2006-1906: TESTING THE "ART" OF ENGINEERING ECONOMIC DECISION-MAKING

Joseph Hartman, Lehigh University

JOSEPH C. HARTMAN is an Associate Professor in the Department of Industrial and Systems Engineering at Lehigh University, holds the George Kledaras Endowed Chair, and serves as Department Chair. He received his Ph.D. (1996) and M.S. (1994) in Industrial Engineering from the Georgia Institute of Technology and B.S. in General Engineering from the University of Illinois at Urbana-Champaign (1992). His research interests are in economic decisions analysis and dynamic programming. He is an active member of ASEE, IIE, and INFORMS and currently serves as Editor of The Engineering Economist.

Testing the "Art" of Engineering Economic Decision-Making

Abstract

Making an economic decision involves both science and art. The "science" is comprised of the analyses applied in the process, such as discounted cash flow analysis, sensitivity analysis, or breakeven analysis. The "art" involves defining the problem, identifying relevant parameters, synthesizing information, trading off multi-attributes, and considering non-economic influences. While traditional quizzes can test whether students understand the science, testing the art is more difficult. We utilize a single question, open-ended final exam for this purpose. Students are given a problem scenario, data, and supplemental information and merely asked whether a capital investment should be pursued or not. It is expected that they will justify their decision, although there are no requirements as to how. We describe our experiences with this approach, which has been implemented for five years now.

Introduction

Problem-based learning attempts to engage students in the learning process by having students (1) work on problems that are perceived as relevant or meaningful and (2) fill in gaps when presented with a situation that is "incomplete." Both of these traits are inherent in real problems – data is incomplete, problems are ill-defined, and results are requested without formal paths of inquiry. Establishing relevance with coursework has been shown to be a critical factor in engineering education [2].

As advocates of problem-based learning, we teach Engineering Economy in a decision-making context [3] such that students understand the entire process of making a capital investment decision from defining the problem; to generating solution alternatives; to estimating before and after-tax cash flows; to evaluating options under certainty, risk, time, multiple alternatives, constraints, and multi-attributes; to post-implementation and project tracking. Furthermore, we utilize numerous media sources to generate realistic problems such that students appreciate its application [4,5]. The goal upon completion of the course, as stated on the syllabus, is that a student is able to make, and justify, a capital investment decision.

While traditional mechanisms of evaluation (homework sets, quizzes, and exams) are good for testing a student's knowledge and skill in the use of formal methodologies, such as discounted cash flow analysis, performing a breakeven analysis, or choosing the minimum cost solution between two mutually exclusive alternatives, they do not necessarily allow for examining other relevant steps in decision-making (problem-solving). In the problem-based learning context, the goal is not relegated to knowing how to apply a methodology (i.e. execute a breakeven analysis). Rather, the goal is that a student understands how to (1) formulate a problem from incomplete data; (2) determine what parameter(s) are critical; (3) identify and execute the correct analysis (i.e. breakeven, project balance, scenario analysis, etc.); and (4) interpret the output from the given analyses. We refer to these skills as being the "art" in engineering economic analysis.

In this paper, we describe our experiences with an open-ended, three-hour final exam question to accomplish our goal of evaluating decision-making and problem-solving skills. While this can be accomplished with the use of projects or case studies [7], we prefer an exam format to test each student individually. Furthermore, in this format, the information provided is relegated, putting the students on an even "playing" field.

Specifically, we give the students a problem scenario with a lot of supplemental information and data relevant to the decision. The problem scenario is generally motivated by a company or government entity that has recently made or is contemplating a capital investment decision. The goal of the exam is to determine if students:

1. Ascertain the important elements of a capital investment decision. That is, they must recognize the problem being solved or opportunity that is presented and be able to identify the critical parameters for making the decision.
2. Marry the analysis (or analyses) to the assessment of critical problem factors.
3. Understand and comprehend when an assumption (or further inquisition) is needed or when data made available is useful.
4. Assess the non-economic impacts (intangibles) of a decision.
5. Can make a decision and put together a coherent argument to defend the decision.

Is the process perfect? No, but we believe it provides a good and fair method in which to assess a student's ability to make an economic decision. Furthermore, as evidenced by data from the past four trials (we are currently in the middle of the fifth trial), students are turning to more pronounced methods of risk analysis (sensitivity analysis, project balance analysis, and scenario analysis) without being asked. This is desired as we stress that basic discounted cash flow analysis is generally not sufficient to make a decision under risk or uncertainty.

The exam has been implemented in IE 226, Engineering Economy and Decision Analysis, at Lehigh University. The class is required by Industrial Engineering and Information Systems and Engineering majors, generally in their junior year. Upperclassmen from other engineering majors, most notably Computer and Mechanical, often take the class as an elective. In our four previous trials, class sizes have ranged from 41 to 67 students. There are currently 57 students in the class.

In this paper, we identify the traits that we believe are important when writing an open-ended exam. We also discuss the traits of a good solution. Finally, we assess the trends in how students have "attacked" these problems over the years. Students are more increasingly using risk analyses, which is encouraging given the difficult investment scenarios posed.

Writing an Open-Ended Exam

The actual "writing" of the final exam is straightforward. We utilize the following format:

> As a new hire to the engineering department, you are to determine whether the following investment should be made. You may use your notes, the text, your knowledge, and the attached information to assess the opportunity. Defend your investment decision rigorously and clearly. State, and justify, all of your assumptions. Your output should closely resemble that of a business case, although it is understood that your time is limited.

If possible, the data for your analysis (or analyses) should be extracted from the attached information. However, if data that you require is not available, state your assumptions to continue your calculations. In addition to defending your assumptions for any data created, you should also state possible sources for the data.

Take time to think about your answer thoroughly before you begin writing. Blue books have been provided. Feel free to take two – one to “scratch out” thoughts and another for the final report. You have 3 hours.

The difficulty with this approach is that the instructor must take the time to find an appropriate problem and do some research to ensure that enough data is made available to the students. We have found that a good problem has the following traits:

- Motivated by an industrial problem that is recognizable by most students.
- Critical factors in the decision can be identified.
- Intangible and non-economic factors are not trivial.

We illustrate by briefly reviewing the three problems we have used in the past. (We used the LNG investment twice, with additional information provided on the second try.)

1. *LNG Facility Investment*: Now defunct Enron Corporation had announced [1] that it is was considering a $300-$400 million development of a liquefied natural gas (LNG) terminal in the Bahamas to serve the Florida market, where gas demand was forecast to double between 2000 and 2009. In addition to the terminal in the Bahamas, plans were to build a 90-mile pipeline to move product to a location north of Miami. In the first trial, students were presented with one article that had considerable data. In the second trial, additional information such as historical natural gas prices and demand was provided.

   Key Elements: In a provided article, the president of Enron stated that a price of $3 per thousand cubic feet of natural gas makes this look like “a very attractive business,” thereby defining a very critical parameter. The environmental sensitivity of the area and “hot topic” of LNG investments were also interesting additions to the problem.

2. *Concorde Retirement*: One week before the final exam, British Airways and Air France announced that they would retire the Concorde from service within the year [6]. The students were given six different articles with information ranging from operating costs (when compared to current aircraft), development costs, demand, ticket pricing, and limited flight usage (due to airport restrictions).

   Key Elements: A number of critical costs were identified, including fuel costs and demand/price estimates. The students found the Concorde to be an interesting topic, as it is the only supersonic plane ever used commercially. Also, the students had to realize that the $3 billion in development costs were sunk costs, and thus irrelevant in analysis. Finally, the non-economic issue of a sonic-boom possibly affecting wildlife was another point of interest.

3. *Gold Mining Restart*: The students were presented with four articles and current gold and silver prices to evaluate the re-opening of a silver and gold open-pit mine on the Argentine-Chile border by Barrick Gold Corporation [8]. The operation was originally approved in 2001, but was delayed due to low gold prices. The company was evaluating (in the spring of

2005) whether to reconvene operations, which would lead to the production of gold and silver in 2009.

Key Elements: Clearly, the price of gold, or differential between the price of gold and the operating cost of removing the gold, is a critical factor – critical enough to delay the original investment. A number of non-economic factors were highlighted concerning the open-pit mining process.

Fortunately, for the instructor, the Web makes it relatively easy to assemble the required information. Searching media outlets such as *The Wall Street Journal* or the *Financial Times* will generally help identify a problem scenario. Company press releases, usually available on their website, can further augment this information. Finally, supplemental information is usually required. For example, in the mining problem above, historical spot price data for silver and gold over the past 10 years was gathered and provided. Similar information concerning inflation rates, demand, or relevant historical prices may also be gathered as necessary.

Grading an Open-Ended Exam

Identifying the critical parameters helps develop a road map for how the exams are to be graded. Essentially, grading this exam is similar to grading a project. However, one cannot expect comprehensive and perfectly coherent analysis (and conclusions) due to the time constraints. Thus, great value is placed on identifying the critical parameters (hopefully through some sensitivity analysis, even if it is rudimentary) followed up by some risk analysis involving the critical parameters.

For example, the gold mine investment decision is clearly linked to the price of gold. First, the student should be able to recognize this as an important input variable. Preferably, an estimate of the project's cash flow diagram can be ascertained (this was fairly straightforward as mining companies disclose an inordinate amount of data, including tonnage capacity, mineral yields, capital costs, and per unit, ton or ounce, operating cost data) and sensitivity analysis illustrates that the price of gold is critical. Second, given this conclusion, the student should perform some analysis or analyses – such as a breakeven analysis on the price of gold and a scenario analysis on likely gold prices, as they are given plenty of historical data. Conclusions from these analyses clearly lead to a better understanding of the risk of the project. Third, the students must recognize the non-economic impact(s) of the decision. Ideally, these would be integrated into the analysis, but should be noted at a minimum.

In addition to the analysis (or analyses), the student must put together a coherent argument. This includes listing assumptions with justification and tying arguments together. Of course, it must be understood that this is a timed exam and the business case may be a bit incomplete.

While the above describes an "ideal" solution, it does not overcome the fact that grading these exams requires judgment and time on the part of an instructor. Grading the exam is similar to grading a project in that rankings are relative. However, the above provides a roadmap to grading: Answers consisting merely of discounted cash flow analysis should be treated as average or below average. Good answers will probe the cause of risk (usually with sensitivity analysis) while very good answers will analyze the risks identified. Finally, the best answers will tie the logical arguments together, clearly state assumptions, and acknowledge other influential factors, such as non-economic factors. In order to grade fairly, this roadmap must be followed closely. We divide the student solutions according to the following cumulative answers: (1) basic cash flow analysis; (2) identification of risky parameters; (3) risk analysis; and (4) recognizing intangible factors. Again, it takes judgment on the part of the instructor as not all answers fit neatly into these categories and other factors, such as coherent arguments, are important. While grading would clearly be taxing with an extremely large class (100+ students), it is analogous to grading essays or projects.

To put the grading of the final exam in context, it is worth 25% of the final grade. The remainder of the final grade is determined from weekly homework (5%), short quizzes (20%), four projects (25%), and two hourly exams (25%). The homework, quizzes, and exams are more traditional in format (questions requiring specific answers). The measures ensure that the "science" of engineering economic decision analysis is also tested.

Student Analyses

Table 1 provides a count of the analyses performed on exams each year with the number of exams taken in parentheses. Note that this is merely a count and not an assessment of how well the analyses were performed.

Table 1. Exam analyses beyond traditional before-tax discounted cash flow analysis.

Analysis	2001 (56)		2002 (67)		2003 (47)		2005 (41)	
Non-Economic Discussion	23	41%	28	42%	28	60%	25	61%
Expected Value Analysis	20	36%	12	18%	0	0%	2	5%
Payback Period Analysis	15	27%	17	25%	3	6%	18	44%
Cost Estimation	13	23%	2	3%	4	9%	0	0%
Benefit-Cost Analysis	8	14%	2	3%	0	0%	0	0%
After-Tax Cash Flow Analysis	7	13%	20	30%	1	2%	14	34%
Decision Tree Analysis	7	13%	3	4%	10	21%	2	5%
Non-Economic Discussion and Analysis	6	11%	1	1%	0	0%	0	0%
Sensitivity Analysis	5	9%	16	24%	20	43%	20	49%
Scenario Analysis	5	9%	5	7%	10	21%	11	27%
Project Balance Analysis	4	7%	29	43%	6	13%	18	44%
Breakeven Analysis	3	5%	2	3%	17	36%	5	12%
Economic Life	2	4%	1	1%	3	6%	0	0%
Variance Analysis	0	0%	2	3%	0	0%	0	0%

In our first assessment of using this format [4], we noted our frustration that students did not make use of sensitivity analysis to assess the situation and further, did not readily engage in risk analysis. We are encouraged by the increase in the use of sensitivity analysis from 9% (2001) to 24% (2002) to 43% (2003) and 49% (2005) of the students, as shown in Table 1. Similar increases in risk analyses (project balance, breakeven analysis, and scenario analysis) have also been realized. (The Concorde analysis in 2003 lent itself more to breakeven analysis as opposed to project balance analysis, as it is a retirement, not investment, decision.)

We believe this increase to be a direct result of our continued emphasis on the decision-making process, risk analysis, and the use of "real" problems in class. More specifically, we stress in class that these decisions are risky and must be analyzed with techniques beyond the computing of the present worth or internal rate of return of an estimated cash flow diagram. While we do not believe that the content of risk analysis in class has increased with time, it is likely that the emphasis has grown, as the results in Table 1 would indicate.

We have previously surveyed students with respect to using realistic problems in the classroom and the open-ended exam format [4,5]. While the students have been enthusiastic about the realistic problems, they have not been enthusiastic about the exam. This was not unexpected, as the exam does not follow a "typical" format of question-then-answer. However, they do believe it is a fair exam [4].

In our first year of using this format, we did not unveil the exam's format until the end of the year (just before the exam). As the format is not "typical" for an exam, the students were clearly apprehensive. To help alleviate concerns, we now announce the format on the first day of class and explain it on the syllabus. While announcing the exam on day one may not eliminate all anxieties, it provides time for the students to adjust and ask questions over time.

Conclusions

We have described an open-ended final exam format that has been used for several years to evaluate a student's ability to make a capital investment decision in a realistic context defined by incomplete data and high risk. Good exams provide problems that have clearly identifiable critical factors that must be exploited in analysis. Interesting scenarios and intangible attributes are also important.

A longitudinal analysis of previous years' student answers has shown an increase in the use of risk analyses – most notably sensitivity analysis. This is encouraging as the problems clearly call for methods that go beyond traditional discounted cash flow techniques and is most likely the result of the focus placed on risk analysis in class. Future exams will look into whether computers can be supplied such that students can focus on interpreting analyses and their arguments, and not the number crunching.

We believe this work, and the use of real problems in a decision-making format, also has other benefits. These include providing some assessment to the "professional skills" now desired by ABET [10] and providing an interesting way in which to inject real engineering problems into engineering economy courses [9].

Bibliography

1. Barrionuevo, A., "Enron is Looking to Develop a Facility in the Bahamas," *The Wall Street Journal*, January 29, 2001.
2. Felder, R. M., D. R. Woods, J. E. Stice, and A. Rugarcia, "The Future of Engineering Education II. Teaching Methods that Work," *Chemical Engineering Education*, 34(1):26-39, 2000.

3. Hartman, J. C., "Engineering Economy: Suggestions to Update a Stagnant Course Curriculum," *Proceedings of the 1998 American Society for Engineering Education Conference* (CD-ROM), June, 1998.
4. Hartman, J. C., "A Supplemental Resource for Teaching Engineering Economy," *Proceedings of the 2002 American Society for Engineering Education Conference*, (CD-ROM), June, 2002.
5. Hartman, J. C. and M. J. Russo, "Using 'Real World' Problems in Engineering Economy," *Proceedings of the 2004 American Society for Engineering Education Conference*, (CD-ROM), June, 2004.
6. Michaels, D., "British Airways will Retire Concorde Amid Restructuring," *The Wall Street Journal Online*, April 10, 2003.
7. Napper, S. A. and P. N. Nale, Jr., "Using Design Projects for Program Assessment," *Journal of Engineering Education*, pp. 169-172, April, 1999.
8. Pica, C., "Barrick Gold Confident Chile Gold Mine Will Go Ahead," *Dow Jones Newswires*, May 6, 2005.
9. Schmahl, K.E., C.D. Noble and B. Myers, "Where is the Engineering in Engineering Economy," *Proceedings of the 2000 American Society for Engineering Education Conference* (CD-ROM), June, 2000.
10. Shuman, L. J., M. Besterfield-Sacre, and J. McGourty, "The ABET 'Professional Skills' – Can They Be Taught? Can They Be Assessed?" *Journal of Engineering Education*, pp.41-55, January, 2005.