Introduction of Sustainability Concepts into Industrial Engineering Education: a Modular Approach

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Dr. Dima Nazzal, Joseph Zabinski
Stewart School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, GA 30332, USA

Abstract

The importance of sustainability concepts to industrial engineering education is growing rapidly as the field’s traditional objectives interact more frequently with the challenges of a resource-constrained world. In this paper, we first discuss the presence of sustainability concepts in the IE curricula of leading U.S. universities. We then describe a curricular approach, using topic-specific modules, by which we introduced sustainability content into several IE courses over a period of several years. We conclude with observations regarding the state of synthesis between sustainability and IE education, with recommendations about how to use modular modifications to curricula to begin to enhance this synthesis.

Keywords
sustainability, curriculum, industrial engineering, supply chain, education

1. Introduction

Sustainability – organizing processes in ways that reduce their consumption of resources and negative impacts on societal and environment systems – is a vital tool in countering the strain to which increasing human activity subjects these systems. In recent years, society as a whole has begun to recognize that in many instances, sustainable enterprises can meet its demand for goods and services without compromising quality or reliability. Initiatives from the drive towards renewable energy to greater emphasis on work-life balance to climate change mitigation efforts in industry attempt to achieve this goal, and to incorporate sustainability into the existing hierarchy of objectives that human systems seek to attain.

As the professionals tasked with designing, operating, and improving the workings of these human systems, engineers are poised to advance sustainability through direct action. Industrial engineers, with their panoptical perspective on these structures (supply chains, manufacturing operations, transportation networks, etc.) are especially well-positioned to recognize, study, and implement sustainable alternatives into existing systems while balancing commercial, technical, environmental, and social objectives. The tools of their trade – optimization, process modeling and design, and systems engineering among many others – are ideally suited to simultaneously take these different objectives into account.

In order to best use their abilities to address and implement sustainable mechanisms, however, industrial engineers need to understand sustainability and how it interacts with their broader role. Specifically, their education should provide direction on how to utilize the tools of industrial engineering to address sustainability. Ideally, this education would begin as early as possible: the sooner sustainability concepts are introduced to students, the longer these concepts have to take root and synthesize with the rest of the industrial engineering curriculum.

In our work, we examine several aspects of the question of how best to integrate sustainability concepts into industrial engineering education. We first present a brief survey of the current state of the field, considering sustainability in industrial engineering programs at the undergraduate and graduate levels. We then describe a pilot program, funded by an NSF grant and implemented at a large public research university in the Southeast, in which
modules on sustainability concepts were introduced in industrial engineering classes. We conclude with a brief discussion of a generalized curriculum modification framework derived from this pilot program.

2. State of Affairs

To determine the presence of sustainability content in industrial engineering programs, we analyzed programs ranked in the top 30 in the Industrial/Manufacturing/Systems Engineering (“IMS”) graduate category by U.S. News & World Report in 2013. [1] This list was compiled based on responses to surveys by the heads of industrial, manufacturing, and systems engineering departments at 91 institutions. While not comprehensive, we believe that this group of programs is a reasonable approximation of those viewed most favorably within the field today. These programs are ranked on a scale of increasing reputation from 1.0 to 5.0. The program ranked first had a score of 4.8, and the lowest-ranked program was scored 3.0. The average score was 3.67.

We examined the availability of sustainability concepts within the IMS curricula at these institutions, at both the undergraduate and graduate levels. At the undergraduate level we determined whether a minor or certificate was available in sustainability or a reasonably related field; at the graduate level, we considered the availability of master’s and doctoral degrees in sustainability. We also attempted to investigate the number of IMS courses with substantial sustainability content from published course information, as well as the number of sustainability-centric courses with substantial IMS content.

