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Engineering Management within a Systems Engineering Program

Introduction

Designing curricula may seem to be just another design effort, similar to other design projects. And this might be a reasonable analogy if the design project is considered in its entirety, from assessing marketplace needs all the way through to design and quality verification. Thus, one might have this mindset when designing a new graduate curriculum in systems engineering, which is the primary focus of this paper. Just as in other design projects, there are a multitude of concerns and issues that must be addressed in curriculum design. For example, is the curriculum necessary? Who are the intended students? What are their motivations for pursuing this curriculum? What should be the learning objectives of the program? How should the content be segmented into individual courses? What are the core concepts and required courses? Should there be electives, specializations, or concentrations? And if so, what should they be?

This paper will discuss curriculum design for a new Master's degree program in systems engineering, moving from a broad guidelines for graduate program development to the specifics of developing the MS Systems Engineering program (MSSyE) at National University's School of Engineering and Technology. Most particularly, the focus will be on incorporating principles of engineering management into the MSSyE curriculum. This answers the question regarding which specializations, if any, should be included in this new curriculum, and why engineering management should be one of them. It also shows how this was accomplished according to a limited body of graduate curriculum design knowledge.

Systems Engineering and Engineering Management Relationships

Systems engineering, by its very nature, is not specialized and even seems to be difficult to define. According to Blanchard and Fabrycky[1], "to this day, there is no commonly accepted definition of systems engineering in the literature." They go on to provide five definitions, one of which is shown below, from the International Council of Systems Engineers (INCOSE):

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem: operations, performance, test, manufacturing, cost and schedule, training and support, and disposal. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Based on the five definitions provided, they then provide four common themes of systems engineering: 1) a top-down approach, viewing the system as a whole entity; 2) a life cycle orientation; 3) a better and more complete initial definition of system requirements; and, 4) an interdisciplinary team approach. These authors then indicate that systems engineering is highly related to engineering management, "The systems engineering process involves the use of appropriate technologies and management principles in a synergistic manner."

The reason that systems engineering is so amorphous is the focus of its design effort: systems. A system can be virtually anything; however, the focus of systems engineering is on man-made technology systems, and sometimes, on their interaction with natural systems. This very general nature of systems, however, does allow for categorizing them into different areas of concern. One could categorize systems as mechanical, electrical, chemical, aeronautical, biological, electro-mechanical, bio-mechanical, and electro-chemical,. This type of categorization is similar to the categorizarion of the different types of engineering and is oriented towards the product-based technologies. It is also possible to categorize systems at a higher more complex level that consists of systems of systems. For example, one can see transportation systems, which are made up of sub-systems and components such as vehicles, roads, tracks, airways, airports, boarding stations, fuel stations, and maintenance stations, all of which are, in turn, comprised of components and sub-systems. Another example is the system of community utilities provision such as electricity, gas, and water. Other examples are networks of communications – telephones, computers, cable networks, and satellite networks; economic systems – money, banking, trade of goods and services; and eco-systems – rivers, damns, parks, flora, fauna, and agriculture. One additional type of characterization can be based on the end application of the systems engineering process. For example, the end application can be for use in environmental systems, software design, manufacturing operations, or any of a number of other applications. (This type of characterization will be used below.) Indeed, the actual process of systems design can itself be seen as a system, with components and sub-systems including the computer hardware and software, the engineers, the information gathered and processes adopted, and the production methods and equipment, all embedded within larger organizations or higher order systems. It is clear that systems engineering is multi-disciplinary and can lend itself to incorporating various specializations in educational curricula.

There are two primary reasons why engineering management should be included as part of a systems engineering curriculum. The first is that, as noted above, the design and engineering of systems is itself a systems process and is therefore embodied as a system. As INCOSE's statement was quoted above, it is a blending "of appropriate technologies and management principles in a synergistic manner". The second reason, perhaps less compelling but none the less as valid, is that some systems, especially those complex systems of systems, tend to require human involvement and decision making and in some cases management – not necessarily the management of just an engineering process, but the management of technology: its planning, deployment, use, and maintenance. This paper will focus on the first reason and leave the second to be discussed elsewhere.

Engineering management is a discipline in its own right as can be seen by the number of engineering schools that offer a degree. The ABET website shows that there are eight accredited undergraduate programs in the U.S. and one accredited graduate program. Besides these, there are many more graduate programs not listed by ABET including an MS Engineering Management degree offered at National University. Furthermore, the discipline of engineering management is highly related to systems engineering. Kotnour and Farr[2] list four definitions of engineering management from different sources. Three of these definitions use the term "systems." These authors prefer the definition by Omurtag:

> "Engineering management is designing, operating, and continuously improving purposeful systems of people, machines, money, time, information, and energy by integrating engineering and management knowledge, techniques, and skills to achieve desired goals in technological enterprise through concern for environment, quality, and ethics."

