Improving Quality in Introductory Industrial Engineering through Case Studies and Communication

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Abstract

We describe an introductory course in industrial engineering that uses case studies, teamwork, public policy issues, and a focus on the communication demands on engineers to provide —at the beginning of a student's career—a synthetic view of the role of industrial engineers in society. The course covers typical industrial engineering subdisciplines such as engineering economics, operations research, inventory control, logistics, route planning, and location analysis. Instead of surveying a list of topics, the course provides some basic background on financial decision making and then requires students to work in teams on public-policy oriented case studies. The case studies require students to apply technical tools in a "real-life" context, derived from actual consulting experience; to deal with the ethical, social, political, and communication issues inherent in real situations; and to communicate the results of their analyses to both managerial and technical audiences. The paper will describe the class, two cases, and the integration of the writing component; provide a sample syllabus; and present an evaluation showing improvements in communication, general understanding, and motivation for additional study in industrial engineering.

Background and Summary

The course we describe in this paper is the entry point into the Industrial and Operations Engineering (IOE) curriculum at the University of Michigan. Students are generally in their second year of study, but many students at other levels from other engineering disciplines also elect the class. The total enrollment is 130 to 180 per term.

Traditionally, this course has provided a taste of the entire curriculum without obtaining any depth in any single area and followed standard lecture format with a single text and weekly homework assignments completed individually. While enrollment remained high, many students expressed dissatisfaction due to repetition of material in later classes and perceptions of low value added from the course.

We decided to revise the course to address these shortcomings and also to expose students to the environment of a practicing industrial engineer and to improve students' technical communication and team skills. We decided to change the class format to concentrate on a few industrial engineering skills and to use cases with analyses completed in teams.

We found that the cases and teams were a valuable teaching aid and were preferred by students. We also believe they enhanced students' understanding of core material and their technical writing skills.

Outline of Course

In teaching the course, we attempted to provide students with a feel for the sort of problems encountered, and the technical and communication skills required of an industrial engineer. Rather than provide a synopsis of the entire IOE curriculum, we decided to instead provide a *sample* of the types of problems industrial engineers face, and the techniques they use to solve them.

To this end, the course was organized into two distinct sections. In the first section, we took a traditional lecture/homework approach, teaching the fundamentals of engineering economics, an area that we believe all engineers should have an understanding of. The second part of the course was devoted to the solution of four cases that were simplified versions of actual consulting work performed by one of the authors. Skills required to solve the cases were taught as needed. The students worked in teams of four or five to come up with solutions to the cases. Instead of a final exam, we gave three compounding midterm exams, thereby providing strong motivation for the students to assimilate the material throughout the course, not just at the end. A sample syllabus appears in Appendix A.

In the first section of the course, students were required to attend lectures and complete individual homework assignments designed to familiarize them with the fundamentals of engineering economics. We began by introducing basic accounting concepts, so that students would have some appreciation of what accounting terminology and records actually mean. Then, the concept of the time value of money was introduced, and this led naturally to discounting and the calculation of present value. Exercises for this section of the course were derived from real data obtained from the world-wide-web to demonstrate to the students that the skills they were learning were in use, and useful. Methods for valuing simple projects involving the purchase of long-term assets were then explored, including a discussion of why simple-minded rules in widespread use such as the payback period method could lead to incorrect decisions. Finally, we introduced methods for selecting among projects when capital is limited, such as linear and integer programming formulations (which were solved using a spreadsheet solver). This provided a natural lead-in to the second part of the course.

The second portion of the course was designed to give students experience in working within a team environment on cases. Because many of the students had little or no experience in working in teams, we first gave introductory lectures on working within a team, writing reports, and problem solving. We considered it impractical to attempt to have the students give presentations simply because of the sheer size of the class (160 students), and so we provided no instruction in that area.

The first case required the students to code an algorithm to solve a well-structured problem. In particular, the students were required to use dynamic programming to schedule electricity generation given demand forecasts and cost information. Our goal was to give the teams a clearly defined yet complex problem that was too difficult to solve by hand and whose solution would provide a great deal of satisfaction.

The second case involved aspects of engineering economics and location analysis, and the objective was less clear than in the first case. The teams were required to advise a major automotive producer on where to relocate its major facilities. The case included a political/social dimension and is discussed in more detail later in this paper.

Our third case required students to schedule the games played in a professional soccer league in such a way that the schedule was fair to all teams, while minimizing the total distance traveled by the teams. This case introduced elements of scheduling problems and their solution via integer programming methods, and is also discussed in more depth later in this paper.

Up to this point we had avoided the notion of uncertainty in the class. However, we felt that students needed to have an appreciation for the complexities that uncertainty introduces into decision making. Therefore, the last case required the students to determine the number of helicopters a hospital should maintain for the purposes of emergency transport through an application of queuing theory. This case also introduced ethical considerations: should the hospital maximize profits alone, or should it be more concerned with saving lives?

Introduction to Teams and Report Writing

Because many of the students had little or no experience in working within teams and writing reports, we devoted two lectures to an introduction to these skills that are so fundamental to the practice of industrial engineering.

Teams

We devoted one lecture to the issue of how to build, and work within a team. This area is traditionally neglected when students are asked to work on team projects, and this can lead to difficulties when students with no team skills are asked to work together. We first provided some examples of past students reactions to team work, both positive and negative. The quotes given to the class were very well received and were taken from Eaves (1996), a discussion of the lessons learned in teaching team-based courses at Stanford University. It would appear that war-stories are very popular with students. We then moved on to a discussion of team management, with the goal of giving students (1) the ability to recognize difficulties (such as occur, for example, when one member is perceived by others to be contributing less than might be expected to the team effort), and (2) ideas on how to deal with difficulties identified.

Report Writing

Without some guidance on writing reports, it was unreasonable to expect the teams to be able to deliver polished, well-structured reports. Therefore, it was necessary to not only provide an example report to act as a guide, but to also explain why it is necessary to devote considerable effort to structuring the information that will appear in the report. Therefore, we spent one lecture going over examples of both well-written and poorly-written reports, pointing out the strong points and weaknesses of the examples, and abstracting to a set of guiding principles. In particular, we tried to impress upon the students the extremely limited time that senior managers will devote to reading (skimming!) reports, and the implications of this for report structure. We hoped to demonstrate the need for a foreword and summary, two or more paragraphs at the head of the report that summarize the problem, what the team did to address the problem, and the results of the team’s efforts. We also hoped to provide the students with a sense of what information should be presented in the body of a report, what information should appear in an appendix, and what information should be omitted altogether. Students were given an example report based on a Harvard case to act as a guide in writing their own reports. The students found this lecture very entertaining and extremely useful, judging by the comments we received afterwards.

Two Example Cases

We will now discuss two of the cases in more depth, to suggest the scope of the cases and the lessons we hoped students would learn from them.

Case 2: Location for Power Motors

The second case we assigned involved aspects of both engineering economics and location analysis. The problem was somewhat ill-specified as to objective, and there were other considerations besides financial cost. The following is an extract from the document we gave out.

"Power Motors Corporation (PMC) is an automotive manufacturer with over $50 billion of annual sales (13% of US automotive market share). To increase their market share, they believe they must be able to bring products to market even faster than their current industry leading times. Their current dispersed facility locations, however, create significant delays and costs due to travel among their various sites. They have conducted a thorough analysis of travel among the locations and have retained A-Square Consulting to recommend options for new facility locations.

Power Motors has five major corporate sites in West County. They are:

- Headquarters
- Manufacturing Engineering
- Testing Grounds
- Pre-production Plant
- Financial Group HQ.

Besides these sites, Power also has an opportunity to build in a new area outside the County called Green Field."

We provided the students with average driving times among the sites, the number of trips that employees were making between the facilities, space requirements for the facilities and space limitations of the site, building costs, tax rates, and other appropriate cost information. The students were therefore in a position to calculate capital costs and operating cost savings involved with re-siting various facilities. From that information, the students could then use heuristics, integer programming techniques, or direct search methods to determine a financially optimal solution to the problem of where to locate the facilities.

However, the case handout also contained information to the effect that Power's headquarters were located in an urban area that had faced significant hardship, so that Power contributed 50% of the tax revenue and provided jobs for one third of the labor force of the city. Clearly, then, a social cost existed in moving the headquarters of Power away from its present location, and any move could negatively impact the image of Power. Thus, there were also political factors (which could translate into market share impacts) to be weighed by the student teams.

This problem required the identification of a clear objective, the synthesis of several industrial engineering tools, and also some political savvy to identify the possible problem with moving the corporate headquarters. It was pleasing to see that several teams came up with innovative methods to deal with the problem of moving the headquarters (which was financially attractive), including shuttling employees from the urban area to the new location of the headquarters!

Case 3: Scheduling the MLS

This case asks students to schedule the games for the new U.S. professional soccer league, Major League Soccer (MLS). The case is modeled after the basketball league scheduling work done in [1]. The problem for MLS involves many of the same restrictions as the basketball league but is much simpler due to MLS's smaller size. The students' goal is to schedule all required games according to league rules with the minimum amount of travel.

The case was further simplified by reducing the number of teams from the original ten in MLS to the five teams that compose the Western Division of MLS: Dallas, Colorado (in Denver), Kansas City, Los Angeles, and San Jose. The case asks the students to schedule the twenty games that are played solely among these five teams.

Data: The students were given the following information about the teams and rules for scheduling:

- Distances between each pair of cities;
- A sample schedule with a total travel distance of 63,410 miles. The first five weeks of this schedule (with 10 games days) appears in Table 1. The numbers for each city are given to indicate where each team is on each day.
- Teams play every other time twice on the road and twice at home;
- Teams can play at most two road games in a row (without returning home for a game);
- Teams can play at most 2 games per week, one weekday game and one weekend game;
- Teams cannot play the same opponent twice on consecutive dates in the same place;
- The season lasts ten weeks with one additional date for an opening game in the week before the full season starts.

The case description noted that the sample schedule produced excessive travel for Kansas City. The case asked them to consider the fairness of this policy and to suggest any remedies.

Table 1. Sample Schedule for Major League Soccer (numbers refer to cities and indicate the location of a team)

	Schedule Number	Game Day 1	2	3	4	5	6	7	8	9	10	Home
Dallas	1	1	1	5	1	3	2	1	1	4	1	1
Denver	2	1	3	2	2	2	2	2	4	2	5	2
Kansas City	3	4	3	3	5	3	3	2	3	3	1	3
Los Angeles	4	4	4	2	1	4	3	5	4	4	4	4
San Jose	5	5	4	5	5	2	5	5	1	3	5	5
	Bye	5	1	3	2	4	5	1	3	2	4	

Methods: The lecture material for this case focused on integer linear programming solutions for two types of problems:

- the traveling salesperson problem (TSP), and
- the set covering problem (SC).

The students were told that relaxation and restriction are common methods for solving difficult problems such as this one. For relaxation, they were asked how they might find a best schedule for a single team, ignoring all others. The result (due to the maximum road trip constraint) is a two (or four)-vehicle TSP. They were then led through the subtour elimination method using the MS Excel™ Solver™ with integer variable restriction.

After the students developed their optimal single team schedules, we then introduced restriction as in airline crew scheduling. Given a set of possible tours for each team, could they be combined into a schedule for the entire league? Since these tours were known to be optimal for each individual team in absence of any other, we led the students to discover that, in this case, the solution of the problem restricted to these tours alone would indeed produce an optimal schedule.

The students were given the basic formulation of an SC problem to fit the tours together. They were also led to descriptions of all constraints that would be necessary to ensure a feasible schedule. An Excel ™ sheet was developed for a single team to assist them in developing an overall model.

Results: Over 70% of the student teams were able to produce an optimal schedule using the procedures given above. The SC problem involved the solution of an integer program with 200 variables but the Excel Solver ™ readily produced optimal solutions.
Most student teams recognize the fairness issue among the soccer teams. A few suggested sacrificing the league optimal travel distance to increase fairness. Most students were quite impressed with their ability to solve such a complex problem on personal computers with standard commercial software. Follow-up discussions introduced other scheduling issues including mixed product line balancing, airline crew, and emergency room staff scheduling.

Evaluation and Conclusions

We examined several aspects of the teams' development over the term. In particular, we looked qualitatively within teams to check for improvement and compared overall class results for cash flow analysis across the term and their attitudes on each case. We found that the case reports generally led to increased effectiveness in report writing, deeper understanding of some concepts (such as cash flows), and greater satisfaction from students.

Qualitative Writing Evaluation

Each case was assessed in the following areas:

- foreword and summary;
- contents including model formulation, implementation and analysis;
- structure;
- mechanics and style;
- format.

A sample evaluation appears in Appendix B.

Most teams learned to compose forewords that contained the main elements of problem, task and purpose statements. They generally structured their cases well and followed appropriate format. In beginning cases, content material often included too many details that obscured major points. In the last case, almost all teams included necessary material and put unnecessary details in an appendix.

We encouraged teams to alternate responsibilities to allow students to share in all aspects of case preparation. Writing styles, therefore, varied within groups. Improvements through the term were difficult to judge.

Course Material Understanding

A major goal of the class was for students to evaluate complicated cash flows and find net present values. We compared the results on a cash flow question for the first midterm (before Case 2) to results on the last midterm (after Case 2). On 30-point questions of relatively equal difficulty, the median score improved from 18 (60%) to 23 (77%).

In written evaluations, several students commented that net present values only became clear after Case 2. The increase in scores on cash flow questions captures this to some extent.

Student Evaluation of Cases and Project Teams

At the end of the class, we surveyed students for their preferences between traditional homework and cases. These results appear in Table 2. From the results in Table 2, three times as many students prefer cases than prefer individual homework. Reasons for preferring cases included greater motivation due to the cases' practical nature and ability to work with others. Reasons for preferring individual homework centered on schedule problems with teammates, personality conflicts with teammates, and perceived lack of value in teammates' contributions.

Table 2. Responses to Case/Homework Preference

Strongly Prefer Teams and Cases	19
Prefer Teams and Cases	58
Neutral	35
Prefer Individual Homework	16
Strongly Prefer Individual Homework	10

Lessons Learned

Based on our experience, we believe that case-oriented classes offer good opportunities for introducing students to industrial engineering, teaching them fundamental concepts such as engineering economics, and giving them essential writing skills. In future offerings of the class, we plan to continue with case studies. For improvement, we plan to offer more team management training to avoid some of the team interaction problems we encountered in this class.

References

[1] J.C. Bean and J.R. Birge. "Reducing Travel Costs and Player Fatigue in the NBA," *Interfaces 10* (1980) 98-102.

[2] Eaves, B. C. (1996). Learning the practice of Operations Research. Unpublished manuscript.

Authors

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Appendix A: Sample Syllabus

IOE 301 **INDUSTRIAL AND OPERATIONS MANAGEMENT** FALL 1996

Instructor: John R. Birge, 250 IOE, 764-9422, jrbirge@umich.edu
Office Hours: TTh 8-9:30
or by appointment (Secretary: Robin Konkle Mays, 763-1332)
Shane Henderson, 262 IOE, 763-3459, shaneioe@umich.edu
TAs: Doug Johnston, Mike O'Connell

Text: R. A. Brealey, S.C. Myers, *Principles of Corporate Finance*, McGraw- Hill, Fifth Edition, 1996. (RBSM)

Note: Additional material will be available on-line. IOE majors are encouraged to purchase *Handbook of Industrial Engineering*, G. Salvendy, ed., (HIE) from the Institute of Industrial Engineers. Other material will be available on the WWW site, www-personal.umich.edu/~jrbirge/ioe301.

Course Goal: To improve decision-making capability through economic and operational principles and to increase awareness of operational issues and methods.

Concept/Skill Objectives: Through this course, you should obtain the following skills (as for example on the engineering fundaments Course performance will be judged on your ability to explain the concepts, to use basic skills in structured settings, to determine methods to apply in general situations, and to apply mixtures of skills to unstructured problems. The basic skills are:

- understanding measures of performance - accounting/financial terms
- calculating net present values with given rates
- awareness of other financial decision criteria - difficulties
- evaluating projects for new products/process/technology without budget
- formulating linear programming models for capital rationing
- awareness of the role of risk in project evaluation
- formulating basic inventory models
- formulating basic routing models
- evaluating a simple queue

Reading: The following schedule gives reading selections for each day. These assignments should be completed before class to enable some discussion.

Homework: Problems are due on the dates stated below. Sample solutions will be available on the web site on the due date. No homeworks will be accepted after this posting, but your lowest homework score will be replaced by your highest homework score for final scores. Some of the problems require the use of a spreadsheet program with linear programming solver and statistical tools, such as Microsoft® Excel available on most CAEN machines. Each student should submit individual homework responses although collaboration is encouraged.

Teams/Cases: Teams will be assigned for the cases. Your team should prepare a report on each case that responds to the discussion questions. At the conclusion of the class, you will be asked to evaluate each member of your team. A single report for each team is required for each case.

Grading: Grades will be determined according to achievement in each performance area mentioned above. The weight will be 30% for homework and cases, 10% for team contribution, and 20% for each of 3 midterm exams.

Exams: The midterm exams will be given in class on the days below. Room assignments for examinations will be announced in class.

Schedule: The following lists the day and topic of each lecture, the reading for that day, and the homework problems due.

Lecture	**Day** [MW]	**Topics**	**Reading**	**Due**
1	9/3[4]	Introductions, function of operations, subject areas, uses in engineering	HIE, 1	
2	9/5[9]	Basis of engineering decisions, evaluation criteria, balance sheets; financial roles in firm	HIE, 48; RBSM, 1	
3	9/10 [11]	Present value calculations, net present value rules, discounted cash flow model	HIE, 50; RBSM, 2	
4	9/12 [16]	Perpetuities and annuities, Compound interest, alternatives to net present value, nominal v. real rates	RBSM, 3	HW 1
5	9/17 [18]	Common stock evaluation, evaluation of a business, debt/equity differences	RBSM, 4	
6	9/19 [23]	Project evaluation with payback, return on book and irr	RBSM, 5.1-5.5	HW 2
7	9/24 [25]	Projects with resource limits, linear programming formulation, spreadsheet solutions of linear programs	RBSM, 5.6, App; HIE, 103	
8	9/26 [30]	Project selection, project interactions	RBSM 6; HIE, 51	
9	10/1 [2]	Role of risk in project assessment, picking discount rates	HIE, 52	HW 3
10	10/3 [7]	Midterm 1		
11	10/8 [9]	Midterm discussion, investment case introduction, team introduction	Case 1	
12	10/10 [14]	Team exercises		
13	10/15 [16]	Investment case discussion		
14	10/17 [21]	Investment case principles		Case 1
15	10/22 [23]	Distribution game introduction	HIE, 84	
16	10/24 [28]	Distribution game discussion		
17	10/29 [30]	Distribution case principles, EOQ models		Case 2

18	10/31 [11/4]	Newsvendor model, uses of safety stock	HIE, 76	
19	11/5 [6]	Distribution review		HW 4
20	11/7 [11]	Midterm 2		
21	11/12 [13]	Midterm discussion, Multiple requirements, efficient frontiers		
22	11/14 [18]	League scheduling case introduction	HIE, 80, 81	
23	11/19 [20]	League scheduling discussion		
24	11/21 [25]	League scheduling principles, relation to personnel scheduling		Case 3
25	11/26 [27]	Network case introduction, value of uncertainty		
26	12/3 [2]	Network case discussion, principles of probability, queueing		
27	12/5 [4]	Network discussion, Term review		HW 5/Case 4
28	12/10 [9]	Midterm 3		

Appendix B: IOE 301 Case Evaluation Form

Name: ____ **Score:** _____________

We will grade your cases as if we were the client. Therefore, your reports should be easy to read, informative, and complete. Your team adds value to the client only through the competitive advantage you provide through quality scheduling. Therefore, the bulk of the grade will be based on the quality of your solution to the scheduling problem, and the soundness of your technical approach. The case grade may be broken down as follows.

Foreword and Summary (10 points total)
Does your foreword contain problem, task, and purpose statements? Does your summary provide an overview of all the findings and recommendations presented in the paper and does it preview the structure?

Contents (75 points)
- Formulation (25 points)
- Implementation (25 points)
- Analysis (25 points)

Have you covered the necessary technical issues? Have you provided appropriate supporting arguments for your findings and recommendations? Given your assumptions and justified any impacts resulting from these assumptions? Justified your trade-offs and priorities? Have you provided enough information in an appendix for another technical person to duplicate your efforts?

Structure (5 points)
Is the overall organization clear? Are your ideas logically ordered into sections? Are your paragraphs linked together with effective transitions? Are the paragraphs focused under single topic sentences?

Mechanics & Style (5 points)
Do sentences contain correct grammar, spelling, punctuation, and usage, and do they flow together?

Format (5 points)
Does your report include an appropriate "To/From/Subject/Date" heading and section headings? Is the format, spacing, and alignment consistent and appropriate throughout? Are the pages numbered? Laser print? Stapled?

Area	**Points**	**Comments**
Foreword & Summ.		
Contents-Formulation		
- Implementation		
- Analysis		
Structure		
Mechanics/Style		
Format		