Table 1: Availability of undergraduate-level sustainability education at 30 highly-ranked IMS programs in the U.S. (adapted from [1])

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Avg. Score</th>
<th>Avg. No. of Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor/Certificate Available</td>
<td>15</td>
<td>15</td>
<td>3.69</td>
<td>N/A</td>
</tr>
<tr>
<td>IMS Courses with Sustainability Content</td>
<td>10</td>
<td>20</td>
<td>3.90</td>
<td>1.6</td>
</tr>
<tr>
<td>Sustainability Courses with IMS Content</td>
<td>2</td>
<td>28</td>
<td>3.15</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Several trends are apparent from these results. First, half of the programs considered do offer some sort of certification in sustainability concepts to IMS students. IMS courses with sustainability content are offered in a third of the programs, but the average number of such courses offered is quite low, at 1.6 per institution; the average ranking score of these institutions is also higher than that of all programs considered, indicating that these course offerings cluster at higher-ranked institutions. Finally, almost no programs offer sustainability courses with IMS content. Arizona State University stands out as an exception, with at least eight such courses (including Mathematical Concepts and Tools in Sustainability, Energy Use and Conservation, and several others).

Table 2: Availability of graduate-level sustainability education at 30 highly-ranked IMS programs in the U.S. (adapted from [1])

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Avg. Score</th>
<th>Avg. No. of Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masters in Sustainability Available</td>
<td>3</td>
<td>27</td>
<td>3.30</td>
<td>N/A</td>
</tr>
<tr>
<td>Doctorate in Sustainability Available</td>
<td>1</td>
<td>29</td>
<td>3.20</td>
<td>N/A</td>
</tr>
<tr>
<td>IMS Courses with Sustainability Content</td>
<td>8</td>
<td>22</td>
<td>4.20</td>
<td>3.3</td>
</tr>
<tr>
<td>Sustainability Courses with IMS Content</td>
<td>1</td>
<td>29</td>
<td>3.20</td>
<td>6.0</td>
</tr>
</tbody>
</table>

The results at the graduate level evidence similar, and more extreme, trends. Very few programs offer master’s or doctoral degrees in sustainability, and only eight offer IMS courses with sustainability content. While more such courses are offered, on average, than at the undergraduate level, the average ranking score of these institutions (4.20) is even farther from the overall mean and indicates a more pronounced clustering effect of such offerings at higher-ranking programs. Arizona State is the only institution offering sustainability courses with IMS content. Indeed, it is
the only university of those considered here to offer students a full-fledged sustainability program of study at all levels. Its School of Sustainability, established in 2007 and part of the broader Global Institute of Sustainability, is a leader in integrating sustainability education and research.

This survey of the state of affairs emphasizes that sustainability content is neither common, nor deeply integrated, in IMS curricula today. The coursework and degrees available are skewed towards the top-ranked institutions, and Arizona State is the only institution of those considered to fully balance and synthesize IMS and sustainability education. We believe that this situation deserves attention, and propose a method of modifying existing IMS curricula to begin remedying it.

As part of our investigation into these kinds of modifications, we conducted a review of several papers that address similar initiatives. Galambosi and Ozelkan [2] present a thorough overview of the state of the field as of 2011, with respect to both general engineering and management curricula. A number of other authors, including Sullivan and Walters [3] and Kalla and Brown [4] have suggested sustainability modifications to the construction engineering and manufacturing engineering curricula, respectively. Lynch-Caris and Sutherland [5] further develop the reasoning behind advancing sustainability through industrial engineering education. Their work focuses on the importance and applicability of industrial engineers’ unique skill sets and competencies in addressing issues of sustainability. We built on this work through our pilot program, in which we combined sustainability with industrial engineering tools in an educational setting.

3. Pilot Program: Structure

To attempt to better incorporate sustainability concepts into industrial engineering education, we sought to develop several modules focused on different sustainability topics that could be easily integrated into existing courses. We first divided the existing IMS courses at our university into two groups: those that teach methodologies and tools (i.e. Operations Research), and those that introduce new concepts along with the methods to address them (i.e. Facilities Planning). In doing so, we gained a better perspective on course focus and content, ultimately leading to a better understanding of which courses were most appropriate for the introduction of sustainability modules.

Next, we developed a list of sustainability topics that would be suitable for module development. We chose topics that are amenable to industrial engineering methods, and through which, in our estimation, engineers can make immediate impacts. These areas of focus are:

- Life Cycle Assessment
- Design for Sustainability
- Total Quality Environmental Management
- Environmental Management Accounting
- Green Supply Chain Management
- Product Recovery
- Sustainability Performance Metrics

With a set of courses ready for modification, and a number of topics around which to develop modules, we then examined each course in depth to determine what sustainability concepts could be most appropriately introduced.

