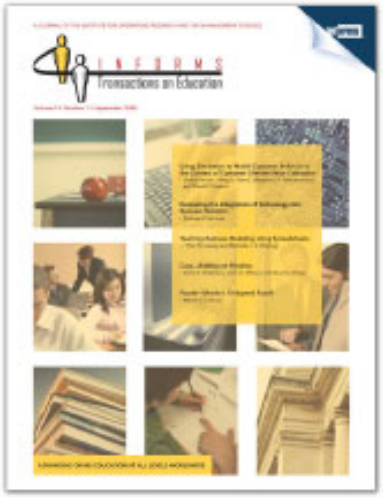

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Operations Research Capstone Courses for Business Majors with Analytical Backgrounds

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Clarkson University provides a one-semester capstone design course required for undergraduate seniors majoring in Engineering and Management. In this paper, we discuss how the capstone experience has been facilitated when the projects are operations research (OR) based. Key aspects include multiple student teams working on a single client's problem, student experience customized to the project, a client focused approach, and coaching of students whose academic background includes a single course dedicated to OR as well as other courses in engineering and management. We suggest why our practices may be applied at other universities with analytically talented business students. Many of our recommended practices apply to industry projects for students from any major (e.g., finding projects with appropriate scope).

Key words: operations research; capstone design; student projects with industry; operations research in business schools; engineering management
History: Received: May 2011; accepted: April 2012.

1. Introduction

Since 1954, Clarkson University has offered undergraduate degrees in Engineering and Management (E&M), originally called Industrial Distribution. However, it is only beginning with the class of 2010 that Clarkson began requiring E&M students to complete a team-based capstone design project as a culmination of their undergraduate education. Most of the time this course takes the form of a student project with industry. The vast majority of students take this three credit hour course during their final semester, though it is possible to take it during their seventh semester if they have satisfied all of the course prerequisites. Some of these capstone design projects focus on solving OR problems and others have related focus areas. All are based on knowledge and skills acquired in earlier course work and involve the process of devising a system or process to meet client needs.

Clarkson has about 3,500 students (3,000 undergraduates) and is located in the small college town of Potsdam in a rural part of New York State near Canada. The small size, university culture, and team projects tend to produce leaders. One out of every five of our alumni is an executive. The university is technically and practically focused with more than half of the students majoring in engineering and more than 20% in business. E&M is the third largest major on campus with nearly 300 fulltime undergraduate students enrolled.

Despite its small size and remote location, Clarkson has been named as having one of the best undergraduate engineering programs in the country (*U.S. News and World Report* 2011). The E&M program builds upon Clarkson's traditional strength in engineering and strong undergraduate programs in supply chain management (ranked #15; *U.S. News and World Report* 2012) and innovation and entrepreneurship (ranked #22; *Princeton Review* 2007). E&M students take courses in engineering, management, and a common core curriculum based primarily in the liberal arts. Some courses reside at the intersection of engineering and management; operations research is a good example of this because it applies engineering principles to management decision problems. The students take one course that is dedicated to operations research; in this course, they solve optimization and simulation problems using spreadsheet models they develop. They take courses related to the application of OR including operations and supply chain management, applied statistics, project management, quality management, organizational behavior, and organizational policy and strategy. In the project management course, students learn technical skills such as creating work breakdown structures; developing project plans, Gantt charts, critical path, PERT, allocating resources, budgeting, using

Microsoft Project software and sociocultural concepts concerning leadership, negotiations, corporate politics, and managing customer expectations. After completing the project management course, students are qualified to take the *Certified Associate in Project Management* exam administered by the Project Management Institute. Other courses develop their engineering and analytical skills such as statics; electrical circuits; thermodynamics; fluid mechanics; and multiple semesters each of calculus, chemistry, and physics. Their communication skills are built through a first year seminar course, a public speaking course, and required communication focus within the major.