In the same reference, these authors also provide a list of professional societies and journals that support engineering management. They list INCOSE and its journal, the *Journal of Systems Engineering.*

As further evidence of the general consensus that the engineering management field is closely related to systems engineering, *The Journal of Engineering Management* (JEE) published a special edition devoted to systems engineering. This edition has six papers, all focused on the concept of systems, systems engineering, and engineering management. The first of these six papers discusses the relationship between engineering management and systems engineering.[3] The second discusses how systems engineering and project management are related.[4] The third talks about organizational design by using systems engineering.[5] The use of systems engineering in managing a US Marine Corp project is discussed in the fourth paper.[6] The fifth paper provides details about managing information technology using systems engineering.[7] and the sixth is about developing and managing a system of systems research center.[8]

Conversely, one of the systems engineering societies, INCOSE, publishes articles related to engineering management in its journal, *Journal of Systems Engineering*. Here are examples of three: the first discusses the management aspects of systems engineering projects in terms of risk reduction and successful mission completion[9]; the second provides details of using systems engineering in strategic management and the transformation of enterprises[10]; and, the third discusses the increasing emphasis on the management aspect of system engineering.[11].

Based on the evidence above, it is rational to include engineering management exposure in any systems engineering curriculum; the remaining issues, then, revolve around the nature and extent of inclusion.

Curriculum Design

Not all graduate curricula are designed by members of faculty who have been informed by curriculum theory: indeed, the literature on curriculum theory and curriculum design is rather sparse and even more so in the area of graduate curricula. Wood and Davis[12,] in one of the foundational publications on curriculum design, note that the literature pertaining to the processes and methods of curriculum design and evaluation in higher education is widely scattered and not in the form most useful to those designing curriculum. Their report identifies the then-available resources and develops a single reference as a basis for curriculum design and evaluation. The report also provides a definition of curriculum as "the totality of courses that constitute a course of study offered by an institution or followed by a student."[12] This is the definition used in the current paper.

Walker[3], in one of the relatively few papers regarding curriculum theory, discusses briefly four traditional types of curriculum theory, which are not mutually exclusive. He claims that these four theories are all "theories of practice" and that they should be thought of as "a family of theories with different purposes and forms bearing on the same problems." Diamond[4] is a more recent text on designing and assessing curricula and courses. While there is some material presented on designing curricula, the contents are far more oriented towards designing individual courses but lack discussions on the finer points of curriculum design such as determining core content, electives, and concentrations or specializations.

Given that there are limited literature resources for guiding graduate curriculum design in general, there is even less available specifically addressing engineering curriculum design And there is relatively more literature that addresses undergraduate engineering curricula than graduate. In one paper on this topic, Gorman, et.al.[15] discuss the lessons learned by 15 faculty members from 15 different institutions in six disciplines (psychology and five engineering disciplines) after participating in a summer fellowship program at Boeing. The goal of the program was to "influence the content of engineering education in ways that will better prepare tomorrow's graduates to the practice of engineering in a world-class industrial environment." The paper proposes improvements to the engineering education process in eight categories, the first of which is curriculum for a bachelor's degree.

In another paper on engineering curriculum, Jarosz and Busch-Vishniac[16] dissected the undergraduate curriculum in mechanical engineering at nine academic institutions. The resulting 1,392 topics represent a baseline for completion of a bachelor's degree in mechanical engineering and were used to determine the body of knowledge that defines mechanical engineering, how degree programs differ, and what role ABET criteria play in defining the mechanical engineering curricula.

Finding little theoretical guidance from the literature on curriculum design (especially for graduate engineering programs and specifically for graduate programs in systems engineering) it became necessary to use a more applied approach to developing the curriculum for a new MSSyE program at National University, while, of course, adhering to the overall guidelines and requirements of the university.

Impetus for a Master's Program in Systems Engineering

The School of Engineering and Technology (SOET) at National University has been in existence for less than four years. It is comprised of the Department of Computer Sciences and Information Systems, and the Department of Applied Engineering. National University itself was established in 1971 in San Diego and now has six schools, colleges, and divisions. The Fact Book[17] of National University indicates that the enrollment consists of approximately 22,000 full-time equivalent students and over 100,000 alumni; that National University has the third largest graduate program in the country and is the second largest private, non-profit institution of higher education in California; that the targeted learner is the working adult having an average

age of about 34 years; and, that the student body is comprised of 35% minorities and 61% women. A significant majority of NU students are working full time, and many have family responsibilities as well. Within NU, SOET offers seven undergraduate engineering and technical degrees and 10 graduate degrees. SOET has approximately 600 full-time equivalent students and continues to grow between 10% and 20% annually. The key aspects of this institutional information are that NU's students are relatively mature, and the fact that they are pursuing college degrees even in the face of significant time and financial pressures indicates a motivation based on a strong sense of purpose. Specifically, our students are typically motivated to improve their employment opportunities through education. Thus, some of our primary responsibilities to our students is to make sure our programs are relevant and produce "marketable" graduates in their specific fields.

Thus, one of the driving forces for implementing a new curriculum at NU is the pressure from the professional community to meet a demand of a specific segment of the workforce for improved education and skills for job attainment or advancement[12,14]. This is especially true of the professional programs in SOET. The MSSyE program was developed to fill a perceived gap in the demand for graduate systems engineering education in both Southern and Northern California, the regions where NU traditionally enrolls students. This perception of marketplace need was based primarily on interactions with major employers, listening to their responses to questions about their greatest needs and the skill sets they find most difficult to fill. The Southern California region, specifically the Los Angeles and San Diego metro areas, has a large contingent of aerospace and other government contractors. It also has some of the largest transportation systems and pubic works infrastructures in the U.S. An online review of engineering curricula of major colleges and universities in the U.S. shows there are altogether around eight MS systems engineering programs (not including industrial and systems engineering degrees) and only one (not including NU SOET) in California.

Designing the program

Having perceived the need for a program in systems engineering, the curriculum design process became a combination of acquired empirical knowledge about systems engineering, and National University's curriculum development procedure. National University is accredited by the Western Association of Schools and Colleges (WASC) and as such all programs must meet those accreditation requirements. Fifty-four quarter units of graduate course credits must be successfully completed, along with any undergraduate pre-requisites not satisfied as part of a student's undergraduate degree. Prerequisite requirements for systems engineering are typically easily satisfied by any undergraduate engineering degree. The standard number of quarter units for a graduate engineering course in SOET is 4.5, which means that a minimum of 12 courses are needed. The standard curriculum approval procedure at NU requires (among other things) that program learning objectives be delineated in accordance with Bloom's taxonomy and that they embody the knowledge that successful students will obtain upon completion. The remainder of the design process consists of determining the content and learning objectives of the specific courses and how these should be structured. Consideration is also given to the use of electives and/or specializations (or concentrations or tracks, as they are sometimes termed), which are seen to be a common aspect of some curricula where a broad foundation in the degree area can be complemented by expertise in any of a number of pertinent areas. As a need for systems engineering was echoed by representatives of companies in a number of varied industries (e.g., defense, telecommunications, software development, aerospace, transportation, public works, and others), the value became apparent for creating a curriculum that included both a set of common foundational elements as well as the opportunity for gaining specialized in-depth knowledge in one of a variety of pertinent fields of application.

National University utilizes a "lead faculty" structure, which assigns degree programs to one full-time professor as the lead faculty responsible for overseeing the development and maintenance of the curriculum. The use of lead faculty overcomes one of the difficulties sometimes encountered in curriculum design: i.e., the need for someone to take leadership of the curriculum design (as described by Wood and Davis).[12] One of the authors of this paper, Elson, is the lead faculty for NU's MSSyE program.

The lead faculty for this program organized an industry advisory group to provide input to the development of program learning objectives and the structuring of courses and their related learning objectives. The use of an industry advisory group along with the development of program objectives mentioned above meet two of the fundamental curriculum design guidelines.[12,14] The resulting MSSyE program consists of six core courses, a two-course capstone sequence at the end, and six specializations consisting of four courses each. The core consist of four systems engineering design, analysis and modeling courses as well as an introduction to an engineering management course and a software engineering course. The six specialization tracks are industrial engineering, engineering management, supply chain management and e-logistics, environmental engineering, software engineering, and enterprise architecture. These areas of specialization reflect the primary market needs identified by the advisory group in addition to interviews and visits with additional company executives. Note that engineering management is one of the specializations. The catalog description of the MSSyE program is shown below:

Program Requirements
(8 courses, 36 quarter units)

SYE 600 Introduction to Systems and the Design Process
SYE 601 Systems Analysis and Design Evaluation (Prerequisite: SYE 600)
SYE 602 Advanced Systems Design (Prerequisite: SYE 601)
SYE 603 System Dynamics (Prerequisite: SYE 602)
ENM 600 Introduction to Engineering Management
SEN 620 Principles of Software Engineering
ENM 607A Engineering Management Capstone Course (Prerequisite: SYE 600, SYE 601, SYE 602, SYE 603, ENM 600, SEN 620,)
ENM 607B Engineering Management Capstone Course (Prerequisite: ENM 607A)

Requirements for the Areas of Specialization
(4 courses, 18 quarter units)
Students must select one of the following Areas of Specialization:

Area of Specialization in Industrial Engineering (895)
(4 courses, 18 quarter units)
IEM 601 Engineering Economy
IEM 602 Managing Production Planning & control
IEM 603 Managing Facilities Planning Layout
IEM 604 Ergonomics and Occupational Safety

Area of Specialization in Engineering Management (900)
(4 courses, 18 quarter units)
Students must select four courses from the following:
ENM 601 Engineering Project Management
ENM 602 Management of Risk, Contracts, and Legal Issues
ENM 603 Managing Projects in Operations Management
ENM 604 Quality Management

Area of Specialization in Supply Chain Management and eLogistics (892)
(4 courses, 18 quarter units)
SCL 601 Supply Chain Management Fundamentals
SCL 602 Strategies, Design and Implementation
SCL 603 eLogistics Management Fundamentals
SCL 604 Advanced Supply Chain Logistics Management

Area of Specialization in Environmental Engineering (901)
(4 courses, 18 quarter units)
ENE 603 Processes of Environment Engineering
ENE 604 Engineering Aspects of Environmental Engineering
ENE 605 Foundation of Air Pollution Engineering and Equipment Design
ENE 606 Principles of Water and Wastewater Engineering and Treatment

Area of Specialization in Software Engineering (902)
(4 courses, 18 quarter units)
Students must select four courses from the following
SEN 621 Software Tools and Processes
SEN 625 Basic Software Architecture
SEN 630 Applied Software Architecture
SEN 650 Human Computer Interface
SEN 651 User Interfaces and Software Engineering
SEN 645 Designing Database Applications
SEN 655 Application Software Development
SEN 635 Software Testing Strategies and Metrics

Area of Specialization in Enterprise Architecture (897)
The specialization courses as listed below is offered in conjunction with the FEAC Institute at National University. Successful completion of all four courses in either certification program is required as part of the Enterprise Architecture specialization Program. The student will choose either DoDAF or FEA(F):

DoDAF [DEPARTMENT OF DEFENSE ARCHITECTURE FRAMEWORK] CERTIFICATION PROGRAM COURSES
DAF 601 Architecture Framework Basics
DAF 602 Core and Supporting Products
DAF 603 Enterprise Architecture Planning
DAF 604 Advanced Architecture Modeling and Analysis

FEA(F) [FEDERAL ENTERPRISE ARCHITECTURE (FRAMEWORK)] CERTIFICATION PROGRAM COURSES
EEA 601 Enterprise Architecture Concepts and Theory
EEA 602 Enterprise Architecture Planning
EEA 603 Enterprise Architecture Implementation
EEA 604 Enterprise Architecture Integration

Choosing specializations

There were several considerations for choosing to implement specializations. The primary consideration was based on what systems engineering is and its generalist nature. This established a need for a 'generalist' foundation. Other considerations were the number of types of specialized systems engineering skills that were the most in demand, the current graduate program offerings in SOET, and the needs SOET was best positioned to fulfill.

Of particular importance for this paper is the nature and extent of incorporating engineering management into the MSSyE curriculum. Decisions were based, in essentially this order of importance, on a combination of advisory group input; faculty experience in this field; analyses of other systems engineering programs; and some reviews by external consultants. The results include a 'generalist' set of foundational engineering management fundamentals for all systems engineering students – an introduction to engineering management, and provide additional in-depth learning of engineering management principles and practices by offering 'engineering management' as one of the areas of specialization.

The engineering management specialization, as shown above, provides four courses: project management, contract management, operations management, and quality management. These are all essential areas of concern for an engineering manager and also provide knowledge and skills for a systems engineer, especially one who is interested in pursuing a management career.

Recommendations

The process employed in developing NU's Master's program in systems engineering, as described above, succeeded in delivering a program in alignment with the stated needs of major employers of systems engineers within NU's traditional market boundaries. This includes reinforcing concepts in engineering management principles for all MSSyE students and offering students the pportunity to develop additional engineering management capabilities by selecting a specialization in project management. This curriculum was arrived at primarily on the basis of empirical information obtained from employers, experienced faculty, external experts, and other professionals skilled in systems engineering.

As a final note, however, we would like to echo the sentiments expressed in the *Journal of Engineering Education* in the article titled "The Research Agenda for the New Discipline of Engineering Education[18]". This paper recognizes the growing decline of the engineering profession in the U.S. as well as the need to do something about it if the country's prosperity and security are to be protected. While we believe that the engineering programs at National University are the best we can provide at the moment, we also believe that we can do much to improve, as can all of the engineering education in the U.S. One area that we would like to emphasize in terms of research discussed in the JEE paper is the area of curriculum design and development, Area 3-Engineering Learning Systems. We recommend that research, in part, be focused on curricula: what are the emerging topics of interest, what are the learning objectives – specific knowledge and skills, in cognitive terms – that should be accomplished, and how are these best defined and then broken into distinct courses that provide for optimum learning? We call on engineering educators to continue their efforts to develop a curriculum theory for the field of engineering that will guide the discipline in optimizing the process of designing the best curriculum for the U.S. engineers of the future.

References

1. Blanchard,Benjamin S. and Fabrycky, Wolter J. *Systems Engineering and Analysis.* 4 ed. *Prentice Hall International Series in Industrial and Systems Engineering.* W.J. Fabrycky and J.H. Mize. Upper Saddle River, N.J.: Pearson Prentice Hall, 2006.
2. Kotnour, Timothy, and John V. Farr. "Engineering Management: Past, Present, and Future." *Engineering Management Journal* 17, no. 1 (2005): 15-26.
3. Farr, John V, and Dennis M Buede. "Systems Engineering and Management: Keys to the Efficient Development of Products and Services." *Engineering Management Journal* 15, no. 3 (2003): 3-9.
4. Dasher, George T. "The Inerface Between Systems Engineering and Program Management." *Engineering Management Journal* 15, no. 3 (2003): 11-14.
5. Burton, Herbert O, and Michael Pennotti. "The Enterprise Map: A Sytems for Implementing Strategy and Achieving Operational Excellence." *Engineering Management Journal* 15, no. 3 (2003): 15-20.
6. Petee, Danny A., and Paul J. Componation. "Predicting USMC SBIR Phase I to II Transition Success by Evaluatino Use of Systems Engineering Capabilities." *Engineering Management Journal* 15, no. 3 (2003): 21-27.
7. Barker, Bruce G, and Dinesh Verma. "Systems engineering effectiveness: A complexity point paradigm for software intensive systems in the information technology sector." *Engineering Management Journal* 15, no. 3 (2003): 29-35.
8. Keating, Charles, Ralph Rogers, Resit Unal, and David Dryer. "System of Systems Engineering." *Engineering Management Journal* 15, no. 3 (2003): 36-45.
9. Sauser, Brian. "Toward mission assurance: a framework for systems engineering management." *Systems Engineering* 9, no. 3 (2006): 213-227.
10. Rouse, William B. "A theory of enterprise transformation." *Systems Engineering* 8, no. 4 (2005): 279-295.
11. Arnold, Stuart, and Harold W. Lawson. "Viewing systems from a business management perspective: The ISO/IEC 15288 standard." *Systems Engineering* 7, no. 3 (2004): 229-242.
12. Wood, Lynn, and Barbara Gross Davis. *Designing and Evaluating Higher Education Curricula. AAHE-ERIC/Higher Education Research Report No. 8.* Washington D.C.: American Association for Higher Education, 1978.

13. Walker, Decker F. "Curriculum Theory Is Many Things to Many People." *Theory Into Practice* 21, no. 1 (1982): 62-65.
14. Diamond, Robert M. *Designing and Assessing Courses and Curricula: A Practical Guide.* 2 ed. *The Jossey-Bass Higher and Adult Education Series.* San Francisco: Jossey-Bass Publishers, 1998.
15. Gorman, Michael M., Vicki S. Johnson, David Ben-Arieh, Shankar Bhattacharyya, et. al. "Transforming the engineering curriculum: Lessons learned from a summer at Boeing." *Journal of Engineering Education* 90, no. 1 (2001): 143-149.
16. Jarosz, Jeffry P., and Ilene J Busch-Vishniac "A Topical Analysis of Mechanical Engineering Curricula." *Journal of Engineering Education* 95, no. 3 (2006): 241-248.
17. *Fact Book.* La Jolla, CA: National University, 2006.
18. Anonymous "The Research Agenda for the New Discipline of Engineering Education." *Journal of Engineering Education* 95, no. 4 (2006): 259-261.