A Distributed Systems Engineering Curriculum for Working Engineers in California

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Abstract

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, information technology companies, utilities, and any other California companies that would benefit from better systems engineering processes. Surveys sent to a broad cross-section of California corporations were used to elicit a list of 44 Systems Engineering Competencies. Analysis of these 44 competencies resulted in a core set of critical skills, plus three Systems Engineering Concentrations: <u>SE Management, SE Processes</u>, and <u>SE Techniques</u>.

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, shortcourse, and distance-learