AC 2007-291: ACHIEVING SUCCESS FOR THE DEVELOPMENT OF A SYSTEMS ENGINEERING DEGREE PROGRAM

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Achieving Success for the Development of a Systems Engineering Degree Program

Abstract

Due to the changing global business environment, the operations of engineering companies in the U.S. are moving from self sufficient engineering operations toward the integration of various engineering operations, including design, production and manufacturing, logistics, sales, and services, at global locations and companies. The education of future engineers has to reflect this changing trend and demand. Systems Engineering (SE) discipline provides this critical need of education to handle the increasing demands for systems efficiency, effectiveness, and integration in engineering and business operations. This paper intends to discuss the process in the design of a Bachelor of Science in SE curriculum. The design is based on an analysis of skill requirements in industry under the current global market environment and global supply chain operations. This paper discusses industry needs in skills and demonstrates the match of skills to various SE courses and the completed curriculum design for a Bachelor of Science in SE program.

Introduction

U.S. engineering/manufacturing companies are changing their engineering operations from in-house operations on design, production/manufacturing, logistics, sales, and services toward outsourcing some operations to various global locations in the current global business environment. A major portion of engineers' functions have been changed from solely performing technical operations to being involved in the integration of engineering operations performed at multiple sites, often various international sites. With this shift in engineering/business environment, the education of future engineers must reflect this changing trend and demand as well. The SE discipline fills this critical educational need to handle the increasing demands for systems efficiency, effectiveness, and integration in engineering and business operations. SE education is critical for the companies in the U.S. to remain competitive and for U.S. engineering graduates to be able to participate in global engineering operations.

This paper demonstrates some activities in designing a Bachelor of Science in Systems Engineering (BSSE) curriculum. The activities include benchmarking other similar programs, performing an industry needs analysis, and fulfilling the needs from other engineering departments and the institution's B.S. requirements. A list of required skills in industry in the SE related fields is used to map to the demand requirements in the regional industry and potential SE courses. This skill set list includes the results of consulting with engineers, managers, and senior management in various industries. The intention is to design a curriculum that can reflect the needs in industry in the current and future global business and engineering environment.

Defining Systems Engineering

Based on the definition listed on the web site by International Council on Systems Engineering (INCOSE), the definition of Systems Engineering is shown below[1]:

> "Systems Engineering is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customers' and stakeholders' needs are satisfied in a high quality, trustworthy, cost-efficient and schedule-compliant manner throughout a system's entire life cycle."

The SE process is called SIMILAR process and usually comprises the following seven tasks[1,2]:

- **S**tate the problem
- **I**nvestigate alternatives
- **M**odel the system
- **I**ntegrate
- **L**aunch the system
- **A**ssess performance
- **R**e-evaluate

This process is not a sequential process and the seven tasks are often performed in parallel and in an iterative manner. By following the SIMILAR process, systems engineers develop clear, concise, and comprehensive problem statements, resolve top-level system problems into simpler, solvable problems, and integrate the solutions to the simpler problems to solve the top-level problem[3]. Without loss of generality, SE concepts can be applied to any system including engineered (or human-made) systems and non-human-made systems or natural systems such as environmental systems[4].

Blanchard and Fabrycky[5] mentioned that SE as an engineering field has very broad applications in a wide variety of industries including energy, telecommunications, construction, manufacturing, transportation and distribution, information technology, financial services, automotive, retail, healthcare and airlines, at all levels from an entry position to top management. This wide applicability, along with a very strong focus to model, analyze, and manage complex engineered systems with proven tools and techniques, can be considered as the primary strengths of SE. Wymore[3] concluded that practically every organization requires systems engineers to identify, characterize and solve the right problems and to eliminate inefficiencies and root-causes that generate these problems.

The Institute for Systems Research, at the University of Maryland[6] provides the following similarity and contrast between SE and other engineering disciplines:

> As other engineering disciplines, systems engineering involves central concepts; uses specific methodologies; includes both analysis and synthesis or design; relies on mathematics to express knowledge; and stimulates research for further engineering benefit. However, systems engineering is qualitatively different. While other engineering disciplines concentrate on using knowledge of the real world (e.g., electrical circuits, materials, robotics), systems engineering finds its focus in constructs of analysis and synthesis for problems involving multiple aspects of the real world.

The SE definitions discussed above provide a clear view of what the SE discipline is and show that SE is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customers' and stakeholders' needs are satisfied in a high quality, trustworthy, cost-efficient and schedule-compliant manner throughout a system's entire life cycle[1]. In conclusion, the SE discipline provides the critical need of education to handle the increasing demands of systems efficiency, effectiveness, and integration in global engineering and business operations.

The Educational Objectives of the BSSE Program

The educational objectives of the proposed BSSE program are as follows:

- Provide students with knowledge and educational opportunities in dealing with systems issues in the competitive global engineering and business environment.
- Produce engineers who will lead in (1) improving the understanding of global engineering issues; (2) developing effective approaches for engineering operations; and (3) providing educational opportunities to train the workforce needed to sustain the growth of global engineering operations/business in the U.S.
- Train engineers to possess the critical thinking, methodological, and communication skills required to advance and disseminate knowledge of systems engineering in supply chain operations.
- Enhance the educational experience in systems, management, and engineering for all undergraduate students at the institution.

We expect that the SE graduates can:

- Handle operational issues from system perspectives,
- Manage units with technical functions,
- Manage units with business & management functions,
- Handle interdisciplinary issues & problems,
- Make decisions at all levels of an organization from the top management problems, to strategic planning, product development and launching, production, marketing & sales, logistics support, and field services,
- Understand future trend in global markets and economy, and
- Manage multinational units, projects, & global supply chains.

BSSE Curriculum Design

The activities in the design of the BSSE curriculum include benchmarking other similar programs, performing an industry needs analysis, and fulfilling the needs from other engineering departments in SE skills and the institution's B.S. requirements. Figure 2 shows the framework for BSSE curriculum design analysis. The framework includes the competitive analysis with some existing programs, the industry needs/skills analysis, the considerations of BS requirements in the institution, and the adoption of the needs and curriculum design at other engineering departments. In benchmarking similar programs at other institutions, we have surveyed various programs in this field and selected seven programs to benchmark.

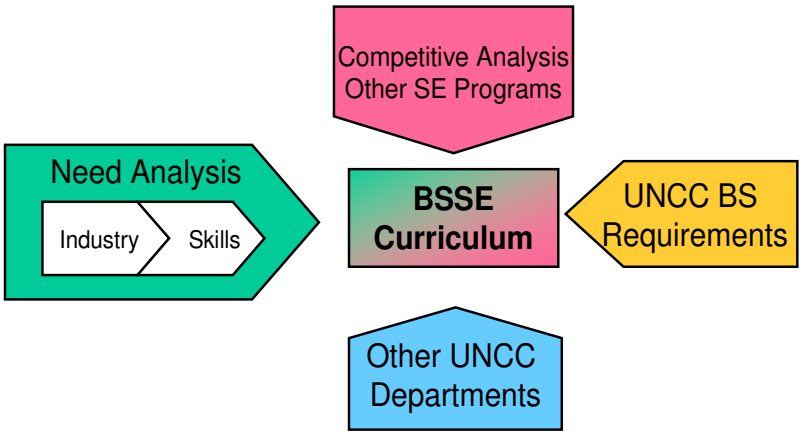

Figure 1. BSSE Curriculum Design Analysis Framework

The major analysis work points to the industry needs in the SE related fields. A list of required SE related skill set in industry is used to map to the demand requirements in the regional industry and to the potential SE courses. This skill list is the results of consulting with engineers, managers, and senior management in various industries.

The Needs in the Region

As part of the analysis, we identified that Charlotte area is the home of the headquarters of nine Fortune 500 companies including Bank of America, Wachovia Corp., Duke Energy, Nucor Corp., Sonic Automotive, SPX, Family Dollar, Goodrich Corp., and Lowe's. In addition, 306 other Fortune 500 companies are represented in the Charlotte area covering a variety of industries in the manufacturing, transportation and distribution, and financial services.

