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USING SIMULATIONS TO BETTER TRAIN FUTURE AND EXISTING CONSTRUCTION MANAGEMENT PERSONNEL

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Abstract: In the construction industry, there is a continued need for training current employees as well as future employees. Such training opportunities that exist include safety, technical, and project management. Historically training has included lectures from subject matter experts by those considered to be experts in a particular subject or field. However, this has required removing personnel from projects to allow time for training or by requiring employees to invest time outside the normal working hours for training. With the advent of the internet, on-site lectures have been replaced with webinars and/or telecast to allow personnel to remain in one location and receiving training; however, many educators cite that student engagement is often limited and learning is not as in-depth when compared to in-person training sessions. One new training technology that is developing is the use of virtual simulations that are designed to allow for specialized training while engaging them in the educational process. One such simulation, the CONstruction INdustry Simulation (COINS), has been developed to train students in the management of a construction company managing multiple projects simultaneously. COINS engages students in the decision making of heavy civil construction and commercial building sector. This simulation has been used in the classroom and now is just available to construction firms to use with personnel. This paper describes the development and use of COINS simulation designed and developed to educate future and existing construction management personnel. It is currently used at a number of different universities including the Czech Technical University in Prague.

1 INTRODUCTION

If one were to survey construction educators and construction trainers, we would find a small number using large scale complex simulations. Most university faculty opt for traditional lectures using powerpoints and a number use case studies, and a few use management games. The question is why don't we use simulations? The definition of a simulation is the imitation of the operation of a real-world process or system over time. This definition begs the question even more, why don't we use simulations? Fear of technology, availability, overly complexity, etc. One such simulation, the CONstruction INdustry Simulation – COINS (Korman, Johnston, Duckworth), has been developed to train students in the management of a construction company managing multiple projects simultaneously and is slowly moving to advance company trainee. COINS engages students in the decision making of heavy civil construction and commercial building sector. This simulation has been used in the classroom and now is just available to construction firms to use with their personnel.

2 LITERATURE REVIEW

While multidisciplinary project-based learning has been advocated in engineering for a number of years, the initiation of the Accreditation Board for Engineering and Technology, Engineering Criteria 2000 (ABET 2000), and its call for a required multidisciplinary experience stimulated increased interest in developing courses in this area. Still more recently, an increased number of papers advocating multidisciplinary project-based curricula have appeared at conferences and in journals. It has become clear that project-based learning is addressing a need in the preparation of engineers that was not previously satisfied by standard curricula (Mergendoller, Strobel).

Dialogue with the construction management Industry Advisory Board (IAB) revealed the following important issues and obstacles our students experience upon entering industry. First, students often have not encountered large-scale team design projects and, therefore, have to learn how to work in such an environment. Thus, on the job, they must gain experience in the process, develop a technical specialization to support their project role, and build their ability to collaborate on and contribute to multidisciplinary projects. Secondly, we discovered that our students were not prepared to apply design and construction engineering fundamentals to real world complex projects, specifically utilizing project controls to monitor and evaluate an active project.

In addition to the educational deficiencies noted in our curriculum, CCE curricula generally do not present an integrated approach to engineering education that includes practical applications of theoretical knowledge incorporating constructability issues. Students often master the course and laboratory work associated with courses in the curriculum, but they do not gain a comprehensive engineering experience that requires them to synthesize what they have learned in their curriculum and extend their knowledge through independent learning that reaches outside their field of study, specifically in the topics of constructability. This is further observed at community colleges where students do not have the opportunity of being immersed in a large-scale engineering academic environment of a four-year institution and frequently lose interest in pursuing further education or an engineering career (Terenzini, Cabrera).

This educational gap is systematic among engineering universities. Design engineers frequently receive limited feedback regarding the constructability of their design once a project has entered the construction phase and how construction engineers receive limited feedback regarding the progress of their project. This stems from the educational gap that exists between design and construction engineering curricula, which fail to address constructability issues and lack educational tools and methods for students to test and validate project control theory (Kilgore, Atman, Yasuhara, Barker, Morozov).

Traditionally, students have not acquired these skills at CPSLO. In fact, our experience and research indicates that while many universities and community colleges offer lower division courses that teach students about project control theory, they are not able to provide an educational experience where students can practice these skills. Therefore, in an effort to produce a project-based learning experience, the CPSLO faculty have been developing COINS–COConstruction INdustry Simulation–to reinforce several key learning objectives and to provide a valuable experience for students to work on projects that require the application and synthesis of project controls and monitoring knowledge. Through the use of COINS, students will be placed in a virtual environment to replicate, as nearly as possible, the working environment they will encounter after graduation. Students will be exposed to exercises that are significantly different from typical homework assignments in conventional courses. COINS requires students to work collaboratively and use effective communication skills. Based on our review of the literature, we expect that COINS will engage students unlike any other teaching intervention as there are currently no Project Based Learning (PBL) solutions using simulations to enable students to conceptualize the demands of scheduling multiple projects with multiple resources. Other engineering simulations, such as Messner's Virtual Construction Simulator, simulate building a specific project, focusing on very specific job areas (Nikolic). COINS, on the other hand, is conceptual in nature, actively involving students in the scheduling of multiple projects and allocating multiple resources concurrently while enabling them to see the relevance in the real world of what they are learning. Finally, we anticipate that COINS will become a model for other civil and construction engineering programs who

wish to enhance their compliance with the ABET 2000 requirements and foster the success of a greater number of students Vogel, Bowers, Bradshaw).

3 CONSTRUCTION INDUSTRY SIMULATION (COINS)

Construction Industry Simulation (COINS) is a computer simulation built to simulate the business environment for a construction company. The players, participants, play the role of contractors, competing in a market with variable demand for construction work. The simulation immerses trainees into the day-to-day operations of a construction company, requiring them to management specific aspects of the company with the goal of procuring and managing construction work in terms of its planning, scheduling, and resource allocation. Student trainees have a choice between commercial construction company, a heavy construction company, or a company that does both. Players are required to set up a complete business strategy including the following tasks:

- examine available information
- determine the best portfolio of jobs to bid on
- create strategies to improve bonding limits
- set strategies to create negotiated work
- develop bid prices for desired jobs
- monitor their financial position as work progresses
- monitor and create strategies to improve company's appraisal metrics
- choose and modify their construction methods to meet due dates and reduce costs
- interpret their competitors' strategies
- respond to changing conditions and situations proposed to the company and driven by the decisions and actions of the company

3.1 Projects and Activities

Each period the simulation generates a list of projects available for the teams to estimate, schedule and propose on. The types of projects include the following: highways, bridges, site development, mass excavation, and underground utilities on the heavy civil side, and multi-family housing, educational facilities, hospitals and medical office buildings, commercial office buildings, and industrial manufacturing facilities on the commercial side.

All projects have nine (9) activities that the teams need to schedule, generate and cost estimate. The activities that must be scheduled and estimated include the following: clear and grub, rough grading, excavation, underground piping, concrete forming and placing, backfill and compaction, placement of aggregate base, asphalt-concrete paving, and finish grading. On the commercial side, the activities include the following: excavation, foundation, basement, framing, closure, roofing, siding, finishing, mechanical, electrical, and plumbing.

In addition the simulation creates an Estimated Time and Cost Report for each job. Using the this information, each company must decide which jobs to bid on, the bid price, and which of the five methods to use for each of the activities.

Every activity has five (5) different construction methods that vary in time and cost. The Estimated Time and Cost Report gives labor and material costs and the amount of time required for every activity using each of the five methods. Heavy construction bids are generally unit price bids while commercial bids are lump sum.

3.2 Use of the COINS Simulations

COINS has been used in several courses including: Professional Practice, Construction Estimating, Construction Accounting, Management of the Construction Firm, and Business Practices

During the 2005/2006 academic year, the simulation was used for regional competition between multiple universities in the Associated Schools of Construction Regional 6 and 7 Student Competition.

Most recently, in November 2009, universities from the Czech Technical University (CTU) - Prague, Czech Republic, Auburn University – Alabama, California State University, Fresno - California, Illinois State University - Illinois, Boise State University - Idaho, Western Carolina University - North Carolina, and Washington State University – Washington, participated in an international competition. Competition Results were evaluated in five categories: Highest Retained Earning - received the highest profit, Highest Appraisal Metrics - the best valuation metrics and third, Most Awarded Projects - the company with the most awarded projects.

4 GAME PLAY SIMULATION

During the simulation, student trainees experience three distinct phases playing through the simulation. These are:

4.1 Phase I – Project Planning and Design

Students begin the simulation in Phase 1 by being presented with a list of potential projects to review. Considering market conditions, student teams proceed by selecting a project to plan and then designing a project control system for the project. This is accomplished by selecting methods for each project activity and balancing the schedule and cost considerations. In Phase 1, students compete against their peers as well as the simulation's virtual companies for award of the project. Award of projects is based on the team's accuracy and proximity to the simulation's internal estimate. Teams that are not initially awarded a project for their efforts must continue with the simulation, refining their plans, until their plans are awarded a project. Thus, the COINS simulation enables student trainees to learn from their mistakes.

