



Engineering Economy Taught Across Engineering Disciplines: Work in Progress

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Work in Progress: Engineering Economy Taught Across Engineering Disciplines

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Abstract

This is a Work in Progress. Students are taught how to model, write, and solve engineering equations as part of their typical curriculum. But what is not covered is how to meld the engineering design world with the economic domain needed to be successful in industry. One author has supervised over 35 industrial design projects, and through his experience found that what industry values most is a detailed Financial Operational Model with clear design and economic parameters evaluated through sensitivity analysis. At Hampton University, engineering economy has been taught to senior chemical engineering students in their first design course. However, this fall a new course was delivered to all engineering students. The new engineering economy class replaced a general education elective so no additional credit/course demand on students was required. The inclusion of all engineering students came about after an interdisciplinary team won a design competition in large part due to a senior chemical engineer's work on the financial operational model and her resulting sensitivity analysis for their product design. Students from all engineering disciplines wanted to learn the skill she so aptly applied.

The twenty-four students are mostly African-American juniors and seniors from chemical, electrical and computer engineering. The primary focus is on construction of a Financial Operational Model in Excel for a process that includes engineering design equations (30-40 typically) combined with economics to build a processing plant that covers the range of indirect and direct costs for both construction and operation of the facility. The assessments for the course are weekly quizzes and a large take home exam. The course begins with students manipulating and simulating an existing financial operational model by creating pie charts for capital and operational expenditures and various sensitivity analyses. After this exposure, students begin the process of building their own financial operational model. The challenge to the students is adding economic elements for mechanical construction, power, circuit design and production, and coding cost estimates for firmware and interface software. Our main objective is to acclimatize students to solving a system of engineering equations across disciplines and linking them to a real economic setup to evaluate the financial viability of a design project.

Keywords

Engineering Economy, Financial Operational Model, Sensitivity Analysis

Introduction

Engineering Economy courses are traditionally motivated by the needs to meet the ABET accreditation requirements [1][2] and mainly capstone design course requirements [3] such that students know how to evaluate the financial viability of capital investments from a business perspective. Recently, the demands of industry/employers have pushed for curricular changes in

the integration and teaching of engineering economy for graduates to be adequately prepared for industry [1][4]. In particular, Rogers [1] summarizes the outcome of the ABET and ASEE studies. The ABET study found that there were inadequate levels of preparation for graduates in problem solving, communicating and working in teams, and understanding the culture in which they work. Furthermore, the ASEE study noted inadequacy in knowledge, skills, and abilities in engineering practice for graduates in areas such as project management, economics and business, teamwork, decision-making, and critical thinking. As such, different teaching approaches of engineering economy are being applied to help with the preparation of the engineering students for engineering practice. In looking at the role of engineering economics in the engineering curricula, Zoghi [3] pointed to approaches that promoted teamwork training and the integration of financial modeling using tools such as Excel. Others have looked at the way the content knowledge is captured and evaluated [5][6]. The general consensus is that industry requires the graduates to have the knowledge, skills, and abilities gained in engineering economy courses. Dr. Aufderheide has supervised over 35 industrial projects and concurs that the work most valued by the companies was the financial operational models developed by the student teams. Yet not until recently have the authors found a textbook [7] that covers both the construction of a proper financial operational model and how to use it to generate various sensitivity analyses to help assess the viability of a design project.

This paper covers the approach that is implemented for multiple engineering disciplines in one institution delivered for the first time. The class had predominantly Junior and Senior students that are African American representing Chemical, Computer, and Electrical Engineering majors. The students were taught Time Value of Money, Cash Flow Charts, Internal Rate of Return, Net Present Value, and various Salvage and Equipment Depreciation Methods [8], which took up roughly 40% of the class time. The rest of the course was focused on the development and use of Financial Operational Models: the melding of engineering design equations with economic and financial calculations to evaluate the feasibility of a design project to be profitable. The course assessments were predominantly quizzes (nine in total) and a take home exam. The exam consisted of a system of 45 engineering design equations covering the operation, sizing, and usage of a stacked hydrogen fuel cell. The students had to build a Financial Operational Model, and do various sensitivity analyses. The focus of this paper is on how the students were taught to build a Financial Operational Model.

Methodology

Financial Operational Model

Covering the Financial Operational Model, its theory, and personal development of a working tool took the class roughly six weeks with the class meeting three times a week for fifty minutes each. This is a considerable undertaking, and like any instructional challenge of merit, requires the buy-in of the students. Thus, considerable time is spent discussing the merits of a Financial Operational Model and explaining that this is the melding of engineering design equations with fabrication costs of goods or processing which in turn is coupled with financial assessment tools of Internal Rate of Return and Net Present Value. The objective of the Financial Operational Model is to evaluate a design project for investment. It is not to come up with a single set of financial numbers; instead, it is to generate sets of sensitivity analysis that covers a wide range of scenarios.

The teaching method as follows. First, explore with the students the more standard sensitivity analysis: change in price of goods, change in price of key raw material(s), change in price of utilities, change in price of labor. These are the ones sometimes discussed in design textbooks. Ask students if that is all there is to a Financial Operational Model? See what the students answer here. Get them to understand the sheer power of having the engineering design melded to the economics. What does that truly mean? Start to get them to see other types of sensitivities that are not simply linear changes in slope but can have actual minimum or maximum optimal values. Examples include key design specifications to the product, parameter uncertainty in the models for a piece of equipment such as extent of conversion of a reactor, or change in the recycle flow rate needed... There are so many possibilities. What about manufacturing changes? Size and throughput of the plant? What if the plant is built to design throughput but there is a shortfall in market projections: how low can production go with equipment sized for the higher throughput and still meet a desired Internal Rate of Return? What if instead of building the plant exactly to the size specified, it was made just a little bigger? How much extra would it cost? How does the payback time change if the market stays at the design size specified with the large equipment purchased? And now, how much more money is made if the market grows to the newer larger sized plant? Is it worth buying the larger plant? Introduce a specialty piece of equipment for which getting a good idea for a price is hard to do... then run a sensitivity analysis using a wide range on possible prices. See what price will still net the return desired. Literally, Dr. Aufderheide has led Industrial Design Projects where the company went in to negotiate a price for a unique piece of equipment using the sensitivity analysis the students generated. And in another case, a company looking to increase its octane value on natural gas took the student financial analysis to a Board Meeting for evaluation, and the project got the go ahead. It is a powerful tool, and sadly the authors have not come across any design or engineering economy text book that covers it properly.

Encourage students to understand that only their imagination limits them to using this flexible tool to develop scenarios to test the worthiness of the design project. Stress over and over again the purpose is not to make a Financial Operational Model to get a value for the Internal Rate of Return, Net Present Value, and Payback time in years. It is to develop scenarios to test the project's viability, to see potential weaknesses that must be studied further before moving ahead with the project, and to plan for success. And that is not all. A good Financial Operational Model is a living document. Once the design is built and put in practice, it still has use. It can be modified to determine upgrades to potential equipment, changes to feed stocks, issues with labor wages, shortages in raw materials, and on and on. By melding the economics to the engineering design, the students have something truly special that can be extremely helpful. In Dr. Aufderheide's review of over 35 Industrial Design Projects, the work that was valued most by the company was the students' Financial Operational Model. In the final report given, often under a non-disclosure agreement, the heart of the report was the design basis and the sensitivity analysis for the project.

1. Sensitivity Analysis

After introducing the pros and cons of a Financial Operational Model, have the students play with an existing completed Financial Operational Model. Give an overview of the parts of the model, and stress how everything is linked so that changing a design parameter on the input page carries through to changing the actual financial analysis of the project with that new set of conditions. Get students to generate not only Sensitivity Analysis where the design variable that is changing

in x-axis of the chart is plotted against Internal Rate of Return (IRR) but also Net Present Value (primary and secondary y-axes), and a second chart where same design variable is plotted against Total Fixed Capital Investment and Payback Time (years). Build these first charts with the students in class. Now cover the concept of a key financial cut off such as a minimum IRR value or maximum Payback Time. Have students evaluate the sensitivity analysis plots. Are the plots linear or nonlinear? Is the slope large (sensitive)? Is this a design parameter that could affect greatly the financial viability of the design project? Get students to choose a wide range for the design parameter so that the plot typically will cross the desired financial cut off. The goal is never to propose a project with a fixed improvement or a single set of financial parameters. Let the people who are deciding the fate of the project come to her/his own conclusions by giving them a range of values that straddles perhaps too low and too high so that the appropriate range lies within and can be evaluated.

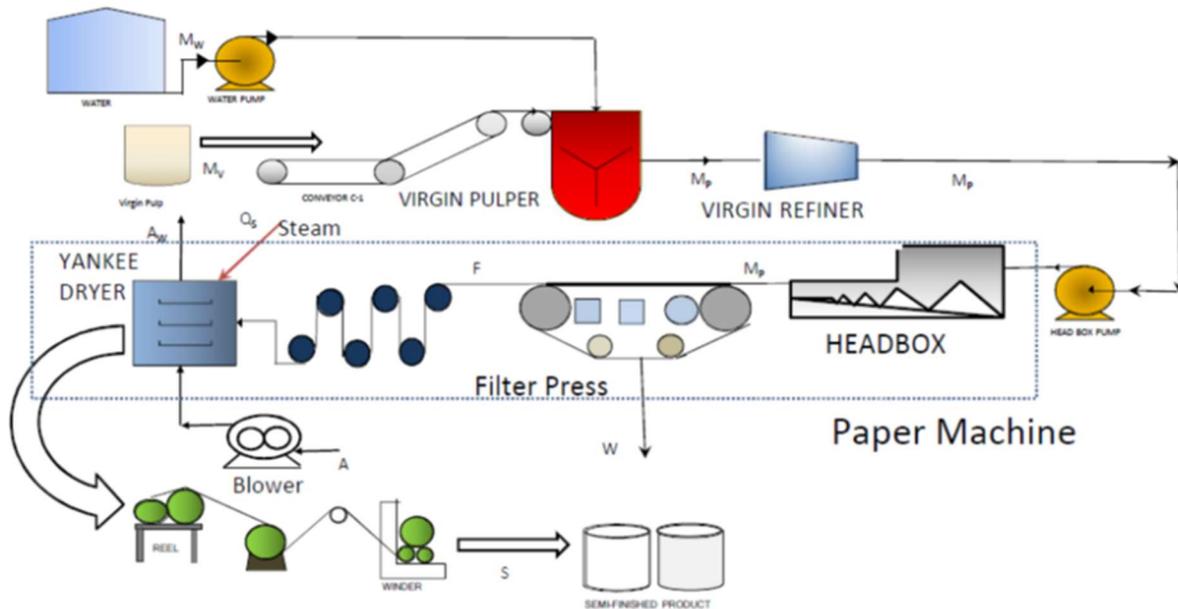


Fig. 1 Process Diagram for Tissue Paper Production

In the Sensitivity Quiz to the students, a tissue paper production facilities was modeled with steady state equations covering major unit operations and mass and energy balances (see Fig. 1 for Process Diagram). The financial model was completed for the students to first run baseline design conditions and analyze the Capital and Operational Expenditures, CAPEX and OPEX (see Fig. 2 for CAPEX) to help determine which unit operations should be chosen for sensitivity analysis of key engineering design parameters. One key parameter was the weight fraction of water in the feed. Students then did a sensitivity analysis for weight fraction of water in the feed generating the graphs in Fig. 3. A desired Internal Rate of Return of 20% was given and from the sensitivity analysis students determined that the water content must be less than 67% in the pulp feed stream.

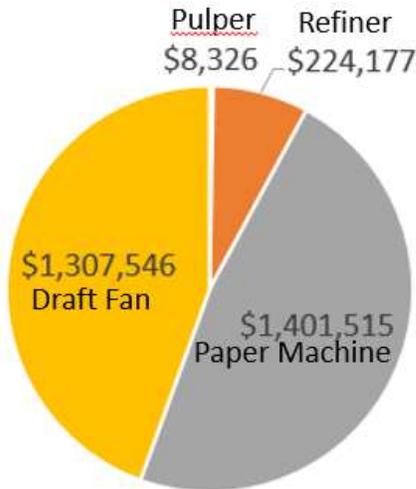


Fig. 2. CAPEX

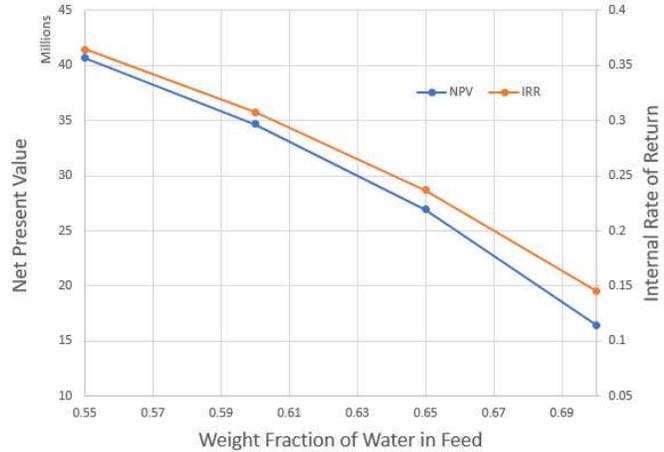


Fig. 3. Sensitivity Analysis Weight Fraction of Water in Feed for Paper Production

2. Capital and Operational Expenditures

Show students where the values are located for the capital expenditures (CAPEX) on the Capital Cost sheet, and operational expenditures (OPEX) on the Profit Loss sheet. Generate pie charts of each. Which piece of equipment or operational cost are dominating? How would these be effected by your engineering model? This determination helps decide which design parameters to use for your Sensitivity Analysis. The first quiz to the students is generating CAPEX and OPEX pie charts and doing two or three sensitivity analysis for a completed Financial Operational Model.

3. Process Calculations

The objective here is that given a set of engineering design equations that the students can solve them using Excel. Students are not doing any modeling of the system but instead utilizing equations given to them. In many cases there may be more equations than needed due to the fact that not all modeling equations are linearly independent. Students start with a process input sheet that has design values already assigned. The goal is to calculate all the dependent variables for the system. The values for some of the variables will be later linked to Capital Cost, Utilities, and/or Profit and Loss pages. Teach the students good practices that Excel is like any programming language and organization and referencing are important. Number the order that the equations are solved, provide the actual equation number for the system and copy and paste an image of the equation into Excel. Make it easy to debug the Excel worksheet if necessary. The authors added cases to the class that were more multidisciplinary containing both chemical and electrical or power engineering. Second quiz given to the students. Word document with all the equations. Excel file with process input page and design parameters specified and dependent variables to be calculated listed.

4. Labor, Utilities, and Capital Cost

This was the third quiz given. The Capital Cost covered the standard changes for size, material type, operating pressure, operating temperature, and year of base price correction. The material covering this was from [9]. Capital Cost sizing is linked to calculated process variables so that cost for any piece of equipment changes dynamically.

5. Total Fixed Capital Investment

It is important to include all the direct and indirect costs associated with purchasing and installing equipment. The page is driven by the base costs of the capital equipment. The factors for installation are multiples of the capital cost total, and taken from [9]. Additional inputs come from the Economic Input page such as cost of land and amount of working capital. Working Capital is not the same as Contingency factor for construction over runs. Working Capital is amount of money added to the loan to cover the purchase and installation of all equipment including acquiring land too. Typically Working Capital covers paying engineers and other staff prior to equipment installation during the period that no revenue is occurring. This is quiz four.

6. Profit Loss

The Profit Loss page is the base accounting sheet for all operating revenue and costs. It is also the worksheet that changes the most outside of Process Calculations for a new project system. The page must include all direct and indirect costs for operation. These factors are taken from [10]. Stress to the students it is easier to remove factors or put in zeros for their calculations than to add in more indirect costs. Companies that have large plant design projects will have in house their own factors. But by having them in the sheet here acts not only as a placeholder but also makes students aware of all the many costs associated with both construction and operation that exist. The page has over a dozen links with Process Calculations, Total Fixed Capital Investment, and Economic Inputs. This is quiz five.

7. Economic Summary

Total revenue comes from the Profit Loss page. Total Fixed Capital Investment is linked to the page of the same name. Discount rate of money is linked to the Economic sheet. Rows for calculating each year's gross, net and cumulative cash flows for each year of the project. Project years start at 0. To calculate the Net Present Value is cumulative cash flow of money that is depreciated to present value using the Project Year as an exponent. Excel can calculate IRR with built in function. Payback years is done using built in conditional statements with linear interpolation to get the number of years plus fraction of year for paying off the Total Fixed Capital Investment. Not enough for a quiz on its own. It was given as potential extra credit for quiz five.