Although fundamental OR methods such as linear programming, simulation, and queueing models are part of their education—and one student team recommended a client use linear programming to allocate resources in the spring 2011 semester—for the most part E&M students are prepared to conduct OR in the historical sense of interdisciplinary teams applying engineering and analytical thinking to solve ill-defined decision problems. This background has strengths and weaknesses in the OR project context. On the downside, E&M students have limited understanding of OR algorithms and software development. On the upside, E&M students are not wedded to any particular technologies; they tend to see the big picture and business processes clearly, communicate well with people of different backgrounds, think creatively, and suggest more easily implemented solutions than might be the case for some students with a strong theoretical foundation in OR.

The E&M program resides in the technically oriented business school; 37% of the business school faculty have engineering degrees and the three faculty members most closely affiliated with the E&M program are all licensed professional engineers with 6 to 27 years each of full-time employment experience in industry. We lean on our industry experience frequently while mentoring students in their capstone design projects.

In crafting our capstone design program, we leveraged what we could learn from others. Maleki (2009a, b) provided helpful insights into how one institution manages its engineering management capstone design projects. We received helpful informal advice from Abel Fernandez, Engineering Management Director at University of the Pacific; Robert Graves, Masters of Engineering Management director at Dartmouth College; and Ken Fordyce, who had facilitated capstone design projects for industrial engineering and OR students at Columbia University.

In creating student experiences for our OR capstone projects in 2011, we used the capstone course model provided by Gorman (2010). In the Gorman model, the faculty advisor acts as the senior partner of a consulting firm with the students (consultants) "owning" the problem, project, and deliverables. In the remainder of this paper, we will describe how we applied the Gorman model—with our own twists—to two example OR projects in the spring semester of 2011. In one of these projects, students analyzed operations at a distribution center and suggested improvements including a new storage layout. In the other project, students analyzed and suggested improvements to the modeling of capacities at an IBM semiconductor fabrication plant for purposes of feeding an aggregated capacity statement into a centralized planning engine. We do not discuss details of these projects. Instead we provide insights into how we managed these OR projects.

2. Project Selection and Initiation

2.1. Finding the Projects

Capstone projects come from three sources in decreasing order of their historical frequency: industry contacts maintained by the program director, other faculty members, and the students. Clarkson University maintains strong ties with industry, for example through the well-attended Career Fairs each semester. Industry recruiters—eager to place their name in front of E&M students and have access to high quality graduates—often propose excellent project ideas. The program director solicits contacts for industry projects through the recruiters while they are on campus. The program director has the greatest responsibility for the success of the program and thus the greatest motivation for ensuring that enough high quality projects are available for the students. Contacts are also solicited from program alumni and members of the Clarkson University Business Leadership Council.

Other faculty members are also motivated to find quality projects. Faculty members who advise a set of capstone teams working on a single problem receive teaching load credit equivalent to half of a regular three credit hour class. Advising capstone projects is interesting and enjoyable because each one is different and the advisor gets to work closely with small groups of students. Faculty members who recruit their own projects get a head start on the process. They gain a better chance of establishing client expectations and responsibilities consistent with their style at an early stage in the process and in framing the scope of the problem faced by the students.

Student motivation for proposing projects can include a problem they find interesting, an opportunity to help a former employer or family friend, the chance to prove themselves to a company they want to join post-graduation, and a 100% guarantee that

they will be assigned to their first-choice project if their project proposal is acceptable.

Regardless of who finds the capstone design problem, the project must be appropriate for E&M seniors, have suitable design content, and involve the consideration and evaluation of alternative solutions with the appropriate financial analysis. The problem must be challenging enough to merit a semester long project but not overwhelming. From the client view, the project must be important enough to merit its involvement but not so urgent that an end-of-semester deliverable would be too late.

Every project needs to have a client employee who facilitates the project and serves as a focal point for student contact with the client. It can take time for the client focal point to jointly work out the scope of a suitable problem statement. Of course, the client knows its business and its problems best, but the faculty know the students and their capabilities and learning needs best. Typically, the first discussion or two occurs vocally to narrow down an appropriate problem. Subsequently, either the faculty member or client writes an initial problem statement and iterates with the other until the problem statement and project objective are finalized.

Client proximity to campus is a factor because of travel time and expense. When frequent travel to the client site is not possible, we consider whether remote communication is reasonable for much of the project. Thus far, all of our OR projects have had at least three face-to-face visits with the client. Because many classes meet on Mondays/Wednesdays or Tuesdays/Thursdays, site visits often occur on Fridays. On one occasion, a busy client focal point drove to campus for a Saturday visit because that worked well for everyone's schedules. Although travel cannot be fully planned until the semester begins, client proximity and likely travel requirements need to be considered before committing to do a project. Funding for travel thus far has been provided by the client or by the E&M program, depending on distance and client capabilities.

We limit the number of projects to fit within our faculty teaching capacity each semester. This has led to postponing some projects or turning clients away temporarily. The more faculty who are available, the greater the number of capstone design projects that can be handled. Enough projects need to be offered so that all final semester seniors can graduate. On at least one occasion, this has resulted in the E&M program director volunteering to facilitate an additional project beyond her normal teaching load. Varying the number of students assigned to each project helps us balance the student demand with the supply of faculty available.

2.2. Assigning Students to Teams

Fewer than 20 students at a time have taken the capstone design course during a single fall semester, and they have a limited choice of capstone projects. The vast majority of students graduate in May and take their capstone design course in the spring semester with multiple offerings available. A two-to-three paragraph description of each capstone project is provided to the students about one week before they register for spring classes. Students provide their first, second, and third choice of projects to work on. Each project involves students meeting with their faculty advisor at a different time; consequently, the other courses students take have an influence on which capstone project they select because they need to avoid conflicts with their other courses. This increases the probability that students get their first (or at least their second) choice. A few students might not respond in time to the e-mail soliciting their project preferences; such students tend to be assigned to the less popular projects that are feasible for their schedules. The director of the E&M program assigns students to projects in approximately first come first serve sequence while also considering the desirability of balancing talent across the projects. The director knows many of the students because she teaches the required first year engineering design course (which facilitates teamwork in a design context) and as a result of various interactions that arise with particular students. The Clarkson student database provides easy access to reports such as E&M seniors sorted by GPA. All this facilitates the creation of balanced teams that correlate well but not perfectly with student preferences and client needs.

2.3. Sets of Teams Per Capstone Problem

Sets of teams may work on a single capstone problem. For example, for our two OR projects in spring 2011, one project had a team of five students working on a distribution center operations design problem and the other project had a team of five students and a second team of four students working on a capacity modeling process for IBM. There are advantages to having multiple teams work on a single problem. First of all, more teams come up with more ideas. For the IBM capacity modeling project, one team had two main recommendations and the other team had three; of these five recommendations, two had strong similarities (and meaningful differences) and the other three recommendations were completely different. Secondly, there are synergies for the faculty member and for the client in dealing with multiple teams. For example, for the faculty member, it is easier to facilitate two teams of five students working on the same problem for the same client than two teams of five students working on two different problems with two different clients.

Teams working on the same problem recognize that students on the best performing teams will tend to get better grades than those on the less successful teams. Consequently, they tend to view the other team(s) as competitors and thus typically do not help the other team(s). More than occasionally students will ask how they are doing with respect to the other team(s). Because it is never possible to give a complete answer to such questions, the faculty advisor may select a subset of the complete answer that provides the greatest motivation to the team asking the question. For example, the advisor may tell Team A that Team B has established a tighter relationship with the client (in order to encourage Team A to interact more with the client) or tell Team B that Team A has thought more thoroughly about X in order to get Team B to think more about X. At other times, the advisor may tell a team not to worry about the other team and focus on its own work. It is a judgment call as to how much the competitive aspect serves as a positive motivator versus a distractor.

