AC 2008-1131: A DISTRIBUTED SYSTEMS ENGINEERING CURRICULUM FOR WORKING ENGINEERS IN CALIFORNIA

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Kurt Colvin joined the Cal Poly faculty in January 2000. He completed a Ph.D. in industrial engineering at Oregon State University in 1999, preceded by a Master's degree in 1997. He has worked as Computer Integrated Manufacturing (CIM) development engineer at Festo Corporation, process engineer at Frito-Lay, systems engineer at System's Integrators, Inc. and Ameridata, where he gained broad experience in many aspects of manufacturing and information systems. He attended Cal Poly receiving a Bachelor's degree in industrial engineering in 1991. He currently teaches manufacturing simulation, industrial automation and Computer Aided Design and Manufacture (CAD/CAM).

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Joel Shrater received MSEE and BSEE degrees from New Jersey Institute of Technology. He is currently the Director of the Technical Education & Development Department of The Aerospace Institute – the education arm of The Aerospace Corporation. Before transferring to the education area, he was the technical Project Lead for the Remote Tracking Station Block Upgrade in the Air Force Satellite Control Network Special Projects Office. His previous experience was at Ferranti Aerospace as the VP of Engineering for the design of a suite of air to ground missiles and support equipment; at Titan-Datron as the manager for Systems Engineering / Control Systems / and Software Engineering departments involved in the design of a wide variety of satellite tracking and communications antennas; at HTL Advanced Technology as VP of Engineering for the design of a wide array of pneumatic products for the aerospace industry; and as Project Engineer for navigation, guidance and control products at Litton, at Singer-Kearfott, and at Bendix.

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Daphne Dador received her M.A. from the George Washington University in Space Policy and Communications. She also holds a certificate from the International Space University. Dador is currently a project manager at the California Space Education & Workforce Institute where she oversees STEM-related education and workforce development projects through a state and federal economic development initiative. As an active member of the space community, her work has often focused on attracting young people to become involved in space activities and careers. She has held leadership roles within numerous space advocacy organizations including the National Space Society and the Space Generation Congress. Committed to representing the aerospace community and its needs she's been awarded a Boeing Fellowship, a Washington Space Business Roundtable Scholarship, among others.

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Matt Everingham received his BS Aerospace Engineering from University of California San Diego. He is currently Manager, Special Projects for the California Space Authority (CSA). He is responsible for the Regolith Excavation Challenge, a NASA Centennial Challenge in its second year of operation focused on accelerating the development of technologies to support lunar in-situ resource utilization. He also launched the New Space Professionals Working Group, an interorganizational team focused on integrating young professionals into space enterprise community leadership activities. Among the projects in support of the working group were a statewide survey of new space professionals, and participation in an Air Force space professional development course. Previous to his work at CSA, as a student he participated in several design projects and competitions, contributing design, analysis, fabrication and testing of composite material structures.

A Distributed Systems Engineering Curriculum
for Working Engineers in California

Introduction

As part of a workforce initiative grant, we are developing a catalog and curricular structure to enable working engineers in California to obtain Systems Engineering education from a variety of providers in a self-paced manner. The target audience for this effort is companies and individuals who require better Systems Engineering capabilities, but lack the resources and infrastructure for training. These include second-tier suppliers to the aerospace industry, biomedical engineering companies, IT, utilities, etc. A list of 44 "Systems Engineering Competencies" was identified and prioritized through surveys sent to a broad cross-section of California corporations. A search for California-based providers of Systems Engineering coursework (primarily universities, but also government and private organizations) resulted in 200+ courses from nominally 20 providers in a delivery format suitable for working professionals: evening, weekend, short-course, and distance-learning. These classes were cross-referenced to the competencies, which were further grouped into a core set of critical skills plus three *Systems Engineering Concentrations*: SE Management, SE Processes, and SE Techniques. By the end of this program, a pilot run of 100 students will have attended a 3-day SE Fundamentals seminar, which will provide both an overview of Systems Engineering and a "roadmap" to independently continue their Systems Engineering education. The physical embodiment of the roadmap is a course catalog that provides the cross referencing between Systems Engineering Competencies and suitable courses, as well as offers curricular guidelines based upon the SE concentrations.

Motivation

The Workforce Innovation in Regional Economic Development (WIRED) Systems Engineering Development Program is an initiative developed under a grant from the US Department of Labor and administered by the California Space Authority. The program is designed for degreed engineers who are currently employed, and who have a need and/or desire to enhance their knowledge, skills, and competencies in Systems Engineering. There is a growing concern about the decline of the US technical workforce in general, and especially in the field of Systems Engineering.[1] As projects and products become more complex, the need for Systems Engineering expertise is ever increasing. While statistical evidence quantifying the specific needs for Systems Engineers is lacking, anecdotal stories clearly show that there is such a need. The target audience for this effort is companies and individuals who require better Systems Engineering capabilities, but lack the resources and infrastructure for training. These include second-tier suppliers to the aerospace industry, biomedical engineering companies, IT, utilities, etc.

For working engineers, the path to Systems Engineering education presents some challenges. There are currently seventy-five institutions of higher education in the United States that offer 130 undergraduate and graduate degree programs that incorporate Systems Engineering.[2] Many of the Systems Engineering curricula provided by academia require a constrained time commitment, e.g. semesters-long courses taught during working hours, or weeks-long, full-time certificate programs. Additionally, they cover prescribed subjects irrespective of the innate

knowledge of the working engineer. This program attempts to fill the Systems Engineering void by educating working engineers in a manner compatible with their needs and availability. It allows them to study where and when they can, what subject matter they need, and at a cost they can accept.

Systems Engineering Competencies

We are currently developing a set of resources, both online and in print, in the form of a "Course Catalog" for a distributed Systems Engineering curriculum. This catalog is being developed to assist working engineers in California to obtain Systems Engineering education from a variety of providers in a self-paced manner. As this is a program targeting California industry, we began with a survey of their needs. A questionnaire was posted on the web and responses were collected electronically (Figure 1). Over 60 users of Systems Engineers covering a broad cross-section of industries were contacted and supplied with the link to the web survey. They included several technology sectors, and a range of positions (senior management, technical management, program management, and chief/lead engineers). Results were tabulated and analyzed, as well as ranked in order of importance to responders. Analysis of priorities resulted in the identification of a common set of 44 *Systems Engineering Competencies* -- skills identified by California employers as the most critical to their continued success and thus targets for continuing education. While focused directly on the needs of California industry, these Systems Engineering Competencies are similar to those developed in other, more broad reference curricula for Graduate Programs in Systems Engineering,[3] and to various academic references for Project Management / Systems Engineering.[4] These SE Competencies form the organizing foundation for a distributed SE curriculum.

System Engineering (SE) Survey

Company Name

Individual Name   Title/Position   Date

	Strongly Disagree				Strongly Agree
	1	2	3	4	5
General Needs					
1 SE is greatly needed by my company	☐	☐	☐	☐	☐
2 System Engineering can be taught	☐	☐	☐	☐	☐
3 All engineers should have some SE training.	☐	☐	☐	☐	☐
4 System Engineers should be certified (tested)	☐	☐	☐	☐	☐
General Competencies and Background					
5 Systems Thinking (i.e. a mind-set) is a key element in SE.	☐	☐	☐	☐	☐
6 Practical SE experience is needed to become a System Engineer	☐	☐	☐	☐	☐
7 System Engineers need to be knowledgeable in project management	☐	☐	☐	☐	☐
8 System Engineers need to be knowledgeable in business administration	☐	☐	☐	☐	☐
9 System Engineers need to be knowledgeable in system architecting	☐	☐	☐	☐	☐
10 System Engineers need to be knowledgeable in the full system life cycle	☐	☐	☐	☐	☐
11 System Engineers can come from any engineering or scientific discipline	☐	☐	☐	☐	☐
Specific Knowledge and Capabilities Needed by System Engineers					
12 Technical Management	☐	☐	☐	☐	☐
13 Program Management	☐	☐	☐	☐	☐
14 Requirements/specification Management	☐	☐	☐	☐	☐
15 Risk Management	☐	☐	☐	☐	☐
16 Influence Management	☐	☐	☐	☐	☐
17 Contract and Sub-contract Management	☐	☐	☐	☐	☐
18 Cost Management	☐	☐	☐	☐	☐
19 Schedule Management	☐	☐	☐	☐	☐
20 Interface Management	☐	☐	☐	☐	☐
21 Configuration Management	☐	☐	☐	☐	☐
22 Data Management	☐	☐	☐	☐	☐
23 Government Policy and Regulations	☐	☐	☐	☐	☐
24 Teamwork and Team Leadership	☐	☐	☐	☐	☐
25 Manufacturing processes	☐	☐	☐	☐	☐
26 Quality Tools and Methodologies	☐	☐	☐	☐	☐
27 Cost Estimating	☐	☐	☐	☐	☐
28 Organizational Structures, Environments, & Psychology	☐	☐	☐	☐	☐
29 Marketing	☐	☐	☐	☐	☐
30 Economics	☐	☐	☐	☐	☐

Figure 1. Systems Engineering industrial survey.

Curricular Guidelines

Creating an entire Systems Engineering postgraduate degree for working professionals is an extremely challenging and expensive undertaking.[5] Any curriculum developed under this program, whether or not it leads to a formal degree, must be both extremely flexible and sustainable beyond the length of this particular effort. A key characteristic of the *distributed* curriculum is that it presupposes SE content is available, but scattered among many providers of educational material, including academia, government, and private organizations. Individual plans of study for participants will depend on many factors, including, but not limited to, their professional goals, course location/time/delivery method, ability to receive reimbursement under company educational reimbursement policies, etc. There is minimal monitoring of progress, exit exams, certifications or degrees awarded under this program. The end goals of a student's continuing education is entirely defined by the student. While this is appropriate for working professionals, the lack of a single end point such as a degree or certificate creates an inherent challenge in providing curricular guidance.

To address this challenge, we have grouped the 44 Systems Engineering Competencies into logical sets that are used to help provide direction and focus for students developing their plan of study. The resulting curricular guidelines include a core set of critical skills (Core Concepts) plus three *Systems Engineering Concentrations*: SE Management, SE Processes, and SE Techniques (Figure 2):

Core Concepts
Skills that have been identified as the highest priority by California employers. Many of these skills utilize techniques from Business/General Management, and provide a foundation for all other Systems Engineering Competencies: oral and written communication, systems thinking, teamwork & leadership, and an overview of Systems Engineering.

SE Management
These skills are useful in managing Systems Engineering efforts and coordinating the role of individuals into an integrated project. These skills generally utilize the techniques of Technical/Project Management, with an emphasis on understanding and managing systems as a whole.

SE Processes
SE Processes are those techniques that are critical to the coordinated development and operation of systems throughout the system lifecycle.

SE Techniques
SE Techniques are engineering skills, many adapted from Industrial Engineering, which are used by practicing Systems Engineers to develop and analyze systems at the detail level.

SE Skills & Competencies	Priority	
Critical Thinking	1	
Teamwork and Team Leadership	1	
Presentation Skills	1	
Writing Skills	1	**Core Concepts**
Influence Management	1	
Systems Thinking	1	
System Engineering Basics	1	
Program/Project Management	2	
Technical Management	2	
Life Cycle Issues	2	
Cost Management	3	
Schedule Management	3	
Cost Estimating	3	**SE Management**
Organizational Structures, Environments, & Psychology	3	
Intellectual Property Protection	3	
Training	4	
Government Policy and Regulations	4	
Marketing	5	
Contract Management	5	
Environmental Issues & Impacts	5	
Requirements/specification Management	1	
Interface Management	1	
Risk Management	1	
Technical Performance Measurement	2	
Reliability/Maintainability/Availability	2	
Design and Synthesis	2	**SE Processes**
Configuration Management	2	
System Architecting	2	
Software Architecture	3	
Data Management	3	
Manufacturing processes / producibility	3	
Decision Analysis	1	
Test, Measurement, & Evaluation	2	
Modeling, Simulation & Analysis	2	
Quality Tools and Methodologies	2	
Survivability	2	
Probability & Statistics	2	**SE Techniques**
Optimization	2	
Statistic Process Control / Six Sigma	3	
Human Factors	3	
Security	3	
Safety & Health Hazards	3	
Drawings and Computer Aided Design	3	
Automation	5	

Figure 2. Systems Engineering Competencies grouped into SE Concentrations.

The three Systems Engineering Concentrations represent increasing specificity, from the "big picture" down to application of specific tools in focused analyses. A goal of continuing education in Systems Engineering would be to become well versed in all areas, with a focus that corresponds to a participant's current or target job function. The role of a project manager will be best served by a concentration in the skills of SE Management; product development engineers will likely find SE Processes to be of interest; design or analytical engineering roles are a fit with SE Techniques. Curriculum guidelines for our program thus suggest that students develop skills that span the Core Concepts plus a focus in one Concentration. Guidelines are also provided for those interested in formalizing their study plan, with options including continuing education credit hours, certificate programs offered by a number of content providers, and professional certification through organizations that offer industry-recognized standards in areas related to Systems Engineering.[6]

Many of the courses in the distributed curriculum have an option of being taken for graduate credit; our guidelines stress, however, that it is extremely unlikely that a series of courses taken from different providers can be integrated together into a graduate degree granted by an academic institution. If a student has a goal of obtaining a Master's degree in Systems Engineering or a related field, one or two courses *may* be transferable into a formal Masters program.

Courses & Content Providers

All of the resources in the resulting catalog have been selected with the working engineer in mind, and hence are limited to: evening and weekend courses, short courses, on-line and distance learning courses. A search for California-based providers of Systems Engineering coursework (primarily universities, but also government and private organizations) resulted in 200+ courses from nominally 20 providers in a delivery format suitable for working professionals. These courses are listed as individual pages in the catalog (Figure 3).

The catalog cross-references course offerings to the Systems Engineering Competencies, resulting in a "roadmap" matrix to assist students in developing their plan for continuing Systems Engineering education (Figure 4). Three major pieces of information are visible in this matrix to help students screen and identify courses of interest:

- **Delivery Method:** Online courses generally offer the most flexibility. If courses are offered onsite (evening, weekend, or short-course), they are grouped by geographical location (Northern or Southern California).

- **Material Covered:** The Systems Engineering Competencies covered in each course are identified by X's in the matrix. This assists students to fulfill their educational goals while avoiding significant content overlap, even if they are taking courses from different providers over their course of study.

- **Breadth/Depth of Material:** While not quantified in this catalog, students can get an idea of the breadth (number of competencies covered) and depth (level of treatment of each competency covered) of the material in a given course by noting the number of competencies covered (X's in the matrix). A large number of skills covered by a single course is typically an indication of a survey course, which may be useful for becoming well versed in the breadth of Systems Engineering, but may not serve a student's needs as part of a focused Concentration. Students are referred to the individual catalog pages for a more detailed description of the course, and encouraged to check with the course provider for confirmation.

Course ID: 17	Course Title: Introduction to Project Management Principles and Practices		
Course Description:	DeliveryMethod: Online	Credit	2.5
Businesses use project management to manage projects and achieve outcomes typically with limited resources and under limited time constraints. This intensive, hands-on course provides an overview of the principles that underlie project management and covers the fundamental skills needed to enhance the outcome of any project. Gain a working knowledge of the nine major areas of the Project Management Body of Knowledge (PMBOK as defined by the Project Management Institute) including human resources management, communications management, scope	Regoinal Locatio Non-Specific	Length	8 meetings
	SEConcentration SE Management	Provider	UC Irvine
	Course Number: MGMT X442.2	Fee:	690
	WebLink		
	Course Skills & Competencies		
	Contract Management		
	Cost Management		
Course Notes:	Program/Project Management		
	Quality Tools and Methodologies		
	Risk Management		
	Schedule Management		

Figure 3. Typical course listing.

Figure 4. Catalog Matrix.

The matrix lists courses by Delivery Method, Regional Location, and Course ID, mapped against Skills & Competencies grouped under SE CORE CONCEPTS, SE MANAGEMENT, SE PROCESSES, and SE TECHNIQUES.

Delivery Method	Regional Location	Course ID	SE CORE CONCEPTS											SE MANAGEMENT												SE PROCESSES												SE TECHNIQUES								
			Critical Thinking	Teamwork and Team Leadership	Presentations Skills	Writing Skills	Cost Estimating	Organizational Structures and Environment	Intellectual Property Protection	Training	Government Policy and Regulations	Marketing	Contract Management	Systems Thinking	System Engineering Basics	Decision Analysis	Systems Architecting	Program/Project Management	Technical Management	Design and Synthesis	Test, Measurement and Evaluation	Modeling, Simulation and Analysis	Life Cycle Issues	Cost Management	Environmental Issues and Impacts	Requirements/specification Management	Interface Management	Risk Management	Influence Management	Configurations Management	Reliability, Maintainability and Availability	Technical Performance Measurement	Schedule Management	Software Architecture	Manufacturing Processes and Producibility	Safety & Health Hazards	Data Management	Quality Tools and Methodologies	Survivability	Probability & Statistics	Stastical Process Control and Six Sigma	Optimization	Human Factors	Security	Drawings and Computer Aided Design	Automation
On Campus	SoCal	130											1	1			1	1		1										1		1														
		131													1																		1													
		149															1																													
		150												1				1										1										1		1						
		151													1																		1													
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		158													1												1						1													
		159																	1	1						1	1	1		1																
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		164	1	1	1										1						1					1		1		1		1					1						1			
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		166													1						1											1														
		209					1																1						1																	
		210	1																1										1																	
		211																																	1											
On Request	NorCal	62													1																															
Online	Non-Specific	9												1				1		1																										
		11												1																																
		12												1																																
		17											1		1					1					1		1					1					1		1							
		34													1																															
		35													1																	1														

Systems Engineering Fundamentals Seminar

In addition to the course catalog, which serves as the physical embodiment of the distributed Systems Engineering curriculum, this program involves development and implementation of a "kickoff" SE Fundamentals seminar for participants. Students will receive a two-day in-class introduction to all of the technical elements of Systems Engineering. The educational goals of this introduction include:

- Improved understanding of the SE practice, processes and objectives.
- Improved awareness of SE relevancy to business goals and industry norms.
- Identified targets for more in-depth learning opportunities.
- Enhanced ability to communicate with customers and suppliers regarding SE activities/tasks.

The third day of the seminar is an orientation to many of the System Engineering resources that are available to participants as they continue their independent study. Representatives from content providers will be present in a symposium format to discuss the details of their specific offerings. The students will then proceed on their own using the course catalog to pursue additional education for subject matter that fits their individual need. By the end of this program, a pilot run of 100 students will have attended the SE Fundamentals seminar.

Follow On Plans

As this program develops, there are some clear indications of the challenges and opportunities in Systems Engineering education for working engineers in California. The process of identifying suitable and available Systems Engineering training has illuminated significant deficiencies and content gaps in particular competency areas. It is our intention to disseminate these observations in a "State of the State in Systems Engineering" publication within the coming year. It is our hope, and the hope of the project sponsor, that identification of gaps, combined with a more quantified measure of the potential market for students, will motivate both academic and commercial educational providers to develop additional materials and flexible course offerings. The end result would be an expanded availability of continuing Systems Engineering education to the benefit of California industry.

REFERENCES

1. International Council on Systems Engineering (INCOSE).

2. W. Fabrycky, and E. McCrae, "Systems Engineering Degree Programs in the United States," Proceedings of the INCOSE International Symposium, 2005.

3. R. Jain, "A Reference Curriculum for a Graduate Program in Systems Engineering," INCOSE Insight, July 2007.

4. See, for example, Eisner, Howard, Essentials of Project and Systems Engineering Management, John Wiley & Sons, New York, 2002.

5. J. Kasser, *et. al.*, "Crafting a Postgraduate Degree for Industry and Government", Proceedings of the International Engineering Management Conference, IEEE, 2004.

6. For Example:
    INCOSE (International Council on Systems Engineering) - Systems Engineering Certification (www.incose.org);
    PMI (Project Management Institute) - Project Management Professional (PMP) Certification (www.pmi.org);
    EMCI (Engineering Management Certification Int'l) - Engineering Management Certification (www.EngineeringCertification.org).