AC 2009-1166: DEVELOPMENT OF A HEALTH-SYSTEMS CURRICULUM IN INDUSTRIAL AND SYSTEMS ENGINEERING

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Development of Health Systems Curriculum in Industrial and Systems Engineering

Abstract

Health systems deal with the transformation of healthcare delivery systems from ineffective, reactive, disease-focused systems to achieve cost-effective, pro-active, health and wellness-focused systems. With the increased need to make healthcare systems safer, more effective and efficient, patient-centered, timely, and equitable, industrial and systems engineering concepts and tools have gained wide acceptance and recognition in the healthcare sector. The strategic use of these tools, such as statistical quality control, supply chain management, modeling and simulation, failure-mode effects analysis, lean thinking, and human factors and ergonomics, can be readily used to measure, characterize, and optimize performance at various levels in a healthcare system. Even though there is currently a shortage of health systems engineers at the MS and PhD levels, very few universities have an established health systems curriculum in their industrial and systems engineering departments.

The Department of Systems Science and Industrial Engineering at the State University of New York (SUNY) at Binghamton (a.k.a. Binghamton University) has been actively involved in teaching and conducting applied research related to health systems since 2001. This paper starts with career opportunities for industrial and systems engineering graduate students with health systems concentration and highlights the gap between the healthcare industry needs and academic course settings. The development of the graduate level health systems curriculum at Binghamton University is discussed and illustrated in details. The course details of the 30-credit curriculum are revealed and explained as to how they can bridge the gap between academia and the healthcare industry. Finally, the future direction of the health systems concentrations under the industrial and systems engineering degree is discussed.

Introduction

As the most versatile engineering discipline, industrial and systems engineering (ISE) has found its applications on the evolvement and industrial advancement of our society, touching almost every industry domain, from automobile manufacturing, to semiconductor production and packaging, to various service sectors, such as healthcare, entertainment, hospitality and transportation industries. ISE curriculum and educational practice, as a key component in the dynamic cycle of knowledge discovery and dissemination, needs to be frequently re-evaluated and the corresponding ISE curriculum needs to be re-designed or re-developed to address the actual and dynamic industry needs. Moreover, such changes will ensure that ISE graduates are equipped with adequate "weapons" that they could use to tackle problems in the real world.

According to the Accreditation Board for Engineering and Technology (ABET), the accreditation criteria on industrial engineering or similarly named engineering program's curriculum, "*The program must demonstrate that graduates have the ability to design, develop, implement, and improve integrated systems that include people, materials, information,*

equipment and energy. The program must include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices."[1] Historically, the ISE curriculum has been developed and modified according to industry trends and society needs. The first ISE curriculum was developed in 1908 at Pennsylvania State University after separating it from the mechanical engineering program.[2] With the rapid industrial evolution, particularly the advancement in the automobile industry, new issues aroused and new methodologies were developed and implemented to provide practical or research oriented solutions. This led to a major adjustment in the ISE curriculum to incorporate topics such as quality control, reliability, operations research, human factors and ergonomics. Later, with the boost of the semiconductor industry from the 1980s, new algorithms and research methodologies were introduced, which resulted in yet another ISE curriculum change.

In addition to the traditional manufacturing and productions systems, ISE theory and techniques have also been widely applied in the service industry. For example, operations research technique is used in airline scheduling to determine the optimal combination of routes and timing of thousands of aircrafts. Furthermore, game theory has been implemented by rental car companies for deciding the best pricing strategies. Healthcare is another major sector in the service industry, which recently draws significant attention from the ISE community, particularly because of the complexity and challenges of the system and huge potential of a variety of ISE applications.

The health system is a complex system that consists of hospitals, clinics, nursing homes, pharmacies, pharmaceutical companies, insurance companies, government agencies, and many other players. While medical practice relies on qualitative and quantitative factors, the management and operation of health systems is a science that relies on rigorous analysis to make decisions that would sustain continuous improvement efforts, while concurrently enhancing the patients' satisfaction. ISE tools can be used in a variety of ways to achieve these objectives. While health systems and manufacturing systems share a lot of similarities, which makes ISE theory and technique applicable in the health system, there exists significant difference between them. This makes studying the dynamics and unique nature of health systems critical and necessary in ensuring the successful migration of ISE knowledge into the domain of health systems.