When a client shares written information with one student team, often the faculty advisor will share that information with the other team(s). This avoids the client spending needless time repeating the information and results in the other team(s) being closer to providing a good solution. For fairness, the faculty advisor notes which student or team made the contribution. At times, the faculty advisor may decide not to share the information with the other team(s) if so doing would be too confusing or particular to the solution path taken by the team that acquired the information. It's a faculty judgment call as to whether the synergies of sharing the information outweigh the potential drawback of the information sharing leading multiple teams converging on a same solution. The key question: *Is this information that anybody solving the problem would need or is it pertinent only to a particular solution approach*?

Some projects are more amenable to more teams than others. Generally speaking, the more clearly specified the problem statement (including constraints, objectives, and operating environment), the more efficient it is to have more teams working on the project. For projects where a big part of the student experience is framing the problem, single team projects work best for all parties (students, client, and faculty member). A multi-team project with a very ill-defined problem is similar to having multiple teams each work on completely different projects. The number of teams per capstone problem can grow if a large number of students is interested in the problem.

For multi-team projects, the client can meet with all teams at once or with teams individually. Generally, meeting with all teams at once is appropriate early in the project and one team at a time is appropriate late in the project. Sometimes because of class schedules, only a subset of a team will travel to the client site for some of the meetings. Particularly late in the project, when a team travels to the client site, team members may split into subteams that meet with different employees of the client. Teleconferences tend to occur with one team (or subset of a team) at a time.

2.4. Assigning Faculty to Capstone Projects

Faculty members are assigned to facilitate capstone design projects just as they are assigned to teach other courses by balancing the supply of faculty expertise with the course demands for expertise. The ideal faculty member for OR projects will have deep knowledge in the problem area being addressed and in likely solution methodologies, familiarity with the client organization and its culture, coaching and mentoring talent, and experience solving practical OR problems (or at least engineering design problems) for clients. When a faculty member is lacking in one or more of these areas, he may ask a colleague for advice informally. It is possible for the faculty member to get advice from the client on some of these matters. The students are expected to acquire the resources and knowledge they need to accomplish their project successfully.

2.5. Client Expectations

Client expectations should be established prior to agreeing to conduct the project, although some details will get worked out later. Key expectations to establish include the following:

- A client focal point who will
  - Answer the students' questions and direct them to others in the client organization.
  - Facilitate the gathering of data as required.
  - Provide feedback on intermediate and final work products of the students.
  - Be available to support the project (the level of client focal point involvement varies as a function of the design problem and the number of student teams).
  - Travel to Clarkson in some situations (generally it is preferable for students to travel to the client site but at times it can be more efficient for 1 or 2 client employees to travel instead of 10 students, for example).
- Clients should have an understanding of
  - Student availability (this is one of five courses they take).
  - Student skill level (similar to that of "new hires").
  - The project must be a learning experience and not simply "work for hire."
  - The potential that the student team solution may not be feasible in the client environment. The primary client benefit from the project may be insights and factors to consider rather than a turnkey solution.

Some universities charge clients a few thousand dollars or more to cover project expenses. The client's willingness to pay a fee indicates that someone with authority to pay the fee will take this project seriously. Because of our rural location and having recently begun the capstone projects, we are not charging all clients at this time in order to stimulate demand for the best projects possible. This may change once the quality of our students' work becomes more widely known. The director is working to identify donor(s) willing to endow a fund for capstone project expenses.

2.6. Orienting the Students

When the previous semester is nearing its end, the faculty advisor may send the students an e-mail reminding them of the project and containing reading assignments for the break and a draft of the course syllabus. Some students will read these during the break and others will not. The e-mail will be resent a couple days before the new semester begins. Although we have yet to pinpoint the ideal volume of reading assignments to send, we suspect a few dozen pages or fewer may be appropriate in most circumstances.

The syllabus has some elements that are common to all projects such as expected effort, travel expense recording, logbook format, academic integrity policy, and forms pertaining to the assessment of the final report and final presentation. Some learning objectives are common to all projects and others are unique to the design problem being solved. Other syllabus information unique to the problem includes the project description, objective, tentative course schedule, grading criteria, and reading assignments.

The reading assignments depend on the project but typically do not include a textbook. In some cases, the client may choose to provide background information related to the project or the client organization. In other cases, the faculty advisor may find helpful articles to share. *Interfaces* is a common source for articles. Gene Woolsey's article on "Walking Thru Warehouses, Toolcribs and Shops" (Woolsey 1978) was useful to the students analyzing distribution center operations.

The initial class session orients the students, establishes expectations, addresses their questions, discusses the reading assignments, and encourages them to meet with their team and begin discussing how they will approach the design problem. A meeting with the client (ideally at the client site) will be arranged as early in the semester as possible subsequent to the first class meeting.

3. Client Focused Approach

Particular attention needs to be given to ensuring that the students interact sufficiently often with the client. It will be their tendency not to interact enough. Students are in the habit of solving well-defined problems. With OR projects, the problems are ill-defined. Even after the problems have been framed and defined, it is necessary for the students to consistently get client feedback on the assumptions they make and the approach they are taking. Both the client and the students will take some assumptions so much for granted that they do not think of mentioning them. Some assumptions need to be confirmed with others employed by the client organization besides the focal point.

Once it appears to a student group that the problem has been well defined, students have a tendency to focus on solving the problem and will be inclined to show their solution to the client only after it has become detailed and polished. Instead, the students should share tentative high-level outlines of their solution before they are fully shaped. This allows the client to provide feedback or suggest adjustments before it is too late. It is ideal if the client contributes to the solution as he or she would thus feel ownership for the idea(s) and be more likely to implement them. Mentioning these points to the students early in the semester is not sufficient. Students need to be monitored repeatedly regarding their level of client engagement throughout the process so that the habit of appropriate client interaction becomes engrained. It is the students' responsibility to work out with the client whether to have regularly scheduled weekly teleconferences or to communicate via phone or e-mail on an as-needed basis. However, the faculty advisor will ask about client interaction during many of the weekly meetings to "encourage" enough interaction.

Students tend to act as if clients are motivated solely by the desire to maximize the objectives of their organization. Students do not appreciate that individuals may have personal objectives that are more important to them than the overall good of their organization. For example, if a proposed solution changes the role of a person from that of a (high status) decision maker to that of a (low status) data provider, it is possible that person may fight such a solution. As Kempf (2009) observed, OR consultants will have more success saying "I can help you make decisions faster" than saying "I can help you make better decisions." Because students are in the habit of thinking solely of organizational needs and objectives, they need to be reminded repeatedly to consider the needs of client individuals. Faculty advisors may ask questions such as "How will this impact Karen's job? How does Bill feel about this? Does Fred understand how this solution will work out for him [even though the change may appear scary at first]?" Generally, we want our students to develop the habit of

considering the needs of clients as individuals while maintaining a focus on organizational objectives. As Gene Woolsey observed, "The right answer unsold is the wrong answer." Woolsey's *Interfaces* articles illustrate the importance of sensitivity to client individual needs (e.g., Woolsey 1978, 1982, 1986, 1988, 1989, 2006). Faculty with limited industry experience can become better advisors by reading these articles.

An additional element of our client focused approach is having client satisfaction as the most important criterion in determining the students' final grades. This is consistent with how consultants tend to be evaluated in industry. Each faculty advisor determines the percentage of the grade assigned directly to client satisfaction or to other line items that depend upon client satisfaction. For the two OR projects of the spring 2011 semester, the students were told the following in the syllabus:

The following elements will be considered in determining your grade in approximately descending order of importance:

- Client satisfaction
- Estimated magnitude of the potential or realized impact of your work (implemented work gets more credit)
- Technical quality of the work (this includes using the appropriate tools/methods for the situation)
- Clarity and efficiency in your communications (and for your final report and presentation, thoroughness of your communication)
- Professionalism in all respects
- Individual contribution (this can rise higher in this list if a student doesn't pull a fair share of the load.)

Client employees who attend the final presentation or read the final report may be given assessment forms to complete that rate various attributes on a scale of 1 to 5. Furthermore, the faculty advisor will discuss the project results and their usefulness with key client contacts.

4. Project Execution and Mentoring Approach

Project management, public speaking, and other courses are required prior to or concurrent with the capstone course in our E&M curriculum, so we customize our advice to each team on an as-needed basis. We spend little time discussing generally applicable consulting practices except in the context of their particular project. There are several reasons for this. The approach helps the students maintain focus on their project. The concepts stick deeper in their minds if they learn them as they apply them. And, finally, with only a single semester to complete the project, there is limited time for theoretical discussions.

As discussed in the introduction section above, we applied the Gorman model to structure the project as a consulting engagement with the faculty advisor filling the role of senior partner and the students doing the analysis and making recommendations to the client. The faculty advisor meets weekly with the teams for about an hour. (One of us tried 35-minute weekly meetings but this was not enough time.) At some meetings, particularly early in the semester, all teams are present, but most meetings are with one team at a time. At most meetings, the students present their project's status, technical details and issues they want to share or discuss, and plans for the coming week. Early in the semester, technical details tend to be the student view of the problem and the current processes and design and later in the semester alternative solution approaches and eventually their recommended design. Each student must present technical details at least once during the semester.

In addition to having client satisfaction as a principal objective, of course, the faculty advisor wants the students to learn as much as they can from the experience. Typically, this involves the advisor using Socratic questioning so that the students discover solutions for themselves as much as possible. The faculty advisor must balance allowing students to work out issues for themselves with the desire to keep the project on schedule. If a student team goes an entire week without making substantial progress on a question raised the previous week, the faculty advisor may become more direct in suggesting an approach. Because the students have had only a single OR course, their knowledge of OR methodologies may need to be supplemented. The faculty advisor may suggest reading material on methodologies that may be appropriate for their problem. The distribution center student team found an excellent paper on its own that provided insight into its recommendation for a new cross aisle at the warehouse (Berglund and Batta 2012).

A mistake one of us made was allowing a student team to have the initial client visit without the faculty advisor. The thinking at the time had been that without the faculty advisor present, the students would develop a tighter bond with the client and be more comfortable asking the "stupid" questions they needed to ask. That objective was met and the students did well. However, an unanticipated drawback was that the faculty advisor was less prepared to offer quality advice during the next few weeks of the project than he would have been had he joined the students during the initial visit.

Each student is required to have a one-on-one meeting with the faculty advisor at least once during the first third of the semester and at least once during

the final third of the semester. These meetings facilitate relationship building and allow students to speak candidly about the project. Although students sometimes bring issues to these one-on-one meetings, the faculty advisor drives these meetings by asking questions. In addition to project based questions, the advisor may ask the student about post-graduation plans. Capstone projects allow the faculty advisor to get to know the students well so career advice can be dispensed.

The first step of the project is for the students to develop a reasonable understanding of the problem and an approach for addressing it. The second step is for the students to create a project plan and confirm it with the faculty advisor and client. These first two steps should occur within the first two to four weeks even as teams recognize that the details of each can change. Typically, the tasks to be completed and when are determined prior to complete decisions on who will do them. The advisor encourages the students to include a time buffer of at least one week at the end of the project plan to protect against uncertainties and at least another week to allow time for faculty review of the near-final draft report and presentation and for incorporation of faculty feedback.

The students decide on their own how to allocate assignments to members of their team. Typically, before several weeks have passed, one student will end up as the team's leader either through election or force of personality. For some projects, a team may divide its efforts into subteams that each has its own leader. Although this is all student responsibility, the faculty advisor will keep an eye on team dynamics, encourage the students to work out issues among themselves, and ask Socratic questions to get the students thinking about how to best resolve personnel issues. Occasionally, the advisor may need to chat with a student who is failing to help his team.

To conduct the capstone design projects, the students have used Excel, Microsoft Project (for project management), and Risk Solver (for optimization modeling). They had used this software in their prior classes and have it available in the Clarkson University library and computer labs; some students had it on their personal laptops as well. We have not needed to provide any specialized hardware or software.

We require students to keep a logbook of activities and record the hours spent on each activity totaling a minimum of 135 hours during the semester. Students are encouraged to think of this as the hours they would bill a client and provide enough detail so that the client would not object to paying the bill. Regular transmissions of the logbook can help the faculty advisor monitor the students' activity. This is useful in dealing with those students not carrying their share of the load. Too few hours are an indication of a need for increased activity. A suspicion that hours may be exaggerated can be addressed with questions about the output that resulted from a many-hour activity. Logbook entries and these discussions of them aid in grading individuals on a team project.

5. Project Closure

The final report should be provided to the client at least a few days (and preferably a week) before the final presentation. It is possible that a near-final draft will be provided at that time and a final draft provided on the day of the presentation. Because the final report and presentation are seen by the client, the faculty advisor should provide editorial comments in time for the students to make adjustments before their final delivery.

No matter how much advance planning is done, students scramble to finish at the end of the projects. One student logged 46 hours in his project's final week, not counting the work he did for his other four classes.

We have not yet had a project for which the client was disappointed. We know that day will come and when it does we plan on consoling the students and pointing out that they learned from the experience as well as explaining to the client where we went wrong and how we will avoid a repeat of the failure in the future. If we don't fail once in a while, then we are not tackling problems that are difficult and important enough.

The faculty advisor will receive final feedback from the client. In soliciting this feedback, the faculty advisor's primary goal is to learn what to do better on future projects and strengthen the relationship with the client.

At the conclusion of the project, students are asked as individuals to allocate $20,000 in fictitious bonus money to their team members and themselves and to comment upon the reason for the allocations. It is not permitted to allocate the bonuses equally to all teammates; however, it is permitted to have some of the teammates receive an equal bonus. These peer assessments tend to confirm (rather than enlighten) the faculty advisor's opinion on relative contributions but can result in an individual's grade shifting by half a letter grade from what the faculty advisor thought it might be.

6. Conclusion and Observations

The practices described above were useful in managing capstone design projects for two OR projects in the spring 2011 semester. Each of these projects was successful from a student view (learning) and client view (useful). One favorable sign was an 80-page near-final student report marked up with

the handwriting of the distribution center manager who said he had read it cover-to-cover *twice* prior to the final student presentation. Two months later he said that they had implemented two of the students' recommendations—reconfigured pick area racking and instituted a tracking log for pick totes—and was looking forward to using additional recommendations as they continued to grow their operations.

Practices central to the success included finding appropriate projects with great clients supporting the effort, multiple teams creating recommendations for a single problem, a client focused approach, and faculty advising tailored to the issues at hand.

You might wonder how students who had taken a single course dedicated to OR could do well addressing OR problems. Consider the key elements of successful OR practice. Robinson (2006) said that the generic activities most central to OR practice are analysis and related consulting. Murphy (2005) lists the following 11 steps for building and using OR models:

1. Recognize the symptoms.
2. Observe the situation.
3. Define the problem.
4. Select the appropriate tools.
5. Gather data.
6. Formulate a mathematical model (if necessary).
7. Validate the model.
8. Define scenarios and solve the model.
9. Analyze the results.
10. Communicate the analysis.
11. Implement a solution to the problem based on the analysis.

With their background in engineering and management, these students are strong in steps 1, 2, 3, 5, 7, 9, and 10. Step 11 is something only the client can do. The students addressed steps 4, 6, and 8 with the knowledge they had learned previously at Clarkson, with new knowledge they gained as a result of their particular projects, and through their own creativity and applied common sense. Rather than build detailed math models, they tended to make analytically based suggestions for process design improvements.

Einstein said, "The whole of science is nothing more than a refinement of everyday thinking." It is through the refinement of their everyday thinking as a result of their Clarkson University education that our E&M students have been able to apply OR in solving ill-defined management decision problems and in communicating their recommendations to clients successfully. We believe it is possible for analytically talented business students at other strong universities to do the same.

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