4.2 Phase 2 – Construction Engineering

When a student team is awarded a project, they enter Phase 2. In Phase 2 student teams must manage their project by monitoring and controlling the project activities, analyzing the schedule and costs in reference to the methods to the activities they selected for each activity. Throughout the duration of their project, students are presented with real-life scenarios which they must respond to, thus measuring, testing, and validating the design of the project control system. Therefore, students are able to utilize their knowledge and hone their skills at controlling the process through modifying their project control system. The simulation provides feedback to the students which they then can use to continuously improve their model throughout the duration of the simulation.

4.3 Phase 3 – Project Closeout

Phase 3 begins after students have completed each activity for their virtual project. They have the opportunity to evaluate their performance using several predefined metrics, including Schedule Variance, Cost Variance, Cost Performance Index, and Schedule Performance Index.

5 STUDENT TRAINEE LEARNING PROCESS

As mention above, one of the first activities for the student trainees is to determine what positions will make up their main office overhead. This is reevaluated each period, and hire/fire activity is performed by the team. A report is given to the company telling them how they are handling their personnel and it's requirements. Work scheduling is very important in the selection of the methods so projects can be completed by the contractual deadlines, and the costs reduced as much as possible. Each bid price submitted should cover all the firm's direct and indirect job expenses, its main office overhead costs, and the desired profit. At the end of each period the simulation will determine which company is awarded each available project. The lowest bid will not necessarily win since the computer takes into account several other factors:

- Is the firm's cash-on-hand adequate to provide enough liquidity with regard to the bid price?
- Is the bid price below a minimum amount, computed by the program? If so, then the bid will be disregarded as irresponsible and be rejected.
- Is the bid price higher than the unknown contractors, the presence of this simulated company assures a competitive, uncertain environment with realistic bid prices.
- Is the firm within its bond limits?

At the end of each period, teams receive a progress report for the previous two month period, giving a statement of the firm's work progress on each of its jobs during that time. It shows the amount of work completed as well as the expenses incurred for each activity in every one of the company's projects. The amount of work completed during a period depends not only on the methods selected for the various activities, but also on uncertainty factors during that time such as the weather conditions, labor availability, and the fluctuating cost of materials.

An end-of-period financial report is also provided to the participants showing the expenses incurred during that period. It lists amounts spent on direct construction services, bidding costs, delay fines, taxes incurred, and interest on borrowed money. It also shows payments to the contractor by the owner according to the payment requests and gives total cash-on-hand at the end of the period. Each firm may at any time apply for a loan to improve its financial situation. Loans granted are amortized over a one year time period. Changes in company ratios are also logged along with changes to the company's appraisal metrics:

- Is the firm within its bond limits?
- Financial Liquidity
- Financial Success
- Responsibility
- Pace
- Ethics
- Name Recognition

At the end of a period, the firms can examine their Progress Reports and decide on the effectiveness of the methods chosen for the various work activities. If they wish, they may change them and specify different methods for the following periods. The choice of methods allows companies to utilize slower but cheaper methods if they fear budget overruns, or faster but more expensive methods if meeting contractual deadlines is the main concern. In addition, overtime may be used to speed up certain activities, greatly increasing the labor costs. Firms must be concerned with the amount of liquidated damages on each project as they vary from project to project.

At the conclusion of the simulation, the program provides each participating company with a final report, forecasting the expected results of any on-going projects or their position at that point in time. It also shows the final total worth of the firm. Teams should consider maximization of profit as one of their main objectives, and one of the primary criteria used to evaluate each firm's performance. As the simulation progresses, evaluations of company ratios, and appraisal metrics can be used to determine successful completion of the simulation.

6 LEARNING OBJECTIVES

The phases described in the previous sections were designed with specific learning objectives to ensure that identified curriculum deficiencies were addressed, integrating knowledge from project planning, project procurement, schedule control, and cost control bodies of knowledge. Tables 1, 2, and 3 provide a list of the learning objectives and mechanism COINS uses to assess student learning.

Table 1: Planning and Design Learning Objectives.

Learning Objective	Assessment
Use labor-equipment crew rates and productivity information to select methods for construction activities.	Students submit their reasoning and logic for selecting methods for each activity. COINS provides feedback on cost and schedule completion dates.
Develop a project schedule considering interdependent activity relationships and contract requirements.	Students submit their project schedule. COINS provides feedback on predecessor and successor activities.
Quantify planning, contingency, and bonding expenses and apply to project cost.	Students submit their project cost estimate, including planning, contingency, and bonding expenses. COINS provides feedback on percentages per project.
Calculate and apply percentages of main office overhead cost to multiple projects.	Students calculate the overhead cost and submit with project cost estimate. COINS provides feedback on project resources allotted for the project.
Use information regarding bonding capacity, labor availability, materials availability, liquidated damages, and apply modification factors to develop a construction cost estimate.	Students submit their rationale for selecting resources based on bonding capacity, labor availability, material availability, liquidated damages. COINS provides feedback modification factors.
Apply value engineering fundamentals to decrease schedule requirements and reduce project cost during design	Students submit value engineering consideration to reduce cost and schedule. COINS provides feedback on applicability and feasibility of proposed options.

Table 2: Construction Engineering Learning Objectives.

Learning Objective	Assessment
Update schedule for in-progress projects.	Students submit their reasoning and logic for selecting methods for each activity. COINS provides feedback on cost and schedule completion dates.
Calculate final project cost, considering scenarios involving labor cost increases, material price increases, and overtime compensation.	Students submit their project schedule. COINS provides feedback on predecessor and successor activities.

Apply project acceleration techniques (changing methods, utilization of overtime, etc.) to decrease project schedule on projects that are behind schedule	Students are required to reduce project schedules for in-progress projects in response to market considerations by reducing their total number of work days.
Quantify cost associated with applying project schedule acceleration techniques.	Students submit their project cost estimate, including planning, contingency, and bonding expenses. COINS provides feedback on percentages per project.
Develop progress payment reports based on work completed to date.	Students calculate the overhead cost and submit with project cost estimate. COINS provides feedback on project resources allotted for the project.
Apply value engineering fundamentals to decrease schedule requirements and reduce project cost for project in-progress.	Students submit their rationale for selecting resources based on bonding capacity, labor availability, material availability, liquidated damages. COINS provides feedback modification factors.

Table 3: Project Closeout Learning Objectives.

Learning Objective	Assessment
Calculate and use Cost Variance to determine cost differentials for project cost.	Students calculate cost variances (CV) at project completion. COINS performs an independent CV calculation and provides feedback.
Calculate and use Schedule Variance to determine differentials for project schedules.	Students calculate schedule variances (SV) based at project completion. COINS performs an independent SV calculation and provides feedback
Calculate and use Cost Performance Index to analyze project performance.	Students calculate cost performance index (CPI). COINS performs an independent CPI calculation and provides feedback.
Calculate and use Schedule Performance Index to analyze project performance.	Students calculate schedule performance index (SPI). COINS performs an independent SPI calculation and provides feedback.

7 ASSESSMENT OF STUDENT TRAINEE LEARNING

The simulation has a built-in grading module that can be used to obtain statistic on the various companies for comparison or to use in the classroom for grading the simulation. Each faculty can have their own method of grading. The following criteria can be used by faculty for assessing participation and student learning:

- Is the firm within its bond limits?
- Number of jobs bid
- Minus the jobs rejected (i.e., not enough bonding capacity, substantially low cost estimate, etc.)
- Number of times the number jobs you are the lowest cost
- Number of times the company retained earnings
- Company's appraisal metrics

8 DISCUSSION AND RECOMMENDATIONS FOR FUTURE IMPLEMENTATIONS

Many new hires will come from academic areas other than Construction management. A need for these employees to understand an overall picture of the industry is important. Another group of employees are in accounting area and they too can benefit from a "capstone" look at their companies. To assist in the development of COINS, the developers have developed an Industry Advisory Board (IAB) from the construction industry as well as a working group of educators to continue the development and ideas for changes. Because of the idea of module development COINS can turn on and off some of its modules, making it a better fit in different classes. For example, estimating can be turned to an automatic mode which in a construction accounting class helps the student focus on accounting and not on the estimating itself which can be very time consuming and complex. Periods can move much quicker giving the students more accounting to analyze and in a shorter time in which they can see the changes that occur within a company without being bogged down in the estimating/procurement of work. Billing can be turned on to auto mode and additional projects can be added to each team to create additional project or backlog. The game play between commercial and heavy/civil construction is also modularized so a faculty can play only commercial, heavy/civil or both can be played in one game. Future additions are also planned as modules, i.e. personnel additions, case studies, and wide use of equipment management.

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