Unique Approach to Teaching Heavy Civil Estimating

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This past spring of 2014 working as a Co-PI a team of researchers received a research grant to study Climate Change Impacts on Indoor Air Quality. Grant Funded $996,588.00 Max also holds a patent No. 6,213,117 (2000) for a Motorized, Insulated Damper Assembly for Indoor Air Quality.
Unique Approach to Teaching Heavy Civil Cost Estimating

This paper is an evidence-based practice paper and it is about a unique approach to teaching heavy civil cost estimating.

Abstract

Construction performance and efforts have always been measured in terms of time and budget, and a good understanding of the basis for generating time and cost estimate is required of construction management (CM) students and construction engineering (ConE) students. This is important because they need such knowledge in order to conceptualize, design, and construct projects. The need to create time and cost estimate at some point in a project’s lifecycle is a certainty. Students must be taught how to create an accurate cost estimate, which in part depends on the quality of knowledge transferred to the students. How can educators evaluate the quality of the knowledge transferred to students in the area of cost estimating, if they do not have a real world method to test out the quality of knowledge transferred? The purpose of this paper is to present a unique approach to teaching heavy civil cost estimating, one that allows students to prepare bids on state or local transportation projects. This method also provides the basis for students and educators to assess the quality of the teaching technique in the area of heavy civil cost estimating.

With this in mind, the authors have developed a unique instructional method for teaching heavy civil cost estimating. The course is taught in such a way that students bid projects alongside licensed contractors or bid on recently bid projects. This method provides students with an in-depth knowledge of cost estimating and all the steps that are akin to the real world cost estimating practice. The data collected within the last two years from projects that the students have bid on, show how close students’ bids are to those submitted by licensed contractors. While the approach of bidding alongside other contractors in a real world scenario has its challenges, the option of bidding recently bid projects is the recommended method, because it allows for a wide range of projects to select from, and there is no need try to align with whatever project is bidding at that time. The significance of these methods is three-fold. First, it offers students the kinds of exposures that are typically open to professionals in the construction industry, and as such, the students become practice-ready graduates. Secondly, this method provides a strong basis for students to evaluate the quality of education that they are receiving. Thirdly, educators can assess how well they are performing by looking at how closely the students’ bids fall within those of experienced contractors.

Introduction

Dysert [1] defined an estimate as “a prediction of the probable costs of a project, of a given and documented scope, to be completed at a defined location and point of time in the future.” Estimating is the process of determining the quantity of work and cost of all resources (labor, materials, equipment, and subcontracts) and incidentals required to construct projects. Projects to be built in the future are estimated in the present, and the estimates are developed to show how much the projects will cost at some point when they are finally constructed. Such
projection is based on what is known now and how well the future conditions can be predicted. Therefore, there is no way one can be 100% accurate in predicting and estimating all future conditions of a project. According to Park and Chapin [2], a cost estimate is not useful if it fails to make an accurate projection of the cost of doing the work. Dysert [1] agrees that an estimate could never be 100% accurate. However, the author states that the accuracy of each phase of a project estimate (based on the scope detail) should reliably predict the costs to deliver the project. As such, cost estimates should provide sufficient accuracy to support decision making. Students in the CM and ConE programs are taught to prepare cost estimates for items of work and in some cases a whole project cost estimate, with sufficient accuracy to support decision making. But how can educators evaluate the quality of the knowledge transferred to students in the area of cost estimating, if they do not test it out in the real world?

While it is know that a 100% accurate estimate is not possible, the expectation is that the estimates prepared by students are accurate enough and within an acceptable range. This paper presents a unique approach to teaching cost estimation which allows students and educators to see if the estimates prepared by the students are within a reasonable range of those prepared by licensed contractors. For the students, this method tests the quality of knowledge gained in the area of cost estimating, and for the educators, it provides a path to evaluate the course contents, the student learning outcomes and the areas that need improvements. For contractors, it shows the level of job readiness.