A careful review of the current ISE curriculum reveals the following facts: (i) ISE knowledge is built in large on manufacturing systems, (ii) the majority of examples in textbooks are based on manufacturing systems, (iii) very few universities have health systems concentration in their ISE programs, and (iv) there is no good textbook(s) generalizing ISE tools in health systems. While many researchers and practitioners have been successfully applying ISE tools to modeling and optimizing health systems, there is a gap between the healthcare industry needs and academic course settings. For examples, although lean and six-sigma have been widely adopted and implemented in the healthcare settings to reduce wastes and improve process efficiency, it is still hard to find a healthcare related example in a quality control textbook. Furthermore, common practices in airline scheduling, such as overbooking, have been borrowed for clinic scheduling to compensate patient no-shows. However, little was discussed in the most popular scheduling textbook, "Scheduling: Theory, Algorithms and Systems" by Michael Pinedo.

In summary, the need for bridging the gap between health systems and industrial and systems engineering is urgent. As more and more ISE graduates see their career paths into the healthcare industry, there is a shortage of health systems engineers, particularly at the MS and PhD levels. ISE graduates who receive adequate trainings in health systems often find more career opportunities open to them in the widely defined healthcare domain, such as universities and medical centers, healthcare institutions, governmental and voluntary agencies, research and planning organizations, health insurance companies, healthcare consulting companies, architectural and construction firms, pharmaceutical companies, and manufacturers of healthcare products.[3]

The remainder of the paper presents the development of a graduate-level health systems curriculum in the Department of Systems Science and Industrial Engineering (SSIE) at Binghamton University. Details will be discussed from the aspects of course selection, course design, course modification, and to the leverage of internal and external resources for making the curriculum complete and flexible.

Benchmarking

The development of the health systems curriculum started with benchmarking with other universities' ISE or similar programs. Among the approximately 140 universities that offer ISE or similar programs in the US[4], three major universities, namely, Purdue University, University of Wisconsin at Madison, and Georgia Institute of Technology, have health systems specialization or concentration, either in their ISE departments or through multi-disciplinary initiatives. These findings are summarized in Table 1. The course settings at these institutions were reviewed in detail and used as references and guidelines for establishing the graduate-level health systems concentration at Binghamton University.

Table 1: Health Systems Concentrations at Purdue, Wisconsin, and Georgia Tech[5-7]

Purdue	• Regenstrief Center for Healthcare Engineering • Healthcare Engineering - Signature Area • Multidisciplinary research initiative • Degree awarded by School of Engineering • Goal: To improve the processes of healthcare delivery
University of Wisconsin	• Degree: MS in Industrial Engineering • Specialization: Health Systems Engineering • 30 degree credits required with 15 degree credits in the ISyE Department • Interdisciplinary Program: • Industrial Engineering • Population Health Sciences • Biomedical Engineering • Psychology
Georgia Tech	• Health Systems Institute • Moved out of ISyE Dept. in 2006 • Multi-institutional and interdisciplinary initiative based at Georgia Tech and Emory University • 30 semester hour program - requires 3 consecutive semesters

Course Selection

In order for the curriculum to best suit the need of the healthcare industry and to equip students with the best applicable knowledge, an advisory board was formed to provide advice in the curriculum development. The advisory board members came from various healthcare sectors, such as Mayo Clinic, United Health Services, Virtua Health, Greater New York Hospital Association, and Mount Sinai Hospital. To transform their knowledgeable experience and valuable inputs into consensus and action plan for curriculum development, nominal group technique was used to narrow down the courses that would benefit both the healthcare industry and the students. Among the many suggestions provided by the advisory board members, a unique "Academic Health Care Residency" program was proposed and incorporated into the curriculum. This will be discussed in details in the next sections. Table 2 shows the mapping of the various ISE tools and research areas to their level of application in health systems.

Table 2: ISE Tools and Research for Health Systems[8]

	Levels of Application			
Tools/Research Areas	**Patient**	**Team**	**Organization**	**Environment**
SYSTEM DESIGN TOOLS				
Concurrent Engineering and QFD		X	X	
Human Factors Tools	X	X	X	X
Failure Mode Effects Analysis		X	X	
SYSTEMS-ANALYSIS TOOLS				
Modeling and Simulation				
Queuing Methods	X	X	X	
Discrete-Event Simulation	X	X	X	X
Enterprise-Management Tools				
Supply-Chain Management		X	X	X
Game Theory and Contracts		X	X	X
Systems-Dynamics Models		X	X	X
Productivity Measuring and Monitoring		X	X	X
Financial Engineering and Risk Analysis Tools				
Stochastic Analysis			X	X
Value-at-Risk			X	X
Optimization tools for individual decision making		X	X	X
Distributed decision making: market models and agency theory			X	X
Knowledge Discovery in Databases				
Data Mining			X	X
Predictive Modeling		X	X	X
Neural Networks		X	X	X
SYSTEMS-CONTROL TOOLS				
Statistical Process Control	X	X	X	
Scheduling		X	X	

Those tools were the outcomes of a project report that was approved by the Governing Board of the National Research Council, with members drawn from the councils of the National Academy of Science, the National Academy of Engineering (NAE), and the Institute of Medicine.[8] With funding support from the National Science Foundation, Robert Wood Johnson Foundation, National Institutes of Health, the goals of the project were to: (1) identify engineering applications that could contribute significantly to improvements in healthcare delivery in the short, medium, and long terms; (2) assess factors that would facilitate or impede the deployment of these applications; and (3) identify areas of research in engineering and other fields that could contribute to rapid improvements in performance.[8] Therefore, the introduction of such courses and concentrations into the curriculum further emphasizes the importance of the partnership between engineers, healthcare professionals, and healthcare managers.

Health Systems Curriculum at Binghamton University

After comparing the other universities' health system programs' course settings and incorporating the valuable suggestions from the advisory board members to address the current health systems needs, an ISE graduate-level curriculum at Binghamton University was established, as shown in Table 3. The students can choose either the 30-credit thesis option or the 33-credit non-thesis option. The health systems concentration's objectives, goals, and content were also presented to the department's Industry Advisory Board (IAB). As a major constituency for the program, the IAB provides input and feedback to the department at least twice a year, to ensure what is being taught in the curriculum is consistent with the current industry needs and challenges, among many other things. The health systems plan was well-received by the department's IAB.

For the core requirements, the graduate students are required to take four courses: SSIE 505 Applied Probability and Statistics, SSIE 510 Enterprise Systems Engineering, SSIE 520 Modeling and Simulation, SSIE 561 Quality Assurance for Engineers, and SSIE 537 Industrial and Systems Engineering in Health Care.

Such requirement is consistent with the requirement for students with non-health systems concentration, as these courses build a solid foundation for all ISE students. Furthermore, we believe that students who choose the health systems concentration should not limit their career paths to the healthcare industry due to the versatility of the ISE program. To add the healthcare flavor, these courses were reconstructed. For example, SSIE 510 was renamed from "Science of Manufacturing" to "Enterprise Systems Engineering" by expanding the manufacturing science into wider enterprise system engineering. Furthermore, both SSIE 520 and SSIE 561 were slightly revised to introduce healthcare related course projects and health systems examples.

By leveraging the SSIE department's internal and external resources, the expertise of the faculty from the School of Management and Decker's School of Nursing at Binghamton University (and their current courses), eight courses have been made available as electives. SSIE 537, Industrial and Systems Engineering in Health Care, is a course that has been taught in the SSIE Department for a number of years now. While this course is listed as an elective in the curriculum, it was made required for those pursuing the health systems concentration. SSIE 534, Human Factors in Health Care are, is a newly designed course to address the growing interest in human factors and

ergonomic issues in healthcare. The introduction of this course into the curriculum was inspired by a panel discussion at the Human Factors and Ergonomics Society annual conference in 2004[9]. The panel emphasized the important of applying human factors and ergonomics principles to improve healthcare delivery systems and patient safety.

Table 3: Health Systems Curriculum at Binghamton University (ISE Program)

Core Requirements (12 Credits + 6 Credits Thesis OR 12 Credits + 3 Credits Non-Thesis)	SSIE 505 Applied Probability and Statistics SSIE 510 Enterprise Systems Engineering SSIE 520 Modeling and Simulation SSIE 561 Quality Assurance for Engineers SSIE 537 Industrial and Systems Engineering in Health Care SSIE 599 Thesis **or** SSIE 596 Academic Health Care Residency
Health Systems Potential Campus-wide Electives (3 Credits + 3 Credits min)	SSIE 534 Human Factors Engineering in Health Care BME 502 Medical Engineering and Health Care (Bioengineering Department) NURS 532 Health Care Delivery Systems (Decker School of Nursing) NURS 540 Epidemiology and Biostatistics (Decker School of Nursing) MHCA 530 Management in Healthcare Delivery Systems (School of Management) MHCA 560 Healthcare Policy Analysis (School of Management) NURS 633 Advanced Health Systems and Public Policy (Decker School of Nursing) MGMT 500 Management Information Systems (School of Management)
Preferred Course Choices (12 Credits for Non-Thesis OR 6 Credits for Thesis Option)	SSIE 511 Advanced Production And Schedule Control SSIE 533 Human Factors in Engineering and Design SSIE 541 Justifying New Technology SSIE 550 Introduction to Systems Optimization SSIE 553 Operations Research SSIE 644 Foundations of Adaptive Optimization SSIE 660 Stochastic Systems SSIE 605 Applied Multivariate Data Analysis SSIE 630 Neural Network and Genetic Models A Free Course from either Health Systems or Preferred Course choices
Note: 1) Total Number of Credits Required: 30 (Thesis)/33 (Non-Thesis); 2) At least one 600-Level Course is Required	

The other nine SSIE courses are listed as preferred course choices, among which at least one 600-level course is required for the health systems concentration. The topics cover various ISE modeling tools and techniques that can be applied in health system. Again, the healthcare 'flavor' is added into those courses through class examples, case studies, course projects, and reading assignments, thereby further emphasizing the breadth and depth of the industrial and systems engineering discipline.

Academic Health Care Residency

One of the uniqueness of this health systems concentration is the so-called "Academic Health Care Residency". As stated earlier, the students are given the opportunity to choose either the

thesis option or pursue an Academic Health Care Residency to meet the degree completion requirement. This unique residency program would enable students to get a better understanding of the health systems dynamics. The one- (or two)-semester-long residency can take place in any healthcare setting, such as hospital, primary physician's office, retail pharmacy, or dentist's office. The purpose is to immerse the students in a healthcare setting so that they can gain insights on healthcare environments, truly understand the system processes and patient flow, speak the healthcare professionals' languages and share their concerns and challenges, so that the re-engineered processes can not only be applicable, implementable, and provide value-added, but also be acceptable.

Typical questions that are faced by ISE graduates is: "why would a healthcare professional who has been in his field for 30 years listen to an industrial and systems engineer to change his or her practice?" or "what does an engineer do at a hospital?" This "Academic Health Care Residency" program really prepares the students to be in a better position to apply classroom knowledge into solving real-life problems. Even though this is primarily supported by anecdotal data, engineers generally find difficulties in joining some healthcare organizations, particularly due to their lack of clinical knowledge and experience. With such concentrations and residency programs, the barriers and challenges that industrial and systems engineer face in healthcare systems can be easily overcome, thereby facilitating the diffusion of this discipline into healthcare delivery systems.

Representative Course Details

"Practical" and "Applicable" were the philosophies or principles that were used in designing the program's courses. Therefore, in this sub-section, two representative courses are analyzed to show how the course contents are closely related and easily transformable to actual health systems applications.

SSIE 537 (Industrial and Systems Engineering in Health Care): The application of industrial and systems engineering principles to continuous process improvement in the healthcare domain will be studied. Concepts that will be addressed include, but not be limited to, introduction to health systems, healthcare policy and decision making, hospital accounting and finance, healthcare delivery system modeling and optimization, process mapping, value stream mapping, quality enhancement, scheduling, lean, six sigma, simulation, supply chain management, inventory control, and information management.

SSIE 534 (Human Factors Engineering in Health Care): This course introduces and emphasizes the role that human factors engineering/ergonomics plays in healthcare systems, with a focus on its applications to help improve quality, safety, efficiency, and effectiveness of patient care. Focused topics include human factors in workflow models, work system design for patient safety, human error analysis/taxonomies to reduce medical errors, task analysis and data collection methods in healthcare environments, clinical staff workload and patient safety, physical ergonomics in healthcare and human performance modeling, and diffusion and adoption of technology in healthcare, with emphasis on the usability and design of medical devices and information systems.

Conclusions and Final Remarks

To better gear the academic activities towards recent industry trends, the Department of Systems Science and Industrial Engineering at Binghamton University developed a graduate-level health systems curriculum. The ISE health systems concentration officially started in the fall 2008 semester. Preliminary statistics show an increased enrollment in the redesigned health systems courses. For example, the enrollment in SSIE 537 increased from 30 in fall 2007 to 47 in fall 2008. Also, SSIE 534, a course first offered in spring 2009, primarily as an elective for the health systems concentration, currently has an enrollment of 15 students. Furthermore, the preliminary statistics also indicate a 100% job placement rate (in the healthcare industry) for all the five recent graduates (of the health systems concentration), who worked on healthcare related research during their graduate studies. As the development of the health systems curriculum is a continuous improvement process, feedback from advisory board members, graduate students who took the redesigned courses, and healthcare employers who hired our graduate students are constantly solicited and evaluated to enhance the course settings and program structure. With more data becoming available in the future, more results will be reported to disseminate the lessons learned and share best practices with other institutions that are interested in introducing healthcare systems into their academic programs.

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