<table>
<thead>
<tr>
<th>Course Name</th>
<th>Catalog Description</th>
<th>Modules to be Introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to Industrial</td>
<td>An overview of the issues important to the operation of an industrial or service</td>
<td>Social and environmental responsibility</td>
</tr>
<tr>
<td>Engineering Administration</td>
<td>service facility</td>
<td>Green process design and operation</td>
</tr>
<tr>
<td></td>
<td>Engineering organization and administration; delegation of authority and responsibility; effective use of</td>
<td>Social and environmental responsibility</td>
</tr>
<tr>
<td>Resources</td>
<td>Environmentally and energetically limited resources</td>
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<td></td>
</tr>
<tr>
<td>Quality Engineering</td>
<td>Basic concepts and techniques of quality control; applications of statistics in industrial research; design of quality assurance systems; reliability engineering</td>
<td>Serviceability of products at the consumer to extend product life</td>
</tr>
<tr>
<td>Manufacturing Engineering</td>
<td>Introduction to manufacturing engineering, with emphasis on current and emerging technologies in metalworking and electronics</td>
<td>Modular product design and Design for Maintainability</td>
</tr>
<tr>
<td>Industrial Facilities Planning and Design</td>
<td>Comprehensive design of industrial production systems, including interrelationships of plant location, process design, and materials handling</td>
<td>Green Facilities Design and the Carbon Footprint</td>
</tr>
<tr>
<td>Operations Research</td>
<td>Introduction to linear, non-linear, and dynamic programming. Decision analysis, random processes, and queuing. Course covers theory through application and implementation of results</td>
<td>Impact of packaging on the environment and evaluation of sustainable packaging</td>
</tr>
<tr>
<td>Production and Distribution Systems</td>
<td>Decision rules in industrial environments including Forecasting, Production Planning, Scheduling, Inventory Control, and Project Monitoring</td>
<td>Green Supply Chains</td>
</tr>
</tbody>
</table>

In formatting our modules, we sought to develop a ‘microcurriculum’ that would allow the desired material to be introduced and developed within the course of one or two lectures. Tight structuring of this microcurriculum was essential; we found that by focusing on core concepts and relating them to existing course material we were able to quickly introduce meaningful information. For our Green Supply Chains module, for example, we built a short module around this framework:

1. Interaction between manufacturing and the environment
2. Green supply chains and green supply chain management
3. Closed-loop supply chains
4. Why ‘green’ the supply chain?
5. Environmental legislation
6. Environmental metrics
7. Examples of green initiatives’ impact on supply chain management
8. Industry examples

Assignment: In-class quiz in the next lecture covering the topics above
We introduced this module into a course on production and distribution systems, with a focus on decisions in industrial environments (including forecasting, production planning, scheduling, inventory control, and project management). Over the two years of our pilot program, we continued developing modules and deploying them in appropriate classes. We also developed a course focused entirely on sustainability that will be offered for our university’s Honors College beginning in 2015.

4. Pilot Program: Results

In evaluating the success of our pilot program, we sought to examine both our students’ understanding of the material presented and their impressions of the usefulness of the initiative in the context of their education and professional development. To accomplish the first goal, we gave students who took part in two of our modules quizzes; for one of these modules we also had students complete an end-of-term paper. The modules examined were Green Supply Chains (GSC), introduced into a course on productions and distribution systems with 54 students in Spring 2011, and Humanitarian Logistics (HL), which we incorporated into a 61-student course on facilities planning and design in Spring 2011. Nearly all the students achieved high scores on the quizzes administered after both modules; the average score for GSC was 93%, and for HL it was 91%. The average grade on the HL term paper was 96%. We recognize that these results, and the conclusions that can be drawn from them, are limited by the small sample size of students examined. We believe, though, that the combination of successes in quizzes and in the term assignment demonstrate students’ ability to both grasp the information presented through our modules, and to remember and synthesize it over the duration of the semester.

