AC 2010-550: INDUSTRIAL ENGINEERING: IDEALLY POSITIONED TO ADDRESS THE SUSTAINABILITY CHALLENGE

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Industrial Engineering: Ideally Positioned to Address the Sustainability Challenge

Abstract

Industrial Engineers (IEs) have embraced efficiency principles in the design and improvement of manufacturing systems. The lean concept defined by the Toyota Production System has augmented traditional Work Design courses as a tool for eliminating waste in the manufacturing environment. As systems thinkers, the unique skills and tools of the professional IE will build on the idea of eliminating waste to include the complete life cycle of a product. The IE skill set is necessary to support sustainable engineering practices in the design and analysis of products and processes. The purpose of this paper is to discuss the importance of integrating principles and practices of sustainability into IE higher education.

Introduction

The need for sustainable engineering design practices has never been more apparent than in today's scientific and public media. Climate change, chemicals released into the environment, land use changes, and the depletion of natural resources are frequent headlines in the media and the focus of a growing number of scientific journals. The National Academy of Engineering unveiled The Grand Challenges for Engineering in a public statement on February 15, 2008[1] and sustainability was noted as one of four broad realms of human concern. Six (out of 14) of the engineering challenges are related to environmental sustainability: (1) Make solar energy economical, (2) Provide energy from fusion, (3) Develop carbon sequestration methods, (4) Manage the nitrogen cycle, (5) Provide access to clean water, and (6) Restore and improve urban infrastructure.

Industrial Engineers (IEs) are in a unique position to play a key role in the effort to bring sustainability concepts to the mainstream of engineering education. Their historical figures and initiatives are aligned with the current need for sustainable products and processes. The IE skill set includes a systems approach to decision-making required for sustainable design. Traditional topics of study in IE curricula include Systems Analysis, Computational Modeling (Statistics, Engineering Economy, Operations Research, Discrete-Event Simulation) and Work Design. Such courses lend themselves to a discussion of sustainability. The orientation and preparation of IE students puts them in an excellent position to embrace the goal of sustainable design in order to meet the needs of the present without compromising the ability of future generations to meet their own needs.[2] This is particularly the case for IE undergraduate students.

Figure 1 shows the factors that define a sustainable state of development. The three rings represent systems that support humanity: the economy, the environment, and society. The overlap between the rings suggests that we cannot degrade/ignore any one of the rings without adversely affecting another and every ring must be healthy and in balance within the system.[3] The basic framework of Figure 1 may also be viewed by expressing sustainability in terms of three pillars: (i) the Industry/Economy/Technology Systems Pillar, (ii) the Environment/Natural Systems Pillar, and (iii) the Behavior/Society/Individual Systems Pillar.[4,5] All of the pillars must be simultaneously addressed for sustainability. This is sometimes referred to as the Triple Bottom Line of people, planet, and profit.[6]

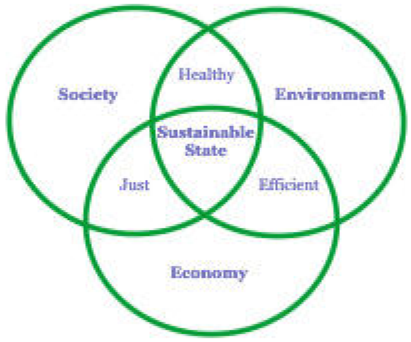

Figure 1: Sustainable Development[7]

Sustainability Topics

In considering the issue of sustainability, and given the importance of engineering education to work towards a more sustainable world, one might reasonably ask: "in what manner should sustainability be infused into engineering curricula?" We believe that the opportunity exists to introduce sustainability content throughout all engineering curricula, including IE. To begin to respond to this opportunity, we would like to begin discussions by proposing the structure shown below. This structure introduces sustainability content through three areas: i) foundational math and science, ii) engineering science, and iii) applied and advanced engineering topics. Within each area, sustainability content can be further broken down into categories.

<u>Foundational Math & Science Categories</u>
These are categories that comprise the building blocks for the engineering student to understand the background and need to consider the environment in decision-making. Proposed categories include (1) Complex Systems & System Dynamics, (2) Natural World Basics, and (3) Institutions and Societal Systems.

<u>Engineering Science Categories</u>
These categories build on fundamental math and science content and introduce additional subject matter in an engineering context. Proposed categories include (4) Chemicals and Materials, (5) Design and the Life Cycle, (6) Alternative Energy Systems Science, (7) Industrial Sustainability, and (8) Implementing Sustainable Practices.

<u>Applied and Advanced Topics Categories</u>
A set of applications and advanced topics are proposed. These build on the foundational and engineering science topics with emphasis placed on taking ideas from theory to reality. Proposed categories include: (9) Sustainable Design, (10) Sustainable Manufacturing, (11) Chemicals & Materials for Sustainability, (12) Energy Production & Distribution, and (13) Sustainable Built Environment.

The next logical question is "into which engineering undergraduate classes should the thirteen sustainability topics be integrated?"

Core Engineering Courses

Many of the core courses in any engineering program across the U.S. could benefit from the integration of sustainability concepts. In order to compare various engineering curricula, a starting point is The Fundamentals of Engineering (FE) Examination. The FE exam is the first step towards a professional engineering license. The morning session is made up of twelve topic areas that can roughly translate to core courses within an engineering undergraduate degree (these topics are listed at http://www.ncees.org and became effective with the April 2009 examinations). The afternoon session of the exam contains topics that are more specific to an engineering specialty. Table 1 lists the twelve topics from the morning session plus an additional topic for the Senior Design Project Class required to meet ABET criteria for accredited engineering programs. It also suggests the sustainability categories that may best fit the FE topics.

Table 1. Mapping Core Engineering Topics to Sustainability Concepts

Core Engineering FE Exam Topic	**Relevant Sustainability Categories**
Mathematics	1. Complex Systems & System Dynamics
Engineering Probability and Statistics	1. Complex Systems & System Dynamics
Chemistry	2. Natural World Basics, 4. Chemicals and Materials 11. Chemicals & Materials for Sustainability
Computers	6. Science and Issues Related to Alternative Energy Systems
Ethics and Business Practices	3. Institutions and Societal Systems 8. Implementing Sustainable Practices 9. Sustainable Design 10. Sustainable Manufacturing
Engineering Economics	7. Industrial Sustainability
Engineering Mechanics – statics/dynamics	5. Design and the Life Cycle 13. Sustainable Built Environment
Strength of Materials	4. Chemicals and Materials 11. Chemicals & Materials for Sustainability
Material Properties	4. Chemicals and Materials 11. Chemicals & Materials for Sustainability
Fluid Mechanics	12. Energy Generation & Distribution
Electricity and Magnetism	6. Science and Issues Related to Alternative Energy Systems 12. Sustainable Energy Processes & Distribution
Thermodynamics	12. Sustainable Energy Processes & Distribution
Senior Design Project	5. Design and the Life Cycle 8. Implementing Sustainable Practices 9. Sustainable Design

The core engineering courses are similar across all curricula. The IE profession spawned from the Industrial Revolution era and continues to evolve as we move from a manufacturing-based country to a knowledge-based country. This evolution has gone from the craftsmen job shop to the mass producing assembly line now to include lean principles. This evolution will continue as IEs strive to improve processes for both the product and the service sectors with changing social, environmental and economic needs.

Brief History of IE

Henry Ford's first batch assembly line attempted to efficiently produce a vehicle while eliminating waste in all forms. The entire vehicle was made at Ford's Rouge Facility where the product life cycle from design to assembly could be managed in one location. Ford's work has transcended time and geography by being implemented into Toyota's Production System (TPS) and the idea of a lean enterprise. Today's global supply chain has added complexity due to the apparent disjointed nature of the development cycle. The idea of Lean Manufacturing was developed to define and eliminate waste in all forms. Waste is identified by Lean as (1) defective products, (2) overproduction, (3) motion that does not add value, (4) transportation resulting in excess material handling, (5) waiting & idle time, (6) excessive inventory, and (7) unnecessary processing. Two additional types of waste are emerging in contemporary lean thinking to be defined as the eighth and ninth deadly wastes – (8) underutilized talent in the workforce and (9) waste of natural resources. The waste of natural resources is an important aspect of sustainability and must be a main focus of contemporary improvement projects. In addition to wastes traditionally defined in the industrial production process, the idea of "lean" is now embraced by many organizations including service organizations trying to eliminate waste in the costly and often inefficient process of serving others.