What follows is a review of how cost estimating is practiced in the real world by practitioners, how educators organize their course contents to educate students in the area of cost estimating, and the method that was used by one educator to bring real world cost estimating experience to his students. In addition, the paper describes how the method has been advanced, and provides reports that show the range of students’ cost estimates as compared to those of licensed contractors.

Cost Estimating in the Real World – Standard of Practice

Over the years several professionals have developed fundamental principles that have guided the way practitioners estimate the cost of projects. Principles are fundamental truths that explain relationships between two or more sets of variables and define actions or steps required to attain some desired objectives. In the construction environment, those desired objectives involve meeting time, budget, scope, and quality. Carr [3] provided seven fundamental principles that should guide good estimating practices: 1) the need to produce realistic estimates; 2) the use of the appropriate level of detail for each stage of project development; 3) making sure to provide a complete estimate of all work items, incidentals, and their costs; 4) documentation of the project scope, estimate basis, project conditions, methods of construction, assumptions, and calculations; 5) inclusion of all direct and indirect costs; 6) including all fixed, and variable costs; 7) accounting for uncertainty with the appropriate level of contingency.

The American Society of Professional Estimators (ASPE) technical papers retrieved from http://www.aspenational.org/page/TechnicalPapers on “how to estimate the cost of…” provide a standard framework of how professional estimators go about preparing the price of an item of
work, or for a whole project. After reviewing over 30 of these technical papers, a theme emerges: scope definition, scope breakdown using MasterFormat divisions and subdivisions as a guide, definition of unit of measurements, consideration of various known factors and cost drivers, consideration of risk factors, quantity takeoff, resources (labor, material, equipment, subcontract) needs, and pricing out all associated resources and efforts needed to complete the work. In addition, the format includes a section for ratios and analysis, which is used for testing out the accuracy of the bid against known benchmarks.

The Association for Advancement of Cost Engineering (AACE) is comprised of construction professionals, and the association’s journals are practice-based and practical. The total cost management (TCM) framework published by AACE [4] details the fundamental principles and framework that inform how practitioners should practice cost estimating and include the following:
1. Plan for cost estimating
2. Quantify scope content
3. Cost scope content
4. Price the cost estimate
5. Simulate and optimize costs
6. Budget costs
7. Analyze cash flow
8. Bidding the cost estimate
9. Review and document estimate
10. Develop and maintain methods and tools

On state DOT projects, the estimates developed by the agencies are based on several standard practices. They start with a clear definition of the scope of work, as defined in the plans and specifications. Then the associated bid items are scoped, and the corresponding quantities are taken off. Typically the estimates are developed at the unit price/bid item level by collecting and analyzing past bids on similar work items and averaging-out the numbers to arrive at the new price. The other option is the cost-method which requires a deep-dive on major cost drivers such as earthwork and structural work and to estimate the work at the element/component level based on applicable tasks and their production rates. Schexnayder et al. [5], looked at various state DOTs and found that they typically use three estimating methods which include historical bid price estimating, detailed estimating, and a combination of both methods.

Irrespective of the directions an estimator might take to prepare an estimate, the fundamental principles and steps are the same, and figure 1 below encapsulates the key activities that show the process of cost estimating and bidding.
### Figure 1. The Process of Cost Estimating and Bidding

**ACCE and ABET Requirements and Cost Estimating Curriculum in CM and ConE Programs – Educating the Students**

In construction management and construction engineering education, the two accreditation bodies include ACCE and ABET and the student learning outcome (SLO) are well defined by...
these accreditation bodies. According to ACCE accreditation document 103 retrieved from http://www.acce-hq.org/images/uploads/Doc_103_Updated_081116_final3.pdf, students graduating with a 4-year degree shall be able to create construction project cost estimates as well as have knowledge on related areas which include 1) ability to analyze professional decision based on ethical principles; 2) analyze construction documents; 3) analyze methods, materials, and equipment used to construct projects; 4) understand construction risks; 5) understand the legal implications of contracts; 6) understand construction project control process; 7) create construction project schedules; 8) create written communications appropriate the construction discipline; 10) create oral presentations appropriate to the construction discipline; 11) apply electronic based technology to manage the construction process; 12) understand different methods of project delivery and the role and responsibilities of all constituencies involved in the design and construction process. The SLO from ABET for construction engineering retrieved from http://www.abet.org/wp-content/uploads/2015/05/E001-15-16-EAC-Criteria-03-10-15.pdf states that students must be able to analyze and design construction processes and systems, applying knowledge of methods, materials, equipment, planning, scheduling, safety, and cost analysis; to understand basic legal and ethical concepts and the importance of professional licensure in the construction industry; to apply basic concepts of management topics such as economics, business, accounting, communications, leadership, decision and optimization methods, engineering economics, engineering management, and cost control.

A review of several CM and ConE syllabi on cost estimating indicate the following common topical areas:

- Use of estimate and types
- Plans and specifications reading
- Materials and methods used in construction
- Quantity takeoffs
- Resources and crew production rates
- Pricing
- Ethics related to cost estimating and bidding
- Direct and indirect costs
- Bid preparation and submission
- Computer applications

The conventional method of teaching cost estimating would include any of the following methods:

1. How to read plans and specs, how to conduct quantity takeoff; how to prepare cost for labor, material, equipment, crew; how to obtain and evaluate quotes from subcontractors; and after which, students are assigned related exercises to complete
2. How to read plans and specs, how to conduct quantity takeoff; how to prepare cost for labor, material, equipment, crew; how to obtain and evaluate quotes from subcontractors; and after which, students are assigned individual items of work to estimate
Prior Work on Unique Methods for Teaching Cost Estimating – The Gap

Research is about learning from others and improving on the work of others, and several educators have paved the way for unique methods of teaching cost estimating. The most impressive methods for teaching cost estimating are those that bring into the classroom real world applications that are evidence-based. From over 20 cost estimating course syllabi reviewed, only a handful provided the students with actual assignment that involve real world project bidding. However, the fact that they are not explicitly written down in the syllabi does not mean that such opportunities are not given to students. Kirk [6], published a well-received work detailing how to teach cost estimating by allowing students to bid on projects alongside professional contractors. Kirk recommended that a cost estimating curriculum should include quantity survey, pricing of activities, bidding strategies, and simulated bid exercises, in which the students would actually undertake and bid projects. The author has successfully implemented and coordinated live bid in his classroom, where students bid on state and local transportation agency projects alongside registered contractors. This method involves coordination with the contracting agency to accommodate the student’ made-up companies and dummy bids, working with the state attorney general’s office on legalities, and coordination with the state to register the student companies as viable contractors. Additional coordination requires contacting the local contractor associations informing them that for academic exercise, students will be submitting dummy bids, and notifying the subcontractors and suppliers of the intent in obtaining dummy quotes from them. The author explained that this method has worked without major challenges. However, he was quick to point out that, in some cases, some contractors, subcontractors, and suppliers might view it as disruptive, and may not be willing to work with the students.

Advancing and Improving on Instructional Methods for Teaching Cost Estimating – Building upon the Work of Others

Course Content and Design – Reflecting Real World Application

For a contractor putting together a detailed estimate, the real world process generally involves: project selection (go/no go); setting up resources for estimating; familiarizing with the scope, detailing associated tasks and conducting quantity takeoff; selecting applicable crew production rates, material and equipment rates, and labor rates needed to come up with associated cost; reviewing and evaluating subcontractor’s quotes; accounting for indirect cost; adding markup; and making sure that all bid/proposal documents are completed properly and provided.

To align with the real world cost estimating practice, the method described in this paper teaches students the fundamentals of preparing cost estimates for heavy civil projects which include: roads, bridges, tunnels, railroad, waterfront structures, retaining structures, water/waste water treatment plants, airports, dams, etc. Students are taught how to conduct work breakdown, scoping, takeoff, costing, pricing, and bidding. The main focus of the course is that students are required to prepare a complete bid package for a project that is being bid by licensed contractors, or a for a project that was recently bid by licensed contractors.

The course content is designed to provide the fundamental principles and practices of cost estimating, and it includes the typical areas, along with a few unique areas. The typical areas
include types of estimate, reading plans and specifications, quantity takeoff, production rates, material rates, equipment rates, analysis of subcontractor quotes, and pricing individual items of work.

The unique aspects of the course content include: helping students to understand the systems, elements, and components of each type of heavy civil project; teaching students about work breakdown structure (WBS) and how to breakdown a project; construction methodology; working out crews and production rates; introducing databases of tasks and resources for students to use as references; learning about the bidding process and putting together a complete bid package; and project schedule development. The focus of the course is the bid project, and this aspect of the course is 50% of the course grade.

**Description of the Method for Bidding Recently Bid Project**

The bidding method described here does not require coordination with state and local agencies, contractors, subcontractors and vendors for participation in live bid simulations. However, it does require coordination with the county engineer to serve as the person to help open and read the bids out aloud.

Bidding the project is reserved for the last four weeks of the semester, at which point the students have acquired the basis of estimating and have completed the course section on “how to estimate the cost of” several items of work that include, but are not limited to: clearing and grubbing, roadway excavation, structural excavation, bases, hot mix asphalt paving, structural concrete bridge, backfill, RCP culvert, etc. At this point the students know how to read plans and specifications, how to breakdown bid items to tasks, how to align each bid item tasks to applicable crew and production rates, how to conduct quantity takeoffs, how to develop crews assemblies and production rates, how to use reference tasks database and resource files, knowledge of the different cost elements, and how to create cost extensions. In addition, the students are taught the elements of bid preparation and submission.

The selection of projects to bid is usually very simple because there is no shortage of projects to bid. Some state and local transportation agencies have current and recently bid projects posted online, and they provide the entire bid package as well as the bid result tabulation. The only challenge is in finding a project that has a limited number of bid items and can be estimated by student teams within four weeks. The goal is to pick a project that is within a range of $0.5M to $3M with a scope of work that captures various aspects of a heavy civil project such as roadway, bridge, drainage, retaining wall.

Planning for a bid requires putting teams together and making sure there are enough people to work on the estimate together. The student teams are usually groups of four, and no more than six, and each team takes on the name of a company. Depending on the number of students in the class, there are usually four to five to seven teams each semester.

The bid package is uploaded to Blackboard for students to access, and, the bid list sheet is enhanced to enable students to complete what is called “bid item mapping.” Bid item mapping requires each team to show knowledge of specification sections and drawing sheets that detail,
and specify the requirements for each bid item. The bid list sheet is also enhanced to capture job direct cost, job indirect cost, markup, and final unit price. In addition to the bid package provided, a database of tasks is provided, and resource files for material rates, labor rates, equipment rates are provided. It is worth noting that the reference cost estimating database of tasks and resource files used in the class, including the estimating software are from the chief estimator software - http://www.infrastructurecost.com/Estimating_Software and are provided at no cost to all the students in the class. As soon as bidding is started, subcontractor quotes are sent to the teams for evaluation of subcontracted items of work, and all bid inquiries are handled quickly to make it easier for students to complete their bids. A bid guideline and checklist is provided to help the teams navigate the bidding process, as well as understand how their bids will be evaluated. Finally, on the bid day, each team selects a bid runner to deliver the bid to the county engineer and wait for the opening of the bids.

**Students’ Bid Compared to those of Licensed Contractors**

In the spring of 2015, there were 26 students in the class grouped into four teams. The project that the student teams bid on was a bridge replacement project with an engineer’s estimate of $554,686.50.

The project involved the replacement of an existing bridge on a county road in Grant County, Washington State, and included removal of the existing bridge, providing a temporary bridge, roadway excavation, embankment compaction, crushed surfacing base course, top course, concrete class 4000 for abutment footings and walls, superstructure for Bridge #399, beam guardrail, and other work all in accordance with the contract plans, contract provisions and standard specifications.

The chart below shows the range of student team bid prices as compared to the engineer’s estimate and those of licensed contractors that bid on the project.

![Figure 2 – Range of student bids on Project No. 1 as compared to those of licensed contractors](image-url)
For select bid items, the table below shows the range of bid prices from contractors as compared to those from the student teams.

Table 1 – Range of students bids on select bid items for Project No. 1 as compared to those of licensed contractors

<table>
<thead>
<tr>
<th>BID ITEM</th>
<th>Contractors’ Price Low to High</th>
<th>Student Teams’ Price Low to High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of existing timber bridge (Engineer’s estimate $50,000)</td>
<td>$12,000 to $65,000</td>
<td>$21,761 to $85,397</td>
</tr>
<tr>
<td>Roadway excavation (Engineer’s estimate $1,337)</td>
<td>$1,719 to $6,685</td>
<td>$1,693 to $4,772</td>
</tr>
<tr>
<td>Commercial HMA class 1/2&quot; incl. PG64-28 paving asphalt (Engineer’s estimate $7,875)</td>
<td>$5,425 to $8,750</td>
<td>$1,406 to $6,318</td>
</tr>
<tr>
<td>Structural excavation class &quot;A&quot; incl. haul (Engineer’s estimate $5,760)</td>
<td>$2,880 to $9,600</td>
<td>$877 to $3,990</td>
</tr>
<tr>
<td>Concrete class 4000 for abutment footing and walls (Engineer’s estimate $35,700)</td>
<td>$33,150 to $89,250</td>
<td>$28,424 to $54,550</td>
</tr>
<tr>
<td>Precast girder superstructure – bridge #399, W-NW (Engineer’s estimate $164,000)</td>
<td>$180,000 to $391,500</td>
<td>$123,342 to $160,703</td>
</tr>
</tbody>
</table>

In the spring of 2016, there were 32 students in the class grouped into five teams. The project that the student teams bid on was a gravity wall project with an engineer’s estimate of $1,259,814.52.

The project involved the construction of gravity wall with moment slab concrete barrier, guardrail, asphalt concrete pavement, drain pipe installation, pavement markings, traffic control, and other work all in accordance with the contract plans, contract provisions, and standard specifications.

Because of the size of this project, and the short amount of time left for students to prepare the bid, some of the bid items were plugged. This means that on a few bit items, the item unit price were preloaded for the students, allowing them to focus on the major bid items.

The chart below shows the range of student team bid prices as compared to the engineer’s estimate and those of licensed contractors that bid on the project.
Figure 3 – Range of student bid on Project No. 2 as compared to those of licensed contractors

For select bid items, the table below shows the range of bid prices from contractors as compared to those from the student teams.

Table 2 – Range of student bids for select bid items on Project No. 2 as compared to those of licensed contractors

<table>
<thead>
<tr>
<th>BID ITEM</th>
<th>Contractors’ Price Low to High</th>
<th>Student Teams’ Price Low to High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Excavation class A incl. haul</td>
<td>$50,540 to $162,450</td>
<td>$28,011 to $97,141</td>
</tr>
<tr>
<td>(Engineer’s estimate $72,200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moment slab traffic barrier</td>
<td>$207,200 to $414,400</td>
<td>$129,370 to $388,842</td>
</tr>
<tr>
<td>(Engineer’s estimate $207,200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crushed surfacing base course</td>
<td>$46,250 to $83,250</td>
<td>$29,204 to $51,946</td>
</tr>
<tr>
<td>(Engineer’s estimate $55,500)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HMA CL. 1/2 in. PG 64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Engineer’s estimate $56,000)</td>
<td>$33,040 to $37,800</td>
<td><strong>$3,652 to $287,328</strong></td>
</tr>
<tr>
<td>Gravel backfill for foundation class A</td>
<td>$12,448 to $24,118</td>
<td>$5,932 to $11,440</td>
</tr>
<tr>
<td>(Engineer’s estimate $7,560)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity block wall</td>
<td>$118,400 to $140,600</td>
<td>$84,244 to $182,162</td>
</tr>
<tr>
<td>(Engineer’s estimate $111,000)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussions

Teaching cost estimating with job readiness in mind. Estimating is a subject which cannot be taught entirely through a textbook, especially if the goal is to prepare students to be job ready. There are actually three parts to an estimate, with the first being the quantity takeoff. This aspect of estimating can be presented through a good textbook, but to truly prepare students in the other two parts -- cost and bidding – only those who have had real world experience in the rigors of cost estimating can help students to understand the systems, elements, and components so that students can be job ready. Therefore, the quality of cost estimating knowledge transferred to students must be tested in real world scenarios to bridge the gap between the classroom and the real world.

Student team bids compared to those of practicing contractors. Students like to know how they compare to practicing contractors on individual bid items as well as an overall bid. This can be accomplished through live bids where their numbers are read aloud along with the contractors’, or through simulated bids where their numbers can be reviewed, compared and scrutinized after the actual bid. It is a process of transferring knowledge through practice. Comparison becomes a valuable process in ascertaining bid preparation and submission, and where students can gain confidence in learning the art and science of cost estimating.

Effectiveness of teaching techniques. Though the authors state that experience in estimating is paramount for teaching students to be job ready, one doesn’t need to be a highly successful estimator or have many years as an estimator. What is important is teaching an awareness of all the elements and resources that form an estimate. There are no exact or right answers when evaluating student work such as can be found in other subjects taught within the curriculum. Cost items and the overall bid are created by being aware of all the elements in creating an estimate: the scope of the project, material, equipment and labor rates, evaluating subcontractor’s quotes, indirect cost, markup, etc. Over the years that the authors have taught the methods described in this paper, and have discovered that it is the process of creating a course that emulates an actual estimate that forms the motivation to learning through a discovery of knowledge – the process of acquiring and understanding knowledge through experiences and real world application.

Challenges encountered. Challenges are encountered in teaching any course, and teaching cost estimating is no exception. The greatest challenge in this course is finding projects that best encompass the elements of estimating while at the same time not overwhelming the students. If the scope of the project and the cost resources are beyond a student’s comprehension, then the motivation to learn through the experience will be lacking. And, the opposite is just as true -- if the project scope is too uncomplicated or simple, the course will lose its motivation and focus.

Improvements implemented. Reviewing the range of student pricing for some bid items, there are indications of their lack of experience and use of checks. Hence the need to evaluate their bids not only at the overall project level but also at an item-by-item level. The bid guidelines and checklists need to be reviewed and updated to include an acceptable range for each bid item. Bid items that fall outside the range will be regarded as non-responsive, and the entire bid will be
rejected. To help student teams address this requirement, students need to be taught the use of “ratios and analysis”, “rule of thumb” and how to use historical past cost data as a guide to check the accuracy of the unit price computed.

Conclusion

Cost estimating is an integral part of any construction process. Teaching cost estimating is best served by education through realism. This is important because students must be taught how to create an accurate cost estimate, and it all depends on the quality of knowledge transferred in their coursework. This paper described a unique approach to teaching heavy civil cost estimating, using a real world method that allows students to prepare bids on actual, recently bid state or local transportation projects. In utilizing actual projects, students are exposed to real world scenarios, and are able to compare their bid results with those of experienced contractors. This method is unique in that it provides the basis for students and educators to assess the quality of cost estimating knowledge delivered. Most significantly, this realistic exposure allows students to become practice-ready graduates.
References: