



A Cross-Discipline, Project-Based Approach to Teaching Engineering Economy

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Abstract

In this paper, we describe a project-based approach to teaching Engineering Economy. The semester-long project has been designed to foster cross-disciplinary interactions between Electrical and Computer Engineering (ECE) students and Civil Engineering and Engineering Technology (CE) students during the Fall 2013 semester. To facilitate the cross-discipline project, a phantom company, Orange Inc., has been fabricated as the employer of the ECE students. Orange Inc. has been described to the students as a consumer electronics company with product lines that compete with those of Apple and Samsung. Additionally, Orange Inc. has an online marketplace where applications and other digital media may be purchased. Due to rapid growth in demand, the availability of the online marketplace has become a concern. Therefore, Orange Inc. has issued a request for proposal (RFP) for the development of a new data center. The CE students were tasked with forming groups (as fictitious companies) to respond to the RFP with the ECE students acting as internal liaisons to aid the CE students in their proposal development. The ECE students were required to generate estimates of quarterly operating and maintenance expenses for the data center and were given a trajectory of expected benefits from the data center over its 10-year expected lifecycle. After the CE groups submitted the proposals, the ECE students were then tasked with generating quarterly pro forma cash flow statements for each proposal. The proposal cash flows were compared using incremental rate of return analysis to determine which proposal was the best from an engineering economic perspective. Finally, each ECE student was required to write a performance report detailing the successes and failures of each individual, the ECE group, and the CE group with whom they worked. A similar reflection piece was required of the CE students.

1. Introduction

Each department within our College of Engineering teaches its own section of engineering economy. Engineering economic analysis in practice, however, evaluates projects with contributions from several different engineering disciplines. In an effort to close the gap between the educational experience and experience in practice, we have developed a project-based approach to foster cross-disciplinary interactions between Electrical and Computer Engineering (ECE) students and Civil Engineering and Engineering Technology (CE) students during the Fall 2013 semester. ECE students were placed on project teams with CE students and were tasked with responding to a request for proposal (RFP) concerning the development of a data center. The ECE students were enrolled in a one-credit engineering economy course whereas the CE students were enrolled in a three-credit project management course, with engineering economy included as a module.

The instructors created a phantom company, Orange Inc., in order to set up the project-based approach. Orange Inc. was presented to the students as a technology company whose product lines compete with Apple and Samsung in the consumer electronics and online marketplace industries. Orange Inc. was experiencing rapid growth, which caused the online marketplace to experience a decline in availability. Therefore, Orange Inc. released an RFP for a design-build of a 50,000-node data center to handle the company's expanding server needs. The RFP was released to interested "companies" (groups from the CE project management course) who responded to the request with a bid submission. ECE students were tasked with developing server specifications for the data center RFP and acting as Orange Inc. liaisons to the CE "companies" preparing bid proposals. A total of six bids (one from each of the CE "companies") were submitted to Orange Inc.'s Chief Financial Officer (the ECE instructor) and Chief Development Officer (the CE instructor). The full estimates from each completed bid were then assigned back to the ECE students, who conducted a rate of return analysis on the submissions. Selection criteria presented within the RFP were then used along with the rate of return analysis of the proposals to select the winning bid.

This project-based approach successfully integrated content across two courses, while providing opportunities for students from four different programs to interact with each other on one project. The instructors' desire for the ECE students to learn more about project management and the CE students to have actual clients provided easy access for coupling the interdisciplinary complexities of a major project for engineering economy students. The result was an increased student appreciation and awareness (based on student reviews) of the effort required to fully bid out a proposal and the economic factors involved in actual cross-disciplinary projects. Students were evaluated independently and as a member of their respective group or "company". Evaluations included generation of project documents and assessments, as well as performance reflection pieces at the conclusion of the project assignment.

The remainder of the paper is organized as follows. Section 2 discusses the origins of the idea to foster cross-disciplinary interactions across departments at the authors' institution. Section 3 provides a description of the phantom company Orange Inc. created to facilitate the project assignment and gives an overview of the project setup. Section 4 describes the request for proposal (RFP) with the details of what the CE students were expected to produce and how the ECE students contributed in the proposal development process. Section 5 provides a description of the engineering economic analysis performed on the proposals upon submission. Section 6 outlines the methods of communication used throughout the semester along with the overall schedule of the project assignment. Section 7 takes a step back and examines the overall course outcomes with respect to the engineering economy course and relates how the project assignment covered a subset of those outcomes. Finally, Section 8 gives an overall reflection on the cross-disciplinary, project-based approach employed by the authors, including what aspects worked well and what aspects failed, with an aim toward improving the assignment in future offerings.

2. Project Genesis

The presented cross-disciplinary, project-based approach to teaching engineering economy stemmed from a four-person discussion that occurred prior to the beginning of the sixteen-week Fall 2013 semester. The discussion centered upon an exploration of alternative and innovative

ways each department within the College of Engineering could teach project management and engineering economy. Currently, each department teaches the course content independently. Electrical and Computer Engineering (ECE) students cover the engineering economy materials within a one-credit course that meets in class once per week. ECE students are introduced to project management distributed throughout their coursework, including a couple of lectures on the critical path method in engineering economy, but do not have a stand-alone project management course. Civil Engineering (CE) students cover engineering economy within a three-credit course offered on project management. The sixteen-week CE project management course includes a five-week module for engineering economy, corresponding to a course with approximately one-credit hour of content covering engineering economy and two-credit hours of content covering project management. Mechanical Engineering (ME) covers project management and engineering economy as modules within a three-credit course offered on the process of design. All courses on engineering economy and project management are offered only to senior-level students in the fall semester.

The initial discussion brought together the Dean of our college with the faculty representative from each department responsible for teaching engineering economy and/or project management. The group expressed a desire to re-evaluate the way engineering economy and project management content is covered within each department and across the college. With a growing enrollment across the college, the discussion focused mainly on long-term planning, brainstorming ways to 1) maintain course content, 2) make faculty resources available for other courses, 3) foster interdisciplinary interactions amongst students and faculty, and 4) utilize project-based learning to give the course content a real-world application. There was also a realization that both project management and engineering economy had turned into floater courses within the ECE and CE departments that passed between faculty members as an assignment. As it turns out, the CE instructor teaching project management and the ECE instructor teaching engineering economy were offering the courses as new preparations. While the long-term planning will likely change how the courses are offered in the future, the faculty members teaching the CE and ECE course content during the Fall 2013 semester felt the new preparations presented an opportunity to try something new and different. This initial four-person meeting led to the development of the Orange Inc. Data Center Proposal project idea that was further developed and implemented during the semester. The ME faculty representative opted out of the project assignment for two reasons: (1) The ME course that includes project management and engineering economy content is well-established, so including the datacenter project assignment would require other material to be cut from the course, and (2) The ME instructor did not feel that the datacenter project assignment was as pertinent to ME students as it was to ECE and CE students.

3. Orange Inc. – Company Description and Project Setup

Orange Inc. is a fictitious American company that designs, develops, and markets consumer electronics. The most popular products developed by Orange Inc. include the uPhone smartphone, the uPad tablet computer, and the uPod digital media player. Additionally, Orange Inc. has a comprehensive digital media online store, called uApps, which is currently hosted on a cluster of 5,000 servers located near the headquarters of Orange Inc. With a three-year growth rate of 8,500% and 2012 net revenue of \$172 million, Orange Inc. is poised to compete with

market leaders such as Apple and Samsung. However, with such fast-paced growth, each potential opportunity for growth must be carefully considered from an engineering economic perspective to ensure sustainability of the company.

Equipped with this backstory, the ECE students were told on the first day of the semester that they were employees of Orange Inc. and were asked to provide input and recommendations to the Chief Financial Officer (CFO) of Orange Inc. as part of an internally selected economic advisory team. The ECE course instructor played the role of the CFO and periodically sent out memos via email throughout the semester asking the economic advisory team to perform engineering economic analysis and provide recommendations on decisions ranging from equipment selection to insurance policy choices. These company-specific problems comprised the homework assignments for the course, covering topics such as present and future worth analysis, equivalence, nominal vs. effective interest rates, and internal rate of return calculations.

To facilitate the introduction of the cross-disciplinary project assignment, the students were told that the utilization of the servers hosting the uApps online store had been steadily increasing over the last two quarters, which has caused some minor issues with availability. Additional servers are being added to the cluster as a short-term remedy, but for a long-term solution the company has decided to pursue a new 50,000-node data center. The company's Chief Development Officer (CDO), played by the CE course instructor, has planned to issue a request for proposal (RFP) to companies interested in bidding for the job.

The interested "companies" were comprised of CE students placed into teams through a random process involving a deck of cards and permanent markers. A volunteer student was asked to hand out one card to each student. Each student wrote her or his name on the card with the marker and returned the card to the volunteer. The cards were then shuffled and dealt to the students to determine the teams. This process yielded six groups: five groups consisting of five students and one group with four students. Once teams were assigned, the students were given five minutes to determine, agree upon, and present their company names. They were asked to exchange contact information, set up an initial meeting time, and provide the key company representative's contact information to the instructor. Interestingly, there was never a requirement for the teams to select a team leader; rather, leaders emerged within each team during the course of the project.

The ECE students were assigned as points of contact to each of the six companies (CE groups) planning to respond to the RFP to assist them in better understanding the needs of Orange Inc. in terms of server selection, networking equipment, generators, and uninterruptible power supplies (UPSs). In an attempt to best distribute the talent and expertise of the students in the class, the ECE instructor selected the members of each point-of-contact group, ensuring there were at least one EE and one CpE student in each group. This process resulted in three groups with four students and three groups with three students.

At the end of the fourth week of classes, the CDO (CE instructor) and CFO (ECE instructor) issued the RFP to the group of interested "companies" in a presentation describing Orange Inc. and the company's need for a new data center. The presentation was held during the normal class period of the CE project management class. However, in an effort to be as authentic as possible, we sent out an email invitation prior to the meeting to the key contact person from each

“company”. The students were asked to attend the meeting as company representatives, with each team considered as an independent, competing company. At the start of the meeting, we told students that we would be divulging company-specific information during the meeting and each student must sign a non-disclosure agreement. When handing out the forms created on Orange Inc. letterhead, we took a moment to step out of role-playing to explain the purpose of this type of form within industry. Because this was the first time the majority of the students had ever seen the form, we wanted to be sure to explain the process and to briefly go over the verbiage found on the agreement. Once the forms were explained, we reverted to Orange Inc. representatives. A single copy of the RFP was handed out to one representative from each “company”. A PowerPoint providing the highlights of the RFP was then presented to the students. At the end of the presentation, the students were encouraged to ask questions.

During the planning phase of the RFP, the instructors discussed incorporating an RFP addendum into the learning experience. Necessity of the addendum was immediately realized during the meeting based upon a few of the questions posed by the “companies”. This led to an addendum being released approximately three days after the original RFP that provided additional details for the shell design component. The RFP itself was issued at the end of the fourth week, which gave the students two months before the proposal was due. The proposal was due at the beginning of the thirteenth week of the semester (c.f., Table 1 for details of the project assignment schedule, Appendix 1 for the RFP, and Appendix 2 for a copy of the addendum).

The point-of-contact groups in the ECE class were assigned in the middle of the fifth week of the semester and the point-of-contact groups were briefed on their role in the project during the sixth week of the semester. In this briefing, the CDO (CE instructor) and CFO (ECE instructor) described the RFP to the ECE students and explained the expectations for them as liaisons to the companies developing proposals to respond to the RFP. Some of the expectations outlined included: 1) to supply server specifications to the company (by the end of the sixth week); 2) to work with the assigned company to help formulate the technical approach; 3) to answer specific technical questions as they arose; 4) to forward questions to upper management when necessary; and 5) to review the proposals once submitted.

4. RFP: Elements and Expectations

The RFP served as the primary document provided to both classes of students to set the expectations. The RFP, which is included in Appendix 1, was modeled after three actual RFPs available from private and public resources. The expectations for the RFP submission were laid out within the RFP, which contained four sections: 1) Background; 2) Timeline; 3) Summary of Request for Proposals, and 4) Proposal Evaluation and Contract Award Procedures. The “Background” section provided a brief description of Orange Inc. and the motivation for the project. The “Timeline” section provided the deadline for submission and the delivery instructions. The delivery instructions included which documents should be submitted, a delivery address, the number of copies required, a statement expressing that late submissions would not be considered, and contact information for proposal related inquiries.

The “Summary of Request for Proposals” section identified the general and project goals of the RFP and the specific requirements requested. The specific requirements included 1) the design

firm contact information, 2) design firm statement of qualifications, 3) document identifying proposed location for facility placement, 4) preliminary shell design of the server building, 5) a document detailing options, sizes, and capacities for generators and uninterruptable power supplies (UPSs), 6) a document detailing options for foundation, 7) a preliminary cost estimate, and 8) the proposed project schedule broken down by task. Additional information was provided in the RFP to detail the design documents requested as part of the preliminary shell design component. For the preliminary cost estimate, the “companies” were asked to provide the total estimated cost for labor, materials, and installation (if required) with an individual breakdown for: site preparation (grading and utilities), land acquisition costs, shell costs, wiring costs, and anticipated annual operation and management cost. The results of the preliminary cost estimate were used for the engineering economic analysis conducted later by the ECE students.

The “Proposal Evaluation and Contract Award Procedures” section provided the weighted breakdown for evaluation. The weighted breakdown for the evaluation used to score the proposal included 15% for location considerations, 35% for the technical approach used for facility design and layout, 20% for the project schedule, and 30% for the results of the economic analysis on the estimated project cost. This final section of the RFP also included a discussion of how contracted work would proceed for the selected company.

It was expected by the instructors that the ECE students would be called upon for help primarily in creating the document detailing options, sizes, and capacities for generators and UPSs. To appropriately determine the capacities needed for the generators and UPSs required a detailed power schedule for all equipment in the data center including the servers, memory banks, networking equipment, lighting, and cooling equipment. Since the ECE students were more familiar with this sort of equipment and were experienced in generating power budgets for buildings, it was a natural fit for the ECE students to help with the creation of this document. The other aspects of the proposal where the ECE students helped were in the cable routing and layout of the server racks in the data center as well as with the preliminary cost estimates.

5. Proposal Evaluation: Engineering Economic Analysis

Prior to the submission of the proposals, the ECE point-of-contact groups were required to perform research on their assigned company’s planned location for the data center and generate estimates of quarterly operating and maintenance (O&M) expenses for the data center including electricity costs to power and cool the servers and associated equipment, replacement costs for faulty parts, salaries of the network administrators and maintenance crew to be staffed at the data center, and any other location-specific costs that should be associated with the data center. The ECE students were also given a common trajectory of expected benefits from the data center over its 10-year expected lifetime. From this trajectory of expected benefits and the estimated O&M expenses, the ECE students were required to generate a quarterly cash flow over the 10-year lifetime. The reason the students were required to generate a quarterly cash flow was to force students to distinguish between quarterly interest and effective interest, especially when using the Minimum Attractive Rate of Return (MARR), which is an effective interest rate¹.

Upon submission of the proposals, the proposals were distributed to the ECE point-of-contact groups for a three-stage review process. Since each proposal included detailed costs required for

the data center to be built, the budget outlined in each proposal gave the ECE point-of-contact groups the initial costs of the data center. These initial costs had to be distributed over the expected 6-quarter construction phase of the project and combined with the previously generated quarterly cash flow over the subsequent 10-year lifetime of the data center. Each point-of-contact group reviewed the proposal submitted by the company assigned to that group in order to generate the 46-quarter cash flow representing the financial side of the proposal. To complete the first stage of the proposal review process, each point-of-contact group was required to determine the *internal rate of return*^{1,2} of the assigned proposal based on the 46-quarter cash flow.

The second stage of the proposal evaluation process paired the point-of-contact groups together and required the larger group to generate an incremental cash flow^{1,2} and perform an *incremental rate of return analysis*^{1,2} to determine which of the two proposals was better from an engineering economic perspective. The minimum attractive rate of return (MARR) for Orange Inc. was given as 5% (for before-tax calculations). Of course the MARR is an effective interest rate, and the incremental rate of return initially determined from the 46-quarter incremental cash flow is a quarterly interest rate. Thus, to determine the better alternative, the students had to convert the quarterly rate of return to an effective annual interest rate before comparing it with the MARR.

The results from the second stage produced three remaining viable proposals. In order to be sure that every ECE student properly understood the incremental rate of return analysis method, the third stage of the proposal evaluation required each ECE student to perform an incremental rate of return analysis on the three remaining proposals. To facilitate this process, the ECE instructor emailed to each ECE student the spreadsheets generated from the first two stages of the proposal evaluation so that each student had the same information and assumptions as a baseline for comparison. For the third stage, the students had to recognize that when performing incremental rate of return analysis on three or more alternatives, the alternatives must be rank ordered by initial cost and compared pairwise starting with the lowest initial cost alternative as the defender and the second-lowest initial cost alternative as the challenger. Each pairwise incremental analysis results in a winner based on the MARR of 5%. Through this process, a single winning bid was selected. Interestingly, the proposal that was the best from an engineering economic perspective was also technically superior and the most professionally organized proposal.

The fourth and final stage of the proposal evaluation process required the ECE students to submit a written performance report in which each individual evaluated the quality of the work produced by the assigned company, along with the performance of herself or himself, and all other point-of-contact members in her or his group. The performance report required students to focus on identifying the successes and failures, the consequences of those successes and failures, and how to recreate success or avoid failure in a similar situation. The goal of the performance report was to gauge how well students perceived issues with the proposals and to force them to reflect on how they could have done better in the project assignment.

6. Methods of Communication and Project Assignment Schedule

Given that the project assignment described in this paper involved two different courses offered in different departments, a significant effort was required to coordinate the assignment. The course instructors periodically met to discuss the progression of the project assignment and often

went to the other instructor's class to help answer questions and aid in setting the expectations for each student group. In terms of communication between the instructor and students, the instructors conveyed information in class and through the use of memos generated on Orange Inc. letterhead. For reference, a timeline for the project assignment is shown in Table 1.

Table 1: Timeline for Project Assignment

Event	Date	Week
Semester begins	8/26/13	1
CE companies assigned	9/12/13	3
RFP presented to CE companies	9/20/13	4
RFP addendum released	9/23/13	5
ECE point-of-contact groups assigned	9/25/13	5
ECE point-of-contact groups briefed on RFP	10/2/13	6
ECE server recommendations due to companies	10/4/13	6
Quarterly O&M expenses and benefits assigned to ECE students	11/12/13	12
2 nd meeting with ECE students	11/13/13	12
Proposals due	11/18/13	13
Proposal evaluation assigned to ECE students	11/20/13	13
Stage 1 and 2 of proposal evaluation due	12/6/13	14
Stage 3 of proposal evaluation due	12/13/13	15
Stage 4 of proposal evaluation due	12/18/13	16
Proposal feedback sent to CE groups	12/20/13	16

To facilitate the implementation of the project assignment, students within the CE course met to work on the project assignment inside and outside of class. Every third class meeting during the open RFP schedule was set-aside for students to work on proposal development. The students were asked to bring their own electronic devices to wirelessly access the Internet in order to complete tasks or perform research. During these in-class meetings, the CE instructor, posing as the Orange Inc. CDO, could be contacted for questions (which were only answered to the “company” requesting the information). Office hours and emails were also well-utilized means of communication between the “companies” and both instructors.

Due to the fact that the ECE course was a one-credit course that met once per week, there were only a couple of classes set aside to work on the project assignment in class. These class periods were used to help the students understand the salient issues concerning data centers that they needed to know to aid the CE student groups. These topics included server selection, power requirements for the servers, networking equipment, generator and UPS sizing, electrical wiring, cable routing, memory storage options, storage connectivity, server cooling options, and merits of location considerations.

After the proposals were submitted, the last two weeks of the CE project management course were dedicated to exploring how business analysis, leadership, and public policy are important to project management. The students were asked to provide a two-page reflection discussing how one of these topics was relevant to their experience working on the class project. Out of 29 submissions, 27 of the reflections dealt with leadership. Within these responses the overwhelming sentiment was that the interdisciplinary experience helped the students work out

means to get everyone moving towards a common goal. The students were used to working with their peers within CE, but working with the ECE students was a new (and good) experience.

At the end of the semester, after the proposals were evaluated, the key contact from each company received an email summarizing how her or his proposal scored and whether or not that design was being considered for the contract award. The email was presented as a memo and provided feedback on the company's submitted proposal. The feedback was not overly detailed, but reflected the content normally provided within letters received following a bid submission.

7. Engineering Economy Course Outcomes and Relation to the Project Assignment

The ECE engineering economy course has the following description in the university course catalog:

“Decision making based on criteria of economic factors including present worth, future worth, internal rate of return, benefit-cost ratio, depreciation, and taxes.”

Given that this was the first time the ECE instructor taught this course, the following course outcomes were devised to align with the catalog description of the course. Upon completion of this course the student should be able to:

1. Interpret and evaluate the time value of money based on nominal and effective interest rates.
2. Generate and analyze cash flow projections for business start-ups and engineering projects.
3. Perform present and future worth analysis to compare economic alternatives.
4. Perform annual worth analysis to compare economic alternatives.
5. Perform benefit-cost analysis to compare economic alternatives.
6. Perform rate of return analysis to compare economic alternatives.
7. Use breakeven analysis to select the best economic alternative based on a given variable.
8. Determine the book value and depreciation schedule of property for the purposes of taxes.
9. Compensate for inflation when performing an economic analysis.
10. Use Microsoft Excel to analyze the financial impact of engineering economic alternatives.

Several engineering economic course outcomes and objectives were covered by this project assignment, including outcomes 1, 2, 6, and 10. However, in hindsight many students did not successfully fulfill all of these outcomes through the project assignment. For instance, several students forgot that the MARR is an effective interest rate, which caused them to make incorrect decisions in the incremental rate of return analysis. Another common mistake was in rank ordering the alternatives in stage three of the proposal evaluation. Many students used the total cost of the project over the entire 46 quarters instead of using only the initial cost. This mistake occurred more frequently than expected largely because the benefits were the same for each alternative (since the benefits were based on the benefit trajectory provided prior to the proposal

evaluation). This in turn led many students to ignore the benefits altogether and consequently become confused on the proper order for performing the incremental analysis.

In the overall schedule for the class, the project assignment required at least a portion of two in-class meetings (out of fifteen) and approximately four weeks of out-of-class work (which could not be allocated to other assignments due to workload considerations). For reference, the breakdown of the topics covered over the semester is provided in Table 2.

Table 2: ECE Engineering Economy Topic Schedule

Week	Date	Topics Covered
1	8/28	Introduction to class structure, cash flows, and business plan organization
2	9/4	Simple vs. compound interest and effective vs. nominal interest
3	9/11	Uniform payment series and capitalized cost
4	9/18	Gradients, continuous compounding, and analysis with Excel
5	9/25	Solving engineering economic problems, present and future worth analysis
6	10/2	Data center briefing and annual worth analysis
7	10/9	Benefit-cost analysis and internal rate of return (RoR)
8	10/16	Incremental RoR analysis and modified internal RoR
9	10/23	Midterm exam
10	10/30	Payback period and breakeven analysis
11	11/6	Valuation and depreciation
12	11/13	Data center Q&A session
13	11/20	Inflation and its effect on rate of return
14	12/4	Project Management: Critical path method
15	12/11	Project Management: Critical path method
16	12/18	Final exam

In addition to the data center assignment, the ECE students were required to write a business plan for a start-up company of their choosing. The purpose of the business plan was to have students develop business models and marketing strategies for a business start-up and map those to reasonable financial assumptions and create pro forma cash flow statements for the business. The business plan assignment was designed to partially cover course outcome 2. The remaining course outcomes were covered by the homework assignments, midterm, and final exam.

The out-of-class work breakdown included approximately five to six weeks of out-of-class work for students to complete the business plan, approximately four weeks for the data center project assignment, and six weeks of homework assignments. In hindsight, using five to six weeks of out-of-class work for the business plan probably was not worth the effort from the perspective that it only covered course outcome 2. However, one of the most difficult aspects of engineering economic analysis is in the formulation of reasonable financial assumptions that contribute to the generation of cash flows for analysis. In this regard, the business plan was a useful and meaningful exercise. In the future offering of the course, the business plan will likely be dropped to accommodate a deeper participation in the proposal development.

The grading for the ECE engineering economy course was allocated with 10% weight for homework assignments, 20% for the business plan, 20% for the proposal evaluations, 25% for

the midterm exam, and 25% for the final exam. For the proposal evaluation grade, the first three stages were each given 20% weight and the performance report was given 40% weight. Rubrics were developed and used for grading the proposal evaluation and business plan.

8. Reflections on the Project Assignment

The three greatest challenges faced during this interdisciplinary, project-based approach dealt with 1) communication, 2) the role of the faculty member, and 3) perceived lack of details provided within the RFP. While communication between students and faculty was readily available, communication between ECE and CE students varied substantially between groups. Some groups communicated freely throughout the process, while other groups had significant gaps between correspondences. The interdisciplinary communication that worked best occurred when both groups were clear about the expected and desired response. For instance, the CE student teams who requested server specific information from the ECE groups by a specific deadline (e.g., a two day turn-around) had a far better response than groups who left the request open ended. Additionally, interdisciplinary groups that communicated through phone or in person had more efficient communication than those who entirely relied upon email.

Role-playing during the project setup and throughout the development of the project assignment was interesting and beneficial to the faculty members involved. As a representative of Orange Inc., the instructors felt closer to the project assignment than on other projects assigned merely for classroom learning. Additionally, the project assignment was a new and open-ended project, and working with the students to complete the project assignment with no predefined outcome was exciting. The instructors also learned a lot about data center development throughout the process.

However, the CE instructor struggled during the proposal evaluation stage to balance the level and detail of the feedback provided to the students. Two groups provided professional quality submissions that were easy and enjoyable to read. The remaining groups' proposals fell short of expectations. Being overly critical was easier while playing the role of an Orange Inc. representative. Rating a poor proposal as "poor" is common and easy to do when minimal feedback is provided on proposals. However, looking at the proposal as a learning experience for the students allowed us to revise proposal feedback to be written in such a way as to provide "positive critical" feedback when warranted. In reflection, the educational value of this experience may improve if the first submission were a draft that received feedback from the faculty team and was offered a chance for revision. For the initial offering, because we wanted to simulate a "real-world" exercise, the additional chance for improvement was not included and the student who made comments expressing an interest in providing revisions was reminded that there are not second chances for poorly written and presented proposals in industry.

While simulating the "real-world" has value, the feedback received from CE students indicated that the project assignment was difficult in part because certain details of what to include in the proposal were not expressly stated. The perceived lack of details was evident in some of the final proposals, as a few of the groups seemed lost in producing professional quality documents. However, two groups exceeded the mark completely and provided submissions that would do well in competing for external resources if the RFP were real. In hindsight the two highest

performing groups did well because of their communication abilities within their groups and between CE and ECE students. Both high performing groups also benefited from having an experienced project leader that had co-op experience.

Generally, the ECE students appreciated the real-world example demonstrated by this assignment, but were uncomfortable with the ambiguity and lack of clarity characteristic of such real-world examples. Both instructors wrestled at times with the tradeoff between handholding and unrestrained ambiguity. Unfortunately, the ambiguity concerning which group was ultimately responsible for obtaining the requisite information about equipment for the data center led to a couple of poor proposals with unreasonable assumptions. This will be corrected in future offerings by providing clear expectations that the ECE students should provide the details with regard to equipment for the data center and the power budget. To further integrate the project assignment across the disciplines we hope to recruit the instructor of the power analysis and design class to include his senior ECE students as members of the “companies” bidding for the data center project. If this happens, the expectations can be more clearly set with regard to which students are responsible for specific portions of the proposal while requiring closer collaboration between ECE and CE students in creation of the proposal.

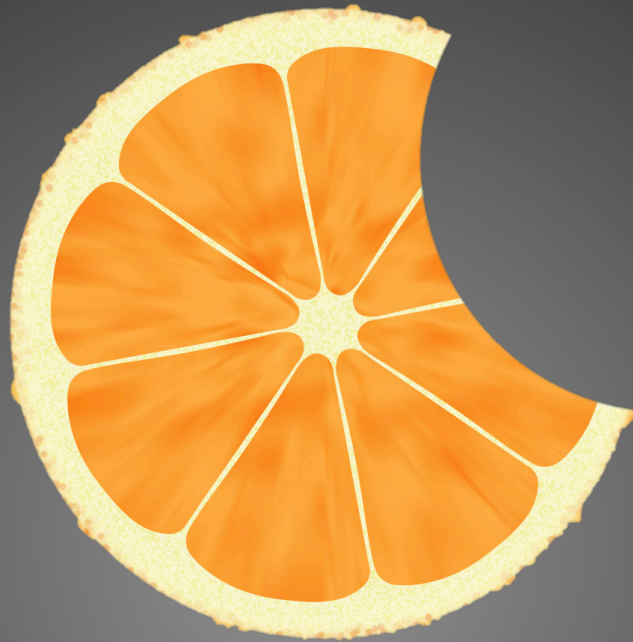
With regard to the engineering economic aspect of the project assignment, it was undesirable that only the ECE students were required to perform the rate of return analysis on the proposals. To address this issue in future offerings of the project assignment, we plan to move the entire project assignment schedule three full weeks earlier in the semester to allow time for the CE and ECE students to revise their proposals based on feedback received from the instructors and for the CE students to perform an engineering economic analysis on the final proposals. To be sure that the CE students do not simply recreate the steps of the analysis performed by the ECE students, the CE students would not be given the details of the analysis of the ECE students and would be required to perform a different type of analysis. Given that CE students are more likely to work in the public sector, a benefit-cost analysis would be a meaningful alternative to the rate of return analysis.

Another applicable topic that should be included in the future offering is depreciation of the different equipment involved in the data center investment. The instructors can go into detail about the different property classes involved in the data center venture and require a detailed depreciation schedule and after-tax calculations to be included in the engineering economic analysis.

References

- [1] Newnan, D.G., Eschenbach, T.G., Lavelle, J.P., “Engineering Economic Analysis,” 11th edition, *Oxford University Press*, New York, 2012.
- [2] White, J.A., Grasman, K.S., Case, K.E., LaScola Needy, K., Pratt, D.B., “Fundamentals of Engineering Economic Analysis,” 1st edition, *John Wiley & Sons*, 2014.

Appendix 1: Orange Inc. Data Center RFP



Orange Inc.

PIN: 92276

Design & Project Management Services for a Data Center

SUBMISSION DEADLINE NOVEMBER 18, 2013

ORANGE INC. DEVELOPMENT DEPARTMENT

REQUEST FOR PROPOSALS (RFP)

PROJECT: 92276

DESIGN & PROJECT MANAGMENET SERVICES FOR A DATA CENTER

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BACKGROUND

Orange Inc. is pleased to release this RFP for design and project management services for a data center to house our uApps e-store. uApps is a comprehensive digital media online store, which is currently hosted on our cluster of 5,000 servers located at our facility in Ada, OH. Increased utilization of our servers in our existing facility has increased causing some minor issues with availability during peak times. We are expecting this trend to continue and have been adding additional servers to our cluster to mitigate the problem in the short term. This data center RFP reflects our interests in developing a long-term solution.

TIME LINE

A. Proposal Submission Deadline:

The proposal deadline is **3:00 PM on November 18th, 2013**. The proposer will deliver the proposal in a sealed and clearly marked package. The proposal shall consist of four individual components within the sealed package. The four components required include the following:

Component 1 - Technical Proposal (hard copies – 1 original and 2 copies; 1 electronic copy);

Component 2 – Statement of Understanding Form (1 original – see Attachment A);
and

Component 3 - Fee Proposals (1 original).

Proposals shall be delivered by hand to:

[CE Instructor's Name]
Chief of Development
Orange Inc.

Email – [CE Instructor's Name]

Note: Proposers are responsible for making sure their proposal package is received by the established contact by the deadline. Proposers are advised against relying on delivery confirmation services. Packages are often mistakenly delivered to the Department of Civil Engineering located in the same building. The packages are not automatically forwarded to the Orange Inc.'s Development Department causing a delay.

Proposals received after the applicable due date and time prescribed in the RFP are late and will not be accepted.

A. Inquiries:

If a proposer requires any clarification or explanation of this RFP, the proposer must submit their request in writing or by email at least a week in advance of the RFP submission date. If Orange Inc.'s Development Department determines that a response is required in writing; an addendum to the RFP will be issued to all identified proposers by email. Inquires must be directed to the contact person listed above or to Orange Inc.'s primary point of contact assigned to your proposal development team.

B. RFP, Contracting, and Work Initiation Schedule

This proposal was released on September 20th, 2013 and will remain open until the closing date. Within two weeks of the closing date, the successful proposer will be contacted. A negotiated contract will be established within three months from the date the successful proposer is notified. Work will commence following establishment of the contract when directed by Orange Inc.

SUMMARY OF THE REQUEST FOR PROPOSALS

A. General and Project Goals:

Orange Inc.'s Development Department intends to contract a qualified firm to provide design and project management services for construction of a data center to house our existing uApps Store.

B. Specific Requirements:

All received proposals should include the following components:

1. Design Firm contact information (firm name and address; primary contact person's name, phone number, and email).
2. Statement of qualifications and experience for each project member on the design team. Identify the team lead and responsibilities for each member.
3. Document identifying proposed location for facility, including contact information for realtor and estimated cost for property acquisition (including property cost, taxes, and insurance).

4. Preliminary shell design of a building to house a 50,000 node server cluster and two (2) staff technicians. The preliminary design should include:
 - a. Plan view of site layout, including: facility placement, utility placement, parking for technicians, and grading requirements.
 - b. Elevation views of building including access points and lighting.
 - c. Floor plan of building including specifying locations for:
 - i. servers
 - ii. server racks
 - iii. networking equipment
 - iv. generators
 - v. uninterruptable power supply
 - vi. cable trays
 - vii. offices
 - viii. small kitchen
 - ix. technician storage/lab space
 - x. receiving dock
 - xi. HVAC for technician needs
 - xii. cooling equipment for servers and other electronic equipment
 - d. Floor plan showing interior lighting and electric outlet placement.
5. Document detailing options, sizes, and capacities for generators and uninterruptable power supplies.
6. Document detailing options for foundation and a range of cost estimates based upon required foundation type.
7. Document detailing the preliminary cost estimate for the planned project. Be sure to provide the total estimated cost with an individual breakdown for:
 - a. Site preparation (grading and utilities)
 - b. Land acquisition costs
 - c. Shell costs
 - d. Wiring costs
 - e. Anticipated annual operation and management costs

Please note that the estimated costs will need to include labor, materials, and installation (if required) for each component.

8. Document detailing cost estimate for professional services to manage the project construction.
9. Scheduled time line for project completion broken down by task.

PROPOSAL EVALUATION AND CONTRACT AWARD PROCEDURES

A. Selection Process

Orange Inc.’s team of internal engineers, project managers, and economic advisory team members will review the submitted proposals. The technical proposal will be evaluated using the following criteria:

- a. Location considerations (Weight 15%)
- b. Technical approach for facility design and layout (Weight 35%)
- c. Project schedule (Weight 20%)
- d. Estimated total cost of project (Weight 30%)

B. Basis of Award

Orange Inc. Development Department will make the contract award to the proposer whose proposal is determined to be of the highest quality and value to the company. Once Orange Inc. completes the proposal review, an award notification will be made to the proposer and contracting negotiations will begin.

ATTACHMENT A

Statement of Understanding/Signature Page



RFP for Project 92276 Design & Project Management Services for a Data Center

Authorized Signature: This RFP must be signed with the full name and address of the Proposer. The below-named individual, submitting and signing this bid, verifies that he/she is a duly authorized officer of the company, and his/her signature attests that all items and conditions contained in the Request for Proposal, for Project 992276 Design & Project Management Services for a Data Center, are understood and accepted.

DATE

Authorized Signature

Company Name

Address

City/State/Zip Code

Print Name of Authorized Signature

Telephone No. with Area Code

Appendix 2: Addendum to the Data Center RFP



ADDENDUM to Project 92276 RFP: Design & Management Services for a Data Center

This addendum serves to update RFP # 92276 to include additional specifications. The additional information is as follows.

1. Bathroom facilities should be included within the floor plan.
2. The timeline for project construction is not to exceed 12 months.
3. The data center will have an expected lifetime of 10 years.
4. Add security camera placement locations, card swipe access locations, fencing, and gated access locations to the appropriate floor plan.
5. Section A (Timeline) in the original RFP called for “four” components to be submitted by the deadline. However, only “three” components are given. “Four” was a mistake in the text. Only the three listed components within the original RFP are required.