Industrial Engineering Courses

Industrial Engineers will have a better understanding of the necessity of sustainability if the topics are addressed throughout the IE curriculum, including the core FE content noted above. In addition, there are unique IE courses that can benefit from the introduction of sustainability topics. The afternoon session of the FE Exam for Industrial Engineers presents questions, that can be loosely translated to IE courses, that we believe can be infused with sustainability content. Table 2 suggests an initial mapping of IE courses to Sustainability Categories for integrating sustainability concepts within courses/topics of the IE curriculum. Examples and additional information on how sustainability might be integrated into three typical IE core courses is found in the following paragraphs.

<u>Systems Analysis</u> One course that often exists in an IE undergraduate program may carry the title of Systems Analysis, Systems Design, Systems Thinking, or Systems Planning. Such a course includes an element of viewing a problem in the context of a larger system. It is noted that the idea of sustainability is consistent with this fundamental approach and perspective to problem solving. Sustainability also requires that an engineer (or designer of a product, process, or system) view their problem as part of a bigger system. The introduction of Life Cycle

Analysis as a tool for examining the supply chain from raw material extraction through the end of life of a product may introduce the idea of sustainability to this course.

Table 2. Mapping Industrial Engineering Topics to Sustainability Concepts

Possible IE Course	Relevant Sustainability Categories
Engineering Economics	7. Industrial Sustainability
Probability and Statistics	1. Complex Systems & System Dynamics
Modeling and Computation	12. Sustainable Energy Processes & Distribution
Industrial Management	3. Institutions and Societal Systems 8. Implementing Sustainable Practices
Manufacturing and Production Systems	10. Sustainable Manufacturing
Facilities and Logistics	9. Sustainable Design 13. Sustainable Built Environment
Human Factors, Productivity, Ergonomics and Work Design	5. Design and the Life Cycle 12. Sustainable Energy Processes & Distribution
Quality	8. Implementing Sustainable Practices

Computational Modeling IEs take a myriad of courses related to statistics and Operations Research. Typically viewed through a lens of computational models, particularly linear programming, problems are typified by an objective function with multiple constraints. A typical objective function is the maximization of profits or minimization of costs. This is again consistent with sustainability; in industry, the idea of making a profit is implicit in any design, because this is needed for the company to stay in business for the long term. However, an additional constraint of natural resource management is necessary to sustain the environment. Other objectives (or constraints) may include land use, chemical releases, energy consumption, and other environmental metrics. An understanding of statistics is also very helpful owing to the uncertainty that exists within the system, e.g., environmental data and environmental models (mapping of CO_2 emissions into sea-level rise for example).

Work Design Traditional IE core courses relate to the design of a production system for the purpose of efficiency and worker health and safety. This aligns with the three pillars of sustainability in that the environment and the society (person) must be considered along with such economic factors as business profitability. The lean principles introduced in this course must include the nine wastes including the waste of natural resources as a metric. Additional objectives within the design of work could be added to measure sustainability.

While it is true that many IE courses can benefit from the integration of sustainability concepts, it is also true that these sustainability concepts must be approached from multiple perspectives. The issue of sustainability does not reside in a single academic degree program, rather, the solution benefits from input across multiple disciplines.

Multi-Disciplinary Concerns

Multidisciplinary teams of scientists and engineers are needed to educate future leaders; this need is evident in numerous reports from agencies that concentrate on higher learning. For example, the Secretary of Education's Commission on the Future of Higher Education Report, the Spelling Report[8], states that in tomorrow’s world a nation’s wealth will derive from its capacity to educate, attract, and retain citizens who are able to work smarter and learn faster—making educational achievement ever more important both for individuals and for society.

The National Academy of Engineering provided guidance along these lines in two important publications *The Engineer of 2020*[9] and *Educating the Engineer of 2020.*[10] NAE states that engineering education must address contemporary challenges through multidisciplinary teams so students will gain the ability to communicate across disciplines. Educators are also called upon to encourage young people to pursue an engineering career through creative ideas and teamwork to promote the idea of a satisfying profession.[11] In addition, students must understand state-of-the-art technology and the complexities associated with a global market and social concerns. Specifically, natural resource and environmental issues will continue to frame world challenges with creative ideas needed to find solutions.

Bringing sustainability topics into an engineering curriculum requires a multi-disciplinary approach as evidenced by the various perspectives that must be included in any good design. Similarly, to integrate the ideas of sustainability throughout an engineering curriculum will require a new approach to teaching engineering concepts.

The engineering curriculum at most universities of higher education is packed with core concepts and additional courses may be met with resistance by students and educators due to the cost of tuition and the need to graduate in a timely manner. Thus, the integration of sustainability concepts throughout the curriculum by bringing concepts into existing courses, rather than creating new courses, is appealing to educators All courses have the potential to bring sustainability concepts into their design with varying levels of depth. Courses could be labeled on a scale of sustainability depth ranging from exposure to immersion. An exposure course may simply include examples of how the course concept is related to sustainability, while an immersion course would include sufficient depth of experience so that the student can undertake a multi-disciplinary design experience.

Conclusions

The need to consider environmental sustainability along with conflicting objectives and multiple constraints during the design of production and process systems is more important today than ever. IEs have the unique skill set and the necessary tools to address this complex problem. The role of bringing together a collaborative team drawn from a variety of disciplines with a common goal of designing sustainable products and processes should include IEs at the core. Changing the way the next generation of IEs (and indeed all engineers) view the design of products and processes in the context of sustainability should become a necessary part of engineering education.

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References

1 National Academy of Engineering (NAE). "Grand Challenges for Engineering." Washington, D.C., February 15, 2008.

2 "Brundtland Commission Report *World Commission on Environment and Development: Our Common Future, (1987)"* http://home.att.net/~slomansonb/Bruntland.html (accessed December 22, 2008).

3 New Jersey Department of Environmental Protection, Division of Science, Research & Technology http://www.state.nj.us/dep/dsr/sustainable-state/what-is.htm, (accessed January 26, 2009).

4 Mihelcic, J.R. and D.R. Hokanson. "Educational Solutions: For a more Sustainable Future." In *Environmental Solutions,* edited by F. Agardy and N. Nemerow. Elsevier, in press, August, 2005.

5 Sutherland, John. "Sustainable Futures Institute." http://www.sfi.mtu.edu (accessed December 22, 2008).

6 Elkington, J. (1994) "Towards the sustainable corporation: Win-win-win business strategies for sustainable development." California Management Review 36, no. 2: 90-100.

7 New Jersey Department of Environmental Protection, Division of Science, Research & Technology http://www.state.nj.us/dep/dsr/sustainable-state/what-is.htm, (accessed January 26, 2009).

8 U.S. Department of Education. A Test of Leadership: Charting the Future of U.S. Higher Education. Washington, D.C., 2006.

9 National Academy of Engineering (NAE). *The Engineer of 2020: Visions of Engineering in the New Century*, National Academy of Engineering of the National Academies, The National Academies Press, Washington, D.C. 2004.

10 National Academy of Engineering (NAE). *Educating the Engineer of 2020 Adapting Engineering Education to the New Century*, National Academy of Engineering of the National Academies, The National Academies Press, 2005.

11 National Academy of Engineering, (NAE), *Changing the conversation: Messages for Improving Public Understanding of Engineering*, National Academy of Engineering of the National Academies, The National Academies Press, 2008.