We also received positive feedback from students on the modules and the broader idea of better incorporating sustainability concepts into their education. We asked students to complete course surveys at the end of the semester, and convened a focus group with students who participated in both courses above to determine their reactions to and suggestions regarding the modules. These evaluations were conducted by the Program Evaluation and Education Research Group, an independent center at our university, to prevent bias in gathering student response data.

Responses to our surveys were mixed but positive. In particular,

- between 94% and 100% of the students agreed (‘Agreed’ or ‘Strongly Agreed’) that our modules developed their understanding of new applications of industrial engineering
- between 88% and 100% of the students said that they were left with “a sense of excitement” about their intended career paths and their abilities to impact society as industrial engineers
- more than half of the students expressed interest in pursuing a Senior Design Project involving one of the sustainability concepts addressed
- all the students (100%) indicated that our presentations increased their awareness of issues and challenges in each of the areas presented

In addition, feedback through the focus group was both positive and insightful. Students generally expressed enthusiasm about the idea of further exploring sustainability through their studies, and were especially excited about the applications of these concepts in their future careers (all quotes in italics from students in the focus group):

“As an industrial engineer, I think we have a lot to provide society, because we are getting the skills on how to do things more effectively and more efficiently, so we are not reinventing the wheel, we are just making the wheel a little better. If we can do this with the concept of how can we do this and protect the environment at the same time...because any environmental movement that is not profitable, is not going to be picked up in the commercial world. If the company cannot do it and be profitable, the company is not going to exist.”

Students also expressed an interest in the social and environmental effects of IMS when its tools are utilized with sustainability in mind:

“As far as coursework I found it more relevant and it [the use of a real-life problem] communicates better [for learning]. It made questions and problems more relevant. In operations research as well, not just supply chains...for
example, if you need to evacuate because a hurricane is coming, these roads can only handle so many people, so how do you negotiate traffic and have a route set? It is easier for me to pay attention and learn it if I am more interested in it. My generation is more conscious of what kind of knowledge I want to hold on to.”

Finally, the only regret students in the focus group mentioned was that the modules were (necessarily) limited in scope and duration:

“There is room in our classes for this topic to be touched on, but having an elective [a whole course] would be better.”

“Having a more in-depth look at [the concepts] would add more...I definitely thought that from that one lecture, you could see that students were more engaged with the relevant issue.”

“If they had a whole course, I could put it on my résumé.”

“It would be a good elective; it broadens the mind of the engineer.”

These results show that our students responded positively to the introduction of sustainability content into their courses, and were interested in expanding their knowledge of and ability to address such topics. Their desire for more information encouraged us to continue our initiative, and to consider expanding it.

5. Conclusions

On the whole, we believe our pilot program introducing sustainability content models into IMS classes is a good first step in expanding access to this kind of material in traditional IMS programs. Eventually, a fully developed initiative would feature many more modules introduced into a broader range of topic courses; in addition, more sustainability-focused courses incorporating IMS methods and tools could be developed. In such a fully balanced and synthesized initiative, a full spectrum of certifications at both the undergraduate and graduate level could be offered.

We believe several factors are essential in the success of these kinds of curriculum modification programs, at any level. First, any curriculum modification requires buy-in and participation from faculty; these initiatives are most effective when a faculty member is designated to drive them, but also benefit from broader enthusiasm across the department. Though we did not conduct formal evaluations of faculty reactions to our initiative, anecdotal evidence suggested positive reactions within our department. Second, flexibility is key in designing modular curriculum modifications. We ‘packaged’ our modules through PowerPoint presentations and quizzes, and in doing so we were able to insert them where and when needed, expanding or contracting the content covered depending on the time and resources available. Finally, we found it useful to research and incorporate instances in which industrial engineering and sustainability are currently interacting in the professional world. Emphasizing the applications of sustainability to our students’ future careers, more than anything else, seemed to excite their imaginations.

By beginning with curriculum modification through modules, progressing through the development of standalone sustainability-focused courses, and ultimately leading to full courses of study in sustainability and engineering, we believe sustainability can be effectively incorporated into IMS education today. Our students and the world in which they will work require this knowledge, and through modular curriculum modification we can begin to provide it.

6. Acknowledgments

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References


