Assimilating Sustainability Concepts in Engineering Management Graduate Program Capstone Projects

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Abstract

Engineering Management (EM) as a graduate program has become increasingly popular in the last several decades, thus offered by many universities worldwide. EM evolved from a business management graduate program where the primary focus was on the business attributes (e.g. economics, marketing). Now, the emphasis of EM programs is on both technical expertise and general management aspects such as project management, operations, business management and leadership. Technical tools that are imparted in an EM graduate program today include modelling, advanced statistics, quality, operations research and technology assessment.

Major world corporations, governments and non-profits are now actively engaged in implementing sustainability related projects with the goal of balancing economics, environment and equity (or social justice or social responsibility), generally known as the 3Es. Sustainability is becoming so important that the American Society of Engineering Management is in the process of publishing its special sustainability issue with features focused on the 3Es. Key technical and EM tools in modern EM programs are becoming necessary for today's leaders for the implementation of sustainability projects. The rigor, tools and methodologies of an EM graduate program easily enables implementation of sustainability projects during EM's capstone project courses. These projects provide hands-on experience to satisfy both the short and long-term goals of an organization.

This paper demonstrates how several sustainability capstone projects related to energy and recycling were implemented as a part of EM's capstone courses. The example projects were sponsored by energy utilities and other organizations. They describe EM's rigor, models and methodologies used to demonstrate how sustainability principles can be effective assimilated into graduate EM capstone courses. With no change to any EM curriculum, student teams were successful in implementing sustainability related projects in their capstone course. This paper will also present ideas of how sustainability related projects can be assimilated in other programs using existing curriculum.

Introduction

According to the well-known author Daniel Babcock, Engineering Management (EM) is the application of quantitative methods and techniques to the practice of management science, highlighting the intersection of quantitative techniques (i.e. engineering methodology) and management [Babcock, 2014]. Engineering Management leadership has become a highly sought skill in today's competitive global technological marketplace. The University's Engineering Management program is designed to bring the benefits of modern technology and high-quality graduate-level instruction to engineers, scientists and technologists interested in furthering their skills in engineering management with specializations in the following areas:

- Project Management to become effective future project managers.
- Systems Management to manage the life cycle of systems including definition, development, deployment and decommissioning.
- Technology Management to manage and lead technology in global marketplace.

These specializations offer practical business perspectives necessary for engineering management. Unlike traditional MBA programs, these programs emphasize management skills that are specifically built on the students' technical backgrounds and experience. The custom-designed mix of management concepts and technical expertise will help prepare professionals to direct major public and private organizations in the increasingly complicated managerial environment. In this program, engineering management principles are broadly based and draw from many different disciplines such as applied sciences, engineering, natural sciences, mathematics, economics, business and social sciences.

This paper demonstrates how the rigor and strength of EM tools and methodologies are used in assimilating sustainability related projects in the graduate program's capstone courses, with no changes to the core curriculum of the program. The paper also briefly discusses modern definition of sustainability, its relationship with EM and its importance in engineering higher education.

Sustainability Definition and its Relationship with EM

The modern definition of sustainability highlighted by the 3Es: Economics, Environment and Equity (or Social Justice), is driven by two key publications, (a) the United Nations Report [United Nations, 1987] and (b) Sustainability Revolution [Edwards, 2005]. It is about enhancing each "E" while balancing the 3Es in any sustainability related project. Skills to understand and critical interpretation of sustainability elements are built in to our EM curriculum.

American Society of Engineering Management (ASEM) is publishing a special issue on *sustainability* in the *Frontiers of Engineering Management* [ASEM, 2018]. This special publication identifies the following as a key reason for the publication: *"The problems of sustainable development are complicated. There is a need to consider multidisciplinary issues of three categories: economic, ecological (environmental), and social sustainability. The challenges of sustainable development may include defining the critical metrics, justifying the collected data, balancing the metrics in these three categories, and making policies for international societies".* The first three topics to be covered in this special publication line up with the 3Es of sustainability.

Additional topics expected to be covered in this special issue include a wide range of important areas including waste management, energy systems and Corporate Social Responsibility (CSR).

The Accrediting Board for Engineering and Technology (ABET) also embraces the key elements of sustainability as they define engineering as: "The profession in which a knowledge of the technical, mathematical and natural sciences gained by study, experience and practice applied with judgement to *develop ways economically in order to utilize the materials and forces of the nature for the benefit of mankind*" [ABET, 2018] (*emphasis added).* Thus, ASEM and ABET, both highly regarded professional organizations, support sustainability to be a part of EM, and thus sustainability is a key aspect of our graduate educational program.

Higher Education in Sustainability

Several higher education institutions in the US teach environmental engineering both in at the undergraduate and graduate levels [Environmental Engineering Degrees]. It is to be noted that environment is one of the 3Es of sustainability per the modern definition discussed above and it is highly technical. It also fits well within engineering departments. It is not uncommon for higher education institutions to teach the full scope of sustainability (i.e. 3Es) under engineering/technology and special departments [Sustainability Innovation, n.d.]. The Ohio State University [Sustainability Education, n.d.] and Harvard University [Sustainability Degree, n.d.] teach the full scope of sustainability under different departments with engineering and management focus. Construction higher education programs have also embraced sustainability. The American Society of Civil Engineers in their publication, *The Journal of Profession Issue in Engineering Education and Practice* notes the following: *Incorporating the concepts of sustainable development in engineering education is becoming a necessity in order to prepare future professional with dynamic mindset and broad knowledge needed to effectively and efficiently solve the interdisciplinary changes of the 21st century* [El-adaway, et al., 2015]. It is also of interest to note that many higher education business schools teach sustainability implementation in their supply chain management courses.

Unique Attributes of Engineering Management Graduate Program

The objective of the graduate EM program offered in the University looks to develop future leaders with skills to both develop and manage complex, technically-oriented projects.

The Engineering Management Handbook published by American Society of Engineering Management [ASEM, n.d.] lays out a clear methodology and the outline for the various curriculum aspects for EM education. ASEM's recommendations include but not limited to professional ethics, management, operations, engineering economics, strategic management and project management. Major universities in the U.S. and around the world have developed EM graduate programs focused on key skills development for students supporting the range of curriculum suggested in the ASEM handbook.

At the University, the curriculum is divided in to three sections: core courses, specialization courses and capstone project courses. Students initially complete a set of six core courses as listed below:

- Engineering Management Concepts
- Project Management Principles
- Risk, Contracts and Legal Issues
- Skills Management
- Quality Management
- Global Trends in Technology

In addition to the core courses, a student is given the option to specialize in one of these three specific areas: Project Management, Technology Management or Systems Engineering. To earn a specialization, students will take four additional advanced level courses. For example, for Project Management specialization, students are required to take the following four courses:

- Operations Management
- Advanced Project Management
- Product Management
- Project Financing Management

The third section of courses in EM program are two courses to complete a graduate-level capstone project. EM capstone projects are generally done in student-teams to reflect the real-world working environment where most projects are done in a team. Teamwork also encourages innovation through team-member interactions.

In the first capstone course, student teams research a project, gather initial data and define a project with clear objectives (Figure 1).

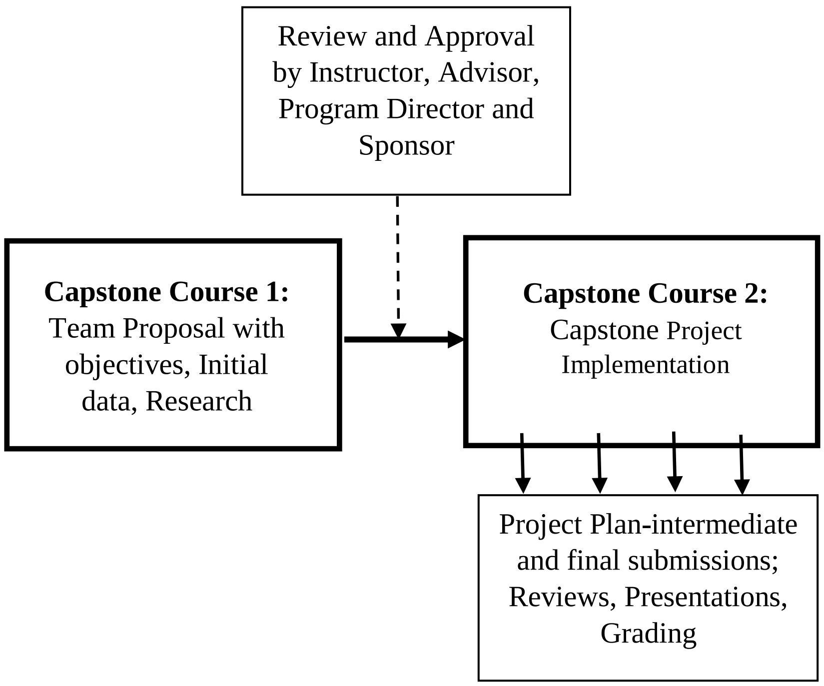

Figure 1; EM Capstone Project's Two Courses and their Outputs

The output of the first capstone course is a detailed project plan addressing all aspects of project implementation including data collection, modeling, risk mitigation, schedule and financial plan. The project is implemented during the second course. Often, the projects are sponsored by companies where the students are already working, thus bringing real-world problems to solve in the classroom.

As can be seen from the course work noted above, EM graduate curriculum is comprehensive both from technical and managerial aspects. During capstone courses, student teams use all the tools and techniques they learned in the curriculum to complete their final project with the following key chapters:

1. Introduction – Project definition, Identify goals and objectives of the project
2. Literature Survey – Detailed literature survey; identify similar and/or related project as case studies examples.
3. Methodology – Variables Identification, Objective Function Optimization and Modelling, sample calculations.
4. Implementation – Complete calculations applicable to the project, analysis and findings
5. Conclusion and Recommendations - specific conclusions and related recommendations derived from the project

By design, the EM program is a structured and comprehensive graduate program that brings together key technical skills and management skills. Courses are taught by experienced full-time faculty members and instructors from industries with experience in teaching and research. This well-structured approach in capstones helps the student teams to assimilate sustainability's full scope into EM capstone projects. This is also a boon for companies sponsoring sustainability projects due to its significance in the current and future business world to get ahead of regulations and competition.

Examples of Sustainability Capstone Projects in the EM Program
As noted earlier, private companies, non-profits and government agencies at all levels are taking steps toward a more sustainable approach in their operations. Before the specific capstone project examples are discussed, it is important to introduce the key aspects of the modern definition of sustainability and identify the attributes of an EM program that help implement sustainability projects.

Students in the EM graduate program have been doing sustainability related projects for the last several years. About a quarter of the capstone projects in the last 5 years have been in the areas of energy conservation, renewable energy, water conservation, electric vehicles and recycling. All projects directly impact the 3Es of *sustainability.* For example, energy conservation and renewable energy projects help reduce the burning of fossil fuel (or eliminate it completely), which impacts the environment in three positive ways. Energy conservation and use of renewable energy reduces the cost of energy in the long run impacting **economy** positively. This also reduces pollutants, thus making the **environment** better for everyone's health and improves planet's ecosystems. Technologies used in both the development of materials for renewable energies and their construction create new jobs, thus impacting **equity** positively.

Now, four examples of sustainability projects completed by the University students with their faculty advisors and instructors in the EM program are described below.

Project 1: Economic Viability of Solar System for Homes [Ahmed, Naik and Troung, 2018]
The objective of this project was to develop both a technical model and financial model to determine the viability of solar systems for single family homes in San Diego County. The research methodology used was Descriptive-Correlation Method. This approach provided the development of a mathematical model supporting the objectives of the project with the model being validated with case-studies.

The project addressed the technical aspects of solar power generation and the financial aspects with both independent and dependent variables in each case. The mathematical model was developed using MS EXCEL software. For model verification and validation, the team used three working home solar systems that were implemented in the last 2-3 years. The predicted and actual value of the model was tested using Chi-Square test for statistical validity. The results of the Chi-Square test indicated that the p-value is significant, and the model demonstrated a high accuracy level of 95%. The hypothesis of the model, "The analytical model developed will be able to help a single-family homeowner of a 2,000-3,000 square-foot home in San Diego County evaluate a solar system based on technical as well as financial requirements," was validated. The output of this project provided an easy interface with several options to customers to assess the economic viability of a home solar system. The output options included purchase or lease and return on investment.

From a sustainability perspective, solar systems greatly reduce or even eliminate using energy from fossil fuels which emit Green House Gases (GHG). For every kWh of energy generated from solar systems, they eliminate about two pounds of GHG emission into the atmosphere resulting in a cleaner environment and healthier living, particularly in congested metropolitan areas. Thus the project supported all the 3Es of sustainability.

The team applied modelling and financial tools learned through the EM curriculum to implement this project. The team developed tools to provide three different options to purchase a solar system: Full Purchase with Cash, Lease Purchase and Purchase with Financing. For each option, the team calculated the Return on Investment (ROI).

Project 2: Use of Gray Water in California [Barnhart, Orca and Worthy, 2011]
This project explored the economic viability of wide-scale residential graywater use to alleviate California's water resource challenges. Two main objectives of the project were to assess the graywater concepts, with its associated technologies and treatment systems, and review specific case studies for the economics of gray water.

With the climate change dramatically affecting seasonal rains in California creating record droughts during this past decade, the state and cities are looking for various ways to reduce the use of potable water by replacing some with gray water usage (e.g. landscape irrigation, toilet flushing). Can gray water be a viable approach economically and environmentally to meet the challenges of water scarcity for people's healthy living conditions (equity)? The team studied the impact of continued climate change in California along with population growth and expected government regulatory changes. The team also reviewed case studies where gray water usage is already in place. These involved a thorough analysis of the background, current government regulations and the acceptance of gray water by the general public. The team analyzed several gray water systems, proposed an alternative or supplemental model to the current water management model and developed a domestic water usage model based on risks and costs. Their conclusion was that California must use gray water systems as a necessity to meet the challenges of future potable water scarcity. The team also recommended policy changes to further encourage the use of gray water. This project again demonstrated that EM students developed sustainability skills necessary to solve a real-world problem.

Project 3: Electric Vehicle Charging Project [Chang, et al., 2016]
Since the introduction of plug-in electric vehicles (PEVs) in December 2010, their sales have significantly increased year after year [Inside EV, 2015]. As of September 2014, the sales of PEVs were over 603,000 in the global market and over 259,000 in the U.S. [Cobb,2014]. According to the PEV Collaborative 2014 Annual Report, approximately 40% or 102,440 of those U.S. market sales were from California. San Diego Gas & Electric (SDG&E) confirmed that San Diego and Southern Orange Counties leased or sold 10,000 EVs within that same period. Based on the current trend, Melaina and Helwig [2014] reported that by 2024, the number of EVs in San Diego would reach 91,000. Chung [2014] declared that with the ever-increasing number of EVs on the roadways, the demand for availability and accessibility of EV charging stations has continued to grow exponentially despite the availability of residential chargers. The objectives of this EM capstone research project were to accomplish the following:

- Identify current problems for the existing charging stations and develop solutions to improve the availability and accessibility of public charging stations in the City of San Diego
- Develop a mathematical model to predict the demand of EV chargers in any city

The distribution and capability of the existing charging networks in terms of electric vehicles, location, charging rate and time of charging in San Diego was examined. A mathematical model to calculate the demand number of public Level 2 chargers for the City of San Diego and then for each zip code was developed. The results showed that although San Diego has enough chargers to accommodate the existing EV's charging demand, the current public charging distribution network is neither well designed nor effectively used. To eliminate the waste resulting from the inefficient charging infrastructure by maximizing the usage rate of each charger, it was recommended that the designed optimal model of this project be utilized and the resulting charging locations be implemented to improve the availability and accessibility of a charging network in the City of San Diego.

The use of EVs drastically reduces GHG emitted in to the atmosphere. On an average, for every mile driven with fossil fuel emits about one pound of GHG. In the long run, EVs will support all the 3Es of sustainability.

Project 4: Waste Management project…convert waste to energy [Rabern, W., et al, 2014]
Time Magazine discussed the designation of San Diego County as the craft-beer capital of America [Gilbert, 2012]. The University System Institute for Policy Research [National University, 2012] states that San Diego County now has approximately 80 breweries of various sizes, generating approximately $299.5 million in direct impact to the local economy annually. Goldhammer [2008] describes the brewing process as producing large amounts of wastewater effluent and solids that must be disposed of or treated. The City and County of San Diego do not currently have a cost-effective system to dispose of tons of brewery waste material generated daily. The waste material, considered food scraps, is made up of water, grains and yeast and can be used for other purposes besides being dumped in the city's only landfill. Landry [2002] published estimates that United States breweries use approximately 400 tons of grain per year to produce beer; approximately 92 percent of the material that goes into beer production is wasted in the form of brewery waste by-products. These waste by-products can be repurposed for a variety of uses; however, San Diego County does not currently regulate the disposal of brewery waste by-products, leaving the individual breweries to decide on the method to dispose of or reutilize the waste. Some of the waste is used to feed livestock or as compost; however, most brewery waste by-products are destined for landfills where it takes up valuable space.

Based on the study team's findings, the rules and regulations existing in California and specifically in San Diego County support the hypothesis that brewery waste by-products could be used to produce energy. Traditional methods of disposal such as using it as animal feed, compost or disposal in the landfill are not sustainable nor an efficient use of the waste products. As the number of breweries increases, the amount of brewery waste will create even larger landfill problems. A solution that involves a collaborative approach to collect and utilize the brewery waste by-product in an anaerobic digester to produce biogas, and in turn create electricity, is not only achievable but it is cost effective and environmentally responsible. There is approximately 6kWh of calorific energy contained in each cubic meter of biogas. Biogas conversion results in approximately 2 kWh of useable electricity the remaining 4 kWh is converted to heat that can be used for various heating applications. An initial capital cost of $5 million dollars and yearly continuous costs of $711,500 dollars are estimated in order to support a facility processing brewery waste collected from all San Diego County breweries. It is estimated that revenue collected from brewery waste conversion to biogas is approximately $1 million dollars annually. The breakeven point is estimated to be at 13.4 years with a kWh price of $0.22 cents, 75% dry Brewers Spent Grain (BSG) feedstock and 4,300 tons/year of BSG. The three variable factors that can decrease the breakeven point are increasing the kWh price above $0.22 cents, higher collection of BSG from breweries over 4300 tons and increasing the dry percentage above 75%.

Conclusion and Recommendations

Based on the projects described in this paper, the University has successfully assimilated the sustainability scope into graduate EM's capstone projects, taking advantage of the rigor and tools provided by the program curriculum. No change was made to the EM program requirements.

The engineering projects described in this paper require students to develop management solutions that include project technical evaluations and financial evaluations, as well as all supporting sustainability principles. The engineering approaches adopted here are validated with data and supported by the client as sponsor, thus making this method of practical hands-on education as an excellent way to develop cost-effective solutions that are environmentally responsible and in-line with the 3Es.

Since companies and governments are moving towards implementing sustainability principles in to their operations, many of the engineering and business school programs can assimilate sustainability concepts into their capstone project implementations.

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