Results and Discussion

The key for the class is to get students as acclimated to using Excel as early as possible. Providing "cheat sheets" for common Excel calculations/programming, helped some students. But really it requires everyone working together in Excel in the classroom in real time. Using Excel is a foundational skill for some High Schools and those students will come in much more prepared and

ready to do calculations and generate charts. It is important to encourage them to assist other students who are not as familiar using Excel.

In general, the quizzes related to the Financial Operational Model that students did poorest was on the Profit Loss sheet forgetting all of the appropriate links or one of the very first quizzes be it sensitivity analysis or the process calculations due to not having Excel expertise yet. Quizzes 3 and 4 covering the Labor, Utilities, & Capital Cost and Total Fixed Capital Investment students did extremely well.

Prior to the Take Home Financial Operational Model Exam, have the students annotate their built models in class completely for extra credit. Students can then use these as their blue print to generate the new design project given to them for the exam. This helped students a lot to do a little more work and describe what they are doing a little bit better. It is nice when students actually go ahead and color code all pages in the workbook and then all links match those colors so that student knows how to update the links when necessary during the building process. The range on the Take Home Exam was from a low of 69 to a high of 90 with an average score of 82.6 with a standard deviation of 8.0.

Conclusions and Future Work

Overall students were very engaged especially during the development and testing of the Financial Operational Model. After a transition period of getting up to speed on using Excel for solving engineering equations and linking financial pages, students did well in all aspects of the course. The exception was a small group of 5th year Seniors who had other courses and design projects which were more their focus than this class. Dr. Aufderheide received a number of comments on how this was very useful information and how the student could see using this after her/his time at Hampton University. The areas that posed the most challenges were difficult engineering equations, especially those that were multiple term empirical fits. The area of the Financial Operational Model that initially posed more problems was the Profit Loss sheet, which is the most complex and has the most outside links to other sheets in the Excel Workbook. The fifty minute classes taught in a hybrid fashion of lecture and Excel programming worked well. Additionally, all quizzes could be completed in this time frame. The Take Home Exam went well albeit a tough system to model which is where most students lost points.

In all, the students have seen processes making therapeutic proteins, producing chemicals, combined immersed electrical heater design with endothermic reaction in a stirred tank, a geothermal electrical power system, and the aforementioned stacked hydrogen fuel cell process. There was not a single complaint from the students about using Excel to solve a set of equations from a different engineering discipline. It is too small of a sample size to conclude that this is the norm to be expected from future classes, but in this class students were enthusiastic and willing to engage with one another and work across disciplines.

Generating the case studies takes considerable effort. For example, the stacked hydrogen fuel cell took forty hours to research, build, write up and test. Four different references were required to cover the complete sizing and engineering for the system. Thus, developing each of these case studies took away time from developing tools for the next iteration of the class. Here are the plans for that second iteration of the course:

1. Printed Circuit Board estimate for electrical engineers to get estimates on their product designs for their senior projects. Found one excellent reference in [11] provides a very detailed activity-based cost estimating system that is perfect to be built into an Excel Worksheet.
2. Develop estimates for fabrication costs for engineering students doing fabrication of products or small scale machinery. There are some commercial software packages available to do these estimates. But would like to make again a spreadsheet that covers this area using the concepts for the software packages so that later on students if they do come across them in industry understand where the calculations are coming from. A promising reference to do the calculations for this is in [12].
3. Calculate estimates for software development. This has been more difficult to find in a single review or periodical. However, a good text book [13] looks like it has all the information. The question is condensing it down to something manageable for students to get rough estimates of firmware/app development costs.
4. Final Team Based Project on Interdisciplinary Engineering. This will require a great deal of effort but should be very rewarding to have a complex process that uses different engineering disciplines that students can build a Financial Operational Model and evaluate the process thoroughly. Work should be entrepreneurial and at a level that completed project could be a Conference paper or Journal article.

These future plans are ambitious but doable, and are bound to be very rewarding. Once developed, they will provide many useful tools to the engineering students and faculty alike. Anyone wishing to download any of the case studies please contact Dr. Aufderheide. A future goal is to gather these case studies in an online repository for everyone to use.

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