately 400 data points were analyzed. An analysis of the total cycle time (calendar days) for each submittal was calculated and recorded. This data was then input into a computer spreadsheet program (Excel). Using Excel's statistical package, the submittal cycle times were analyzed and a mean, mode, and standard deviation were developed for the collected data. Additionally, a confidence interval estimate was made at the 95% level. The mean and mode of the analysis provided an indication of the central tendency of the RFI information cycle, while the standard deviation described the variability of the distribution. According to Babbie, "averages have the advantage of reducing raw data to the most manageable form: a single number that can represent all the detailed data collected" (Babbie, 1990). This single number would provide a statistical benchmark of the time required for a construction organization to process a typical submittal document.

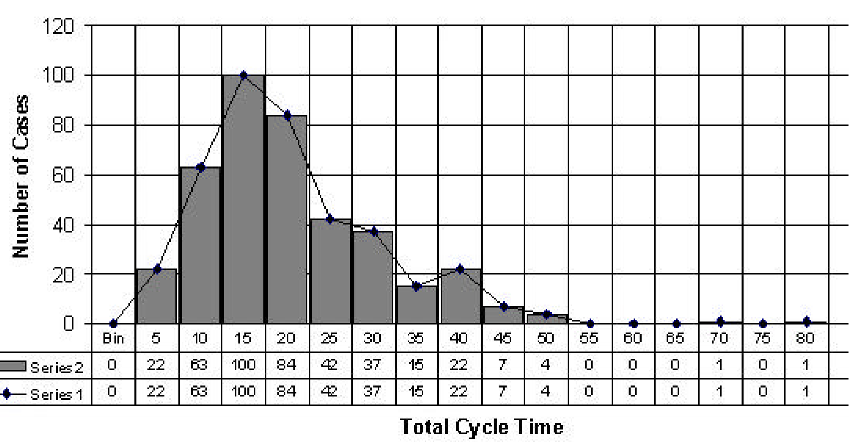
Results

Analysis of the data collected revealed that the average process cycle time for a submittal package was 18.31 days. This number represents the total duration required to process a submittal package, from the day it arrives at a general contractor's office to the day it is re-transmitted to a subcontractor or vendor. The median for the data collected was 16 days, while the mode of the data set, or the value that appeared most frequently, was 13 days. As evidenced by the standard deviation calculation of 10.65 days, the data showed a large range of variability. The data was also skewed to the right. At the high end of the range, a few submittal packages required over seventy days to process, while at the lower end other submittals required only a day for processing. Table 2 provides a summary of descriptive statistics, while figure 2 depicts the frequency distribution of individual submittal cases.

Table 2

Submittal Process Cycles Descriptive Statistics

Mean	18.32
Standard Error	0.534
Median	16
Mode	13
Standard Deviation	10.65
Sample Variance	113.5
Kurtosis	2.75
Skewness	1.26
Range	75
Minimum	1
Maximum	76
Sum	7290
Count	398
Largest (1)	76
Smallest (1)	1
Confidence Level (95.0%)	1.049



	Bin	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
Series 2	0	22	63	100	84	42	37	15	22	7	4	0	0	0	1	0	1
Series 1	0	22	63	100	84	42	37	15	22	7	4	0	0	0	1	0	1

Figure. 2 Submittal Process Frequency Distribution

Some of the variation seen here is the result of the complexity of the submittal packages. Typically a paint sample will require less scrutiny than a concrete reinforcing submittal package. Another reason for the variability may have been the amount of approvals required. As depicted in figure 1.2, the processing of a submittal will often require several approvals including the architect, contractor, engineers and possibly the engineer's consultants. Complex submittals typically require the approval of several sub consultants, while simple submittals require approval by only the contractor and architect.

In developing a significant benchmark, the large standard deviation associated with the submittal data appears problematic; however, a closer look at the data shows that the submittal process cycle means are distributed in a narrow range. Using excel's statistical package, a confidence interval was calculated for the submittal mean using the formula:

$$\bar{x} \pm 1.96\left(\frac{\sigma}{\sqrt{n}}\right)$$

where x is the mean, σ is the standard deviation is the population size, n is the population size and 1.96 equals the area under the normal distribution. At the 95% confidence level, the submittal data has a range of 1.049 days. This suggests that 95% of the means collected from other similar submittal populations would fall between 17.26 days and 19.35 days. The central limit theorem states that "as a sample size (number of observations in each sample) gets "large enough" the sampling distribution of the mean can be approximated by a normal distribution. This is true regardless of the shape of the distribution of the individual values in the population" (Berenson et al. 1988). Given this theorem and the narrow range of the confidence interval (1.049 days), the submittal cycle (18.31 days) appears to be representative of the submittal process for the construction business as a whole. As such, this average provides a statistically significant comparative benchmark.

Conclusions and Recommendations for Further Work

Recent research by the Construction Industry Institute suggests that the efficient movement of information is a critical factor in the success or failure of a construction project. Unfortunately, little effort has been made to understand which information flows are important, or how the flow of information affects the profitability or project performance.

This study identified key construction information flows, and provided a method for developing benchmarks that can be used to measure and improve those flows.

More specifically, this paper analyzed a single information flow: the construction submittal package. Major construction projects typically require 50- 75 individual submittal packages; each of which must be developed, transmitted and reviewed by several members of the construction team. Because these approvals must be made before materials are released for fabrication, the speed with which submittals are processed can have a significant effect on the critical path of a project. The study determined that it takes over 18 calendar days to approve a typical submittal package.

It should be noted that the benchmark developed here represents only a part of the submittal process. Time is also spent by the vendor or subcontractor in preparing the submittal package and transmitting it to the contractor for approval. While this part of the process was not measured here, anecdotal information collected during this study suggests that this part of the process requires an additional 7 - 10 calendar days. This means that an average submittal package has a total cycle time of almost four weeks.

When applied to other critical components, information benchmarking could help improve productivity, reduce project durations, and improve communication performance.

This study raises questions that may serve as the basis for further research. For instance, do firms that use benchmarking have higher profitability levels than firms that do not? Is there a correlation between information cycle times and profitability or customer satisfaction? What are the information flows that are critical to the timely completion of a construction project? What information problems typically result in project delays? How can other systems can be used to monitor and report on key information flows?

Interestingly, the rapid development of construction information technologies should also help researchers with the development of information process cycles. Currently, several project management programs allow users to automatically track the progress of critical items like requests for information (RFI's) , change order approvals, and payment applications. As such, the process times for individual information components can be easily captured and compared against internal or external benchmarks. Software programs could also be developed to automatically track the distribution of specific information components through a project network.

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