Integrating Economic Analysis into Capstone Design

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Abstract

This paper presents the use of engineering economy methods as a design tool in a senior capstone design course sequence within a general undergraduate engineering curriculum. The senior capstone design course sequence includes two semesters, small project teams (i.e., 3-4 students), and primarily industry sponsored projects. The final reports from the capstone work were used to classify the engineering economy methods used in the design process. This work is significant since student teams are using the industry sponsor's preferred metrics and performance measures to determine economic success (or failure) of a design, rather than the classical methods provided by classroom instruction in the traditional engineering economics courses which is generally taken before the senior capstone sequence begins. Observations of 48 senior capstone projects from the past four years indicate that initial cost was used by 31.25% (15 of 48) of the projects and was the preferred economic analysis method, followed by annual worth and simple payback period both at 25% usage (12 of 48). Of the 48 senior capstone projects, 41.67% (20 of 48) of the projects used more than one economic analysis method.

Introduction

Engineering capstone design courses are recognized as "a culminating experience" where students apply "knowledge and abilities to practical engineering problems"[1] that "draws on all previous course work"[2]. The capstone experience permits students to connect theory and practice in the final academic process of developing professional skills of engineering design, professional relationships, and teamwork. Capstone texts each have variations of the design process such as stage-gate, systems engineering, and systems engineering lifecycle; however, no consensus on what specifically constitutes engineering design was found[3]. Research indicates that experienced engineers recognize that the common process being described by these terms is iterative in nature and integral to the design process. These variations all include references to technical and economic feasibility analysis, or trade-off analysis. . As stated by Archibald, Reuber, and Allison[2]: "The importance and relevance of engineering economic analyses is always emphasized when students discuss their projects with practicing engineers. Without this interaction students sometimes consider economics to be irrelevant to design – a subject for business students."

There exists engineering education literature on techniques to solicit, administer, and manage industry sponsored capstone projects[4], integrating the capstone design courses with various components including project management, manufacturing, lean, and six sigma[5-7]. It has also been shown that graduate engineering students benefit by completing industry sponsored projects[8]. A recent review of the literature on teaching engineering design via capstone courses includes details on course design, industry involvement, and teamwork[9].

As the engineering students' capstone experience is marketed, vetted[10], and assessed there seems to have been little work reported concerning the application of economic feasibility analysis as a part of the design process. Lectures, handouts, guidebooks, and textbooks have offerings on developing student abilities regarding project economic analysis, but little on the use of economic analysis in design. A review of research literature provides little pedagogy or methodologies for developing knowledge, skills, and abilities (KSAs) within students that are useful in designing and crafting a quality economic feasibility analysis. Some assessment rubrics were identified, but these seemed to focus more on if an economic analysis was done and not the quality of economic analysis methods applied. Minimal guidance was identified relative to lesson plans for developing economic feasibility analysis as part of design KSAs. This paper, describes some initial efforts toward developing economic analysis KSAs within senior engineering students that have begun from some qualitative research and classroom experiences.

Background

East Carolina University (ECU) initiated its first ever engineering program in 2004. The program culminates in a two semester capstone design project based learning experience for all engineering students. The process of initiating and nurturing the capstone experience within a new engineering program has offered challenges and opportunities. Paramount among these challenges has been the development of industry relations that support industry sponsored projects and campus based projects particularly for the biomedical engineering program of study and the ECU School of Medicine. The latter is largely directed at supporting basic research. The former relies on industry sponsored projects for most of the capstone design experiences. Sponsor feedback has been overwhelmingly supportive of the capstone sequence. Generally, sponsor satisfaction with the project results has exceeded faculty assessment of students' design quality. This seems consistent with an industry tendency to focus on project success over learning outcomes[11]. The capstone process has begun focusing on improving design quality in order to meet academic goals. The first step in improving design quality has been to focus on project problem statements.

Industry and medical school projects are preferred because of their realism and for their ability to imitate the pressures of realty found in industry[12]. These projects are usually proposed as open-ended statements which are believed to increase student motivation, and to provide an introduction to the world of engineering[13,14]. ECU seeks sponsored projects as part of a process requesting potential sponsors to provide project background, summary objectives/requirements, design expectations (deliverables) along with some administrative data including point of contact. Projects are vetted for selection[10]. Students are assigned project teams and projects. The first assignment is to begin crafting a problem statement for the project[15]. Lectures are held once per week and the economic feasibility process[16] is discussed for one full class period and referred to frequently throughout the two semester capstone design course sequence. In addition to class discussions, students are required to purchase a capstone handbook which provides details on the course requirements and design formats required for the course. The handbook requires all student design reports to include economic feasibility analysis using simple payback period, net present value (NPV), and internal rate of return (IRR). Payback period is included as most industry sponsors use payback period in decision making processes. Gibson[17] reports that various industries use economic measures including benefit/cost (B/C), return on investment (ROI), IRR, and simple payback period.

Faculty conducted assessments have consistently indicated issues in the quality of student developed economic analysis. Part of the quality issues stem from assigned faculty advisors waiving course requirements particularly for projects involving basic research and work standards design projects. Another contributing factor is sponsor requirements that differ from course requirements. In that case students are required to satisfy both. An additional contributing factor is the plausibility of conducting time-value-of-money analysis of one-off equipment (or processes) used to support biomedical research. This latter issue supports cost analysis but not return rates. The assessments have indicated a need for more focus on economic feasibility analysis.

In order to understand the application of economic feasibility analysis, a qualitative review of ECU's previous years' capstone design final reports was made to determine what engineering economics tools were applied in capstone design. The survey was initially developed to gain insights on how to structure both pedagogical materials and assessment rubrics to improve the capstone experiences for senior design students.

Results

The final reports from the most recent four years of senior capstone design were analyzed to determine which engineering economic tools were used were applied to the capstone design analyses. These results included 48 projects, with 12 in the pharmaceuticals industry, 10 in the manufacturing industry, five in both the machining industry and health industry, three in both the electric transmission industry and warehousing industry, two in both the aerospace industry and agriculture (food supply) industry, and one project in each of the following industries: bioprocess, construction, foundry, military, outdoors, and trucking/logistics. The results are provided in **Table 1** and **Table 2**, sorted by industry type. These results are summarized in **Figure 1** and **Figure 2**. Note, for simplicity, rate of return methods (IRR, ROR, ROI) were grouped together, and annual worth methods (AW, EUAC, EUAW) were grouped together.

Observations

The following observations based on the 48 projects are made:

- 18.75% (9 projects) of the projects did not include an economic analysis. Occasionally, project teams do not include economic information due to the industry sponsor's request for privacy; however, in that situation student teams are asked to create a realistic economic analysis for reporting purposes.
- 39.58% (19 projects) of the projects included one economic analysis method.
- 31.25% (15 projects) of the projects included two economic analysis methods.
- 8.33% (4 projects) of the projects included three economic analysis methods.
- 2.08% (1 project) of the projects included four economic analysis methods.
- The most frequent economic analysis method was initial or first cost; with 31.25% (15 projects) of the projects using this method.
- Both the annual worth method and simple payback method were used in 25% (12 projects) of the projects.
- The net present value method was used for 16.67% (8 projects) of the projects.
- The operations and maintenance costs were analyzed for 12.5% (6 projects) of the projects.
- A rate of return method was used for 8.33% (4 projects) of the projects.
- Both the manufacturing costs and breakeven analysis was performed for 4.167% (2 projects) of the projects.

- The following methods were used by 2.08% (one project) of the projects: B/C ratio, estimation, future worth, and life cycle costs.
- For industry types having more than four projects, no specific economic analysis method was used for all projects within that category.

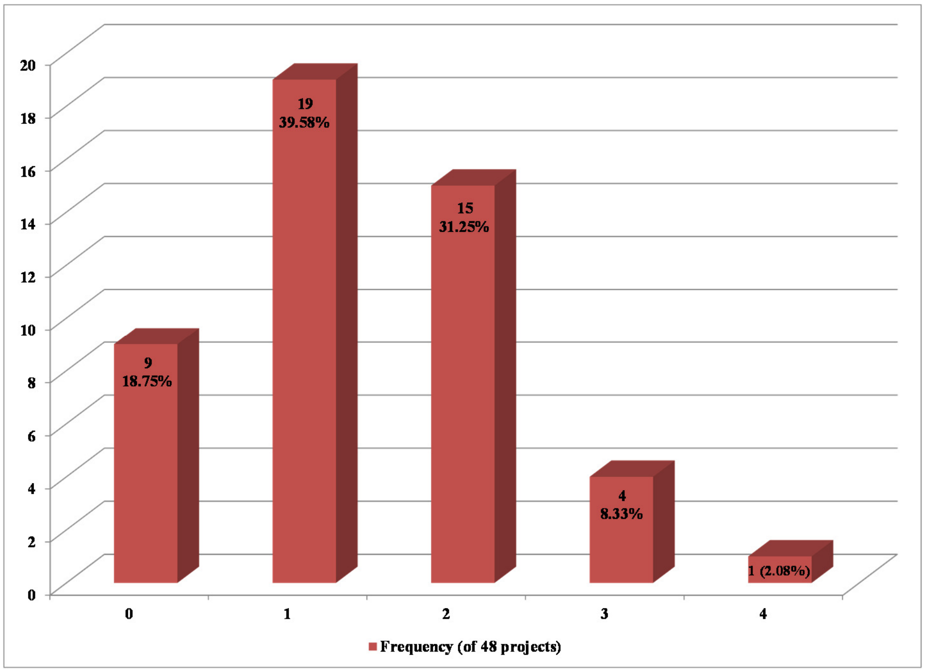

Figure 1: Number of engineering economic analysis methods used by the 48 projects. For example, 18.75% of the projects (nine of the projects) did not complete an economic analysis.

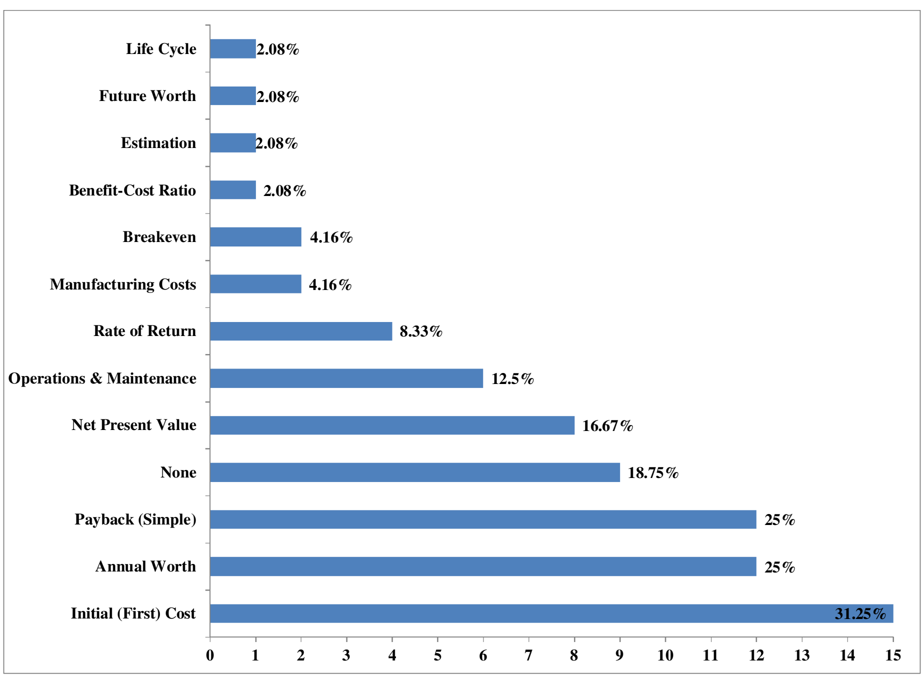

Figure 2: Usage of various engineering economic analysis methods by the 48 projects.

Table 1: The list of projects, sorted by industry type, including brief title, project type, completion date, and engineering economic analysis method. (Continued with Table 2.)

Project	Industry	Project Type	Date	Analyses
Modulated Lighting of Approach/Avoidance Inclinations	Aerospace	R&D	Spring 2011	Annual Worth, Initial Cost
Lift Safety Harness for Aft Transmission Installation and Removal	Aerospace (Helicopter)	Mechanical	Spring 2011	Initial Cost, B/C Ratio
Extraction and Purification of Pigment from Purple Sweet Potatoes	Agriculture (Food)	Bioprocess	Spring 2012	None
ConAgra Cookstand	Agriculture (Food)	Electro-mech	Spring 2008	Payback
Design and Optimization of Firefly Luciferase production, Purification and Characterization at the Benchtop Bioreactor Scale	Bioprocess	R&D	Spring 2009	Initial Cost, O&M
DIY Affordable Hurricane Shutters	Construction	New Product Development	Fall 2012	Initial Cost, Mfg Costs
Waukesha Electric Senior Capstone Project	Electric Transmission	Mechanical	Spring 2010	Annual Worth, Payback
Human Simulated Voltage Testing for Ground Grid Integrity of Transformer Substations	Electric Transmission	Electrical	Spring 2013	Annual Worth
Rice Emission Impact Study	Electric Transmission	Emissions, controls	Fall 2012	Initial Cost, Payback
Nucor Scrap Barge Watering System	Foundry	Mechanical	Spring 2008	Initial Cost
Push-up Pal	Health	Exercise Physiology	Spring 2012	Payback, NPV
ECU Balance "Limits of Stability" Testing Prototype Improvement/Redesign	Health	Mechanical	Spring 2013	Initial Cost
Electrical Stimulation Instrumentation for 2D and 3D Cell Cultures	Health	Bio-Med Basic R&D	Spring 2013	Initial Cost, O&M
Development of the Structure and Steering of a Manual Mobility and Exercise Device "Citty Stepper"	Health	Mechanical, New Product Design	Fall 2012	Estimation
Plantar Flexion Device	Health	Mechanical, Controls	Spring 2011	Annual Worth
Preventive and Predictive Maintenance Program Design for an Industrial Equipment Fabrication and Repair Facility	Machining	Industrial, preventative maintenance	Spring 2011	None
Queuing System for the Management and Scheduling of Deferrable Work	Machining	Industrial	Spring 2012	Future Worth, Annual Worth, Payback, ROR
Smart Maintenance	Machining	Industrial	Spring 2012	Annual Worth, Life Cycle, Payback
Material Handling at the Roberts Co	Machining	Industrial	Spring 2012	NPV
Estimating System Design	Machining	Industrial	Spring 2008	None

Glossary:

O&M: Operations and Maintenance Costs

B/C Ratio: Benefit – Cost Ratio

NPV: Net Present Value

ROR: Rate of Return (includes ROR, IRR, and ROI)

Mfg Costs: Manufacturing Costs

Table 2: The list of projects, sorted by industry type, including brief title, project type, completion date, and engineering economic analysis method. (Continued from Table 1.)

Project	Industry	Project Type	Date	Analyses
Key Profile Milling Machine Production Rate Improvement	Manufacturing	Mechanical	Spring 2013	NPV
Design a Tablet Holding Device Used to view a Visual Troubleshooting Guide for Kehin Maintenance Employees	Manufacturing	Mechanical	Spring 2013	Annual Worth, NPV, Payback
Identification Systems of Hardware Packs	Manufacturing	Industrial	Spring 2013	Annual Worth, Payback
Analysis of Paint Defects at NACCO Materials Handling Group	Manufacturing	Industrial, Mechanical	Spring 2013	Annual Worth
NACCO Materials Handling Group Portable Battery Charger Warranty Testing	Manufacturing	Electrical	Spring 2013	Initial Cost
Essential Job Functions Analysis	Manufacturing	Industrial	Spring 2011	None
Narrow Width Base Arms & Load Wheel for Reach Truck	Manufacturing	Mechanical, New product development	Fall 2012	NPV, Breakeven
CPP Material Efficiency Analysis	Manufacturing	Scrap reduction, mechanical	Spring 2008	None
Dyneema VOC Emissions Reduction	Manufacturing	Mechanical	Sprint 2011	Initial Cost
Energy Consumption of Low-lift Walkie Trucks	Manufacturing	Energy Conservation	Fall 2010	ROR, Payback, NPV
Compressed Air System Improvement in Utility Usage	Military	Mechanical piping	Spring 2013	O&M
Instant Fixed Backpack Based Canopy	Outdoors	New product development	Spring 2013	Initial Cost, Mfg costs
Solution for Producing Tepid Water Ranges in Emergency Wash Stations	Pharmaceuticals	Mechanical piping, safety	Spring 2012	Initial Cost, O&M
Water conservation Analysis and Design for DSM Pharmaceuticals	Pharmaceuticals	Mechanical process piping, green/lean	Spring 2011	Payback
Covidien PM Program Design	Pharmaceuticals	Industrial	Spring 2013	O&M
Water Conservation Analysis and Design for DSM Pharmaceuticals	Pharmaceuticals	Resource conservation	Spring 2011	Initial Cost
Design Analysis of Downstream Effects by Increasing production Capacity	Pharmaceuticals	Bio-process	Spring 2013	Initial Cost, O&M
M&TE Tracking System Design	Pharmaceuticals	Industrial	Fall 2012	None
DSM Conservation	Pharmaceuticals	Resource Conservation	Spring 2010	Annual Worth
Chiller Efficiency Report	Pharmaceuticals	Industrial	Spring 2008	Annual Worth, Payback
Process Database Design	Pharmaceuticals	Industrial	Spring 2009	None
Air Compressor Efficiency Analysis	Pharmaceuticals	Industrial	Spring 2008	Payback, ROR, Annual Worth
RFID Lab Design	Pharmaceuticals	Industrial	Fall 2008	Initial Cost
Automated Tracking System for Field Standards	Pharmaceuticals	Industrial	Fall 2012	NPV, Breakeven
Bumper Test Stand	Trucking/Logistics	Mechanical	Spring 2011	NPV
Implementation of Lean Principles in Moen of Kinston's Distribution Center	Warehousing	Industrial	Spring 2009	None
City of Greenville Public Works Warehouse Project	Warehousing	Industrial	Fall 2011	None
Dyneema Warehouse Logistics	Warehousing	Industrial	Fall 2011	ROR

Discussion, Conclusions, and Future Work
As mentioned in the background section, student teams have multiple requirements for senior capstone projects with industry sponsors. The teams must satisfy both the academic requirements and the sponsor's project requirements. Oftentimes, the student teams focus their economic analysis on the sponsor's preference, while ignoring the academic requirements. At ECU the capstone students are required to complete simple payback period, net present value (NPV), and internal rate of return (IRR) analysis methods for the academic requirements. *Note, it is entirely possible that the students complete these analyses but do not include them in the final report; which for purposes of this paper was the method for obtaining the economic analysis method.*

The preferred method of first cost, followed by annual worth and simple payback period mimics observations presented in engineering economics textbooks when observing industry preference[18,19]. Further research could be completed to determine if facility size, company size, and project purpose had specific correlation to the engineering economic analysis.

Another issue to evaluate further is the preferred method for product development projects, particularly in the health and bioprocess industries. The student teams are often developing or fabricating equipment to aid with a health or bioprocess experiment. Thus, it is hard to estimate, let alone compute, an accurate benefit or revenue to allocate to the project. The initial cost of the development and fabrication is the only accurate measurement that students can use as a design criterion. Further research on how to quantify the benefit of research and development for student capstone projects is warranted.

The authors believe that teaching engineering economic methods that industry prefers is important to prepare students for the workplace. However, all classical methods of engineering economic analysis are important to teach for a variety of reasons; for example, preparing for the engineer-in-training and professional engineer exams, quantitative and financial literacy, mathematical application, engineering design, analytical decision-making, graduate school preparation, and lifelong learning.

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