According to the Charlotte Chamber of Commerce web site, Charlotte is the 3rd best business location in the U.S. and accommodates the 7th highest new and expanded business activities[7]. Due to this dynamic business environment, 11,761 new jobs were generated in 2005. According to economic forecasts, the business index continues to be positive, as it has been in the past five years. Because it also has one of the best real estate markets in the country with a cost of living lower than the national average and an active airport that facilitates easy access, migration to this area has increased dramatically over the past several years. In fact, the population of Mecklenburg County is expected to increase 19.3% from about 880,000 in 2007 to 1,050,000 in 2012. Due to the ever-improving business opportunities and increasing population, this region is expected to have a growing need for educational services at both the undergraduate and graduate levels.

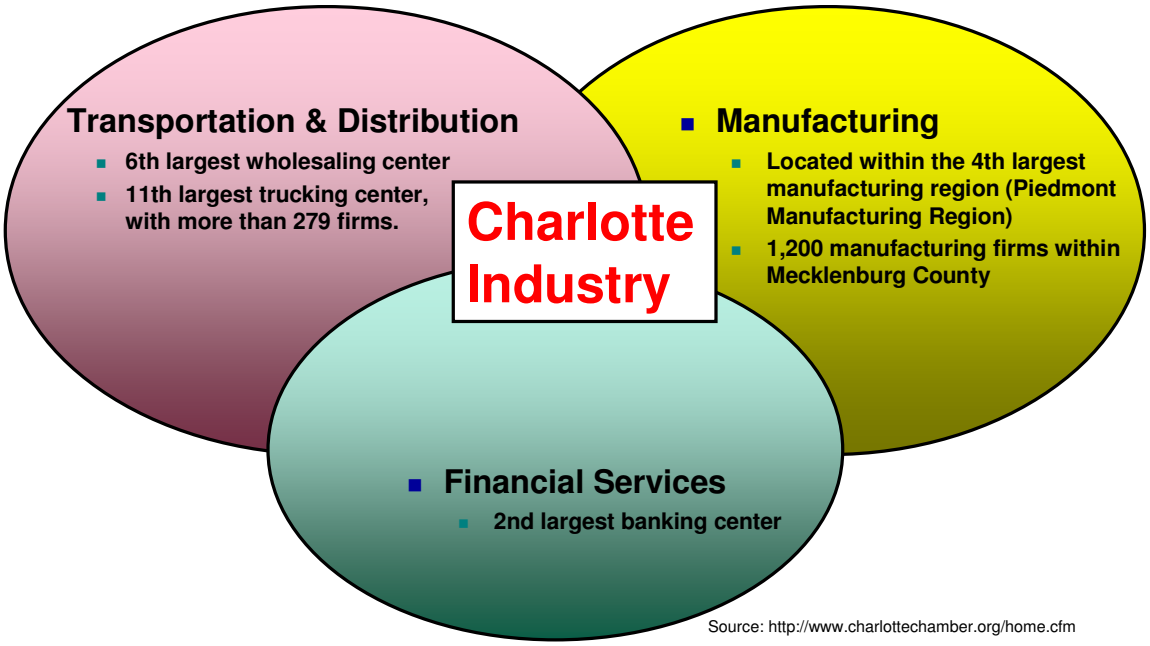

Figure 2. Local Industry Segmentation

Since the SE graduates will be prepared to work in a wide variety of industries, local industry needs for the major industry sectors demonstrate that it is an excellent location for the new BSSE program. Based on our analysis, the following areas capture the main SE skills required in industry in the Charlotte area, in North Carolina, in the U.S., and globally:

- Decision and Risk Analysis
- Systems Modeling and Optimization
- Systems Design, Planning and Analysis
- Supply Chain and Logistics Engineering
- Quality Engineering
- Engineering Management
- Communication and Presentation
- Understanding of Global Business Dynamics

A list of required skills in industry was developed based on the information of skill needs we have gathered from various industries in the past two years and the three industry segments in the Charlotte region. It is the foundation for the BSSE curriculum design.

Required Skills in Industry

By working with industry, we have developed a required skill set with fifty skill items and map them to the three industry segments in the Charlotte region and to the potential SE courses. Tables 1a and 1b show the required skills we have gathered and how they were mapped to the three industry segments and to the SE courses.

No.	Skills	Fin.	Transp. & Dis.	Manuf.	Courses
1	Network Design	√	√	√	Network Modeling & Analysis
2	Facility Layout Design	√	√	√	Facilities Design & Planning
3	Quality Control	√	√	√	Quality Engineering
4	Project Management	√	√	√	Project Management
5	Risk Management	√	√	√	Engr. Decision Analysis
6	Decision Analysis	√	√	√	Engr. Decision Analysis
7	Costing and financial analysis	√	√	√	Engr. Economic Analysis
8	Modeling	√	√	√	Operations Res.-Deterministic
					Operations Res.- Probabilistic
					Comp. Meth. for Sys Engr. I, II
					Calculus I, II, III
					Matrices & Linear Algebra
9	Simulation	√	√	√	Sys. Simul., Modeling & Anal.
10	Optimization	√	√	√	Operations Res.-Deterministic
11	Communication and Presentation	√	√	√	Intro to Tech Comm
					English I, II
12	Problem Solving	√	√	√	Engr. Decision Analysis
					Engr. Systems Optimization
					Sys. Simul., Modeling & Anal.
13	People Management	√	√	√	Project Management
14	Ergonomics and Safety	√	√	√	Human System Interface
15	Statistical Data Analysis	√	√	√	Prob. & Stat. for Engr. & Engr. Exper. Design
					Sys. Simul., Modeling & Anal.
16	Six-Sigma Quality	√	√	√	Quality Engineering
17	Implementation Experience	√	√	√	Systems Design Project I, II
					Prof. Development & Intro to Engr I, II
					Systems Engr. Concepts
					Industrial Capstone Project
18	Programming	√		√	Comp. Meth. for Sys Engr. I, II
					Programming for Systems Engineers
19	Spreadsheet Modeling	√	√	√	Comp. Meth. for Sys Engr. I, II
20	Value and performance measurement	√	√	√	Value Engineering & Engr. Economic Analysis
					Project Management
21	Process Mapping, Analysis & Design	√	√	√	Systems Engr. Concepts
					System Design & Deployment
					Product & Process Design
22	Demand Planning	√	√	√	Operations Management
					Supply Chain Management
23	Supply Planning			√	Operations Management
					Supply Chain Management
					Production Planning and Inventory Control
24	Transportation Planning & Scheduling		√	√	Supply Chain Management
25	Factory Planning & Scheduling			√	Production Planning and Inventory Control

Table 1a. Required Skills in Industry

No.	Skills	Fin.	Transp. & Dist.	Manuf.	Courses
26	Inventory Planning and Control		√	√	Production Planning and Inventory Control
27	Product Design	√		√	Product & Process Design
28	Service Planning	√	√		Service Operations Management
29	Spare Parts Planning	√	√	√	Production Planning and Inventory Control
30	Computer Aided Design			√	Computer Aided Design
31	Capacity Planning	√	√	√	Production Planning and Inventory Control
32	Strategic Planning	√	√	√	Operations Management
33	Supplier Relationship Management	√	√	√	Supply Chain Management
34	Customer Relationship Management	√	√	√	Supply Chain Management
35	Global Business Dynamics	√	√	√	Introduction to Global Issues
36	Intercultural Relations	√	√	√	Global & Intercultural Connections
37	International Trade Laws	√	√	√	Introduction to Global Issues
38	Business Laws	√	√	√	Introduction to Global Issues
39	Business Ethics	√	√	√	Ethical Issues
40	Purchasing	√	√	√	Supply Chain Management
41	Contract Management	√	√	√	Supply Chain Management
42	Reverse Logistics		√	√	Supply Chain Management
43	Recycling and Green Supply Chains			√	Supply Chain Management
44	Lean System Design	√	√	√	Lean Mfg Systems
45	Pricing, Rebates and Revenue Management	√	√	√	Pricing Optimization and Game Theory
46	Benchmarking	√	√	√	Supply Chain Management
47	Product Lifecycle Management	√		√	Product & Process Design
48	Material Handling Systems		√	√	Automation & Material Handling Systems
49	Enterprise Resource Planning Systems	√		√	Information and Decision Support Systems
50	e-Business Techniques	√	√	√	Electronic and Technology Enabled Business

Table 1b. Required Skills in Industry

The BSSE Curriculum

The BSSE curriculum is designed based on the above mentioned analyses and is shown in Figures 3a and 3b.

Freshman Year			
ENGR 1201 Intro to Engr I	2	ENGR 1202 Intro to Engr II	2
CHEM 1251 Chemistry I	3	PHYS 2101 Physics I	3
CHEM 1251L Chemistry I Lab	1	PHYS 2101L Physics I Lab	1
MATH 1241 Calculus I	3	MATH 1242 Calculus II	3
ENGL 1101 English Composition	3	ENGL 1102 Writing in the Academic Community	3
Liberal Studies Elective*	3	ECON 1101 Economics for Non-Majors	3
	15		15
Sophomore Year			
PHYS 2102 Physics II	3	SEGR 2105 Comp. Meth. for Sys Engr. I	3
PHYS 2102L Physics II Lab	1	STAT 3128 Prob. & Stat. for Engr.	3
SEGR 2101 Systems Engr. Concepts	3	MATH 2164 Matrices & Linear Algebra	3
MATH 2241 Calculus III	3	Liberal Studies Elective*	3
ENGL 2116 Intro to Tech Comm (W)	3	*Track Course**	3
SEGR 2106 Engr. Economic Analysis	3		
	16		15

Figure 3a. The proposed BSSE Curriculum

Junior Year			
SEGR 3141 Quality Engineering	3	SEGR 3102 Sys. Simul., Modeling & Anal.	3
SEGR 3105 Comp. Meth. for Sys Engr. II	3	SEGR 3103 Human System Interface	3
SEGR 3101 System Design and Deployment	3	OPRS 3113 Operations Res.- Probabilistic	3
OPRS 3111 Operations Res.- Deterministic	3	Track Course*	3
*Technical Elective**	3	*Technical Elective**	3
	15		15
Senior Year			
SEGR 3290 Systems Design Project I(W)(O)	1	SEGR 3291 Systems Design Project II(W)(O)	3
ENGR 3295 Prof. Development	1	SEGR 4141 Engr. Exper. Design	3
Liberal Studies Elective*	3	SEGR 4103 Network Modeling & Analysis	3
SEGR 4102 Decision and Risk Analysis	3	Liberal Studies Elective*	3
SEGR 3111 Project Management (W)(O)	3	Technical Elective*	3
SEGR 4113 Production Planning and Inv. Control	3		
*Track Course**	3		
	17		15

*Notes: Total Hours 123
1. (W) indicates courses with emphasis on writing and (O) indicates courses with emphasis on oral communication
2. SEGR/ENGR 3295 Prof. Development can be taken in Fall or Spring during the senior year

Figure 3b. The proposed BSSE Curriculum

The following list includes some technical elective courses that are part of the curriculum and will be used to serve the students at other engineering departments as well.

- SEGR 2111 Introduction to Engineering Management
- SEGR 2121 Intro to Logistics Systems and Supply Chains
- SEGR 4101 Engineering System Optimization
- SEGR 4111 Value Engineering Management
- SEGR 4112 Organizational Systems Management
- SEGR 4121 Design & Planning of Logistics Systems and Supply Chains
- SEGR 4122 Implementation of Logistics Systems and Supply Chains
- SEGR 4131 Computer Aided Design & Manufacturing
- SEGR 4132 Facilities Planning & Material Handling Systems
- SEGR 4133 Product and Process Design
- SEGR 4134 Automation & Systems Design
- SEGR 4135 Lean Manufacturing Systems
- SEGR 4142 Reliability Management

Conclusion

With the changing global business environment, the operations of engineering companies in the U. S. are moving from self-sufficient engineering operations toward the integration of various engineering operations, including design, production and manufacturing, logistics, sales, and services, at global locations and companies. More companies require their engineering personnel to obtain the skills that can increase and improve systems efficiency and effectiveness within the life cycle of a product, a process, or a system. The education of future engineers must reflect this changing trend and demand.

The SE discipline provides this critical need of education to handle the increasing demands of systems efficiency, effectiveness, and integration in global engineering and business operations.

It is critical that current engineering education in the U. S. remain competitive for engineering graduates in these global engineering operations. To meet this demand, we have performed the analysis of industry skill requirements and needs for the design of a BSSE curriculum. We expect this curriculum design will meet the needs of industry and students in current and future global engineering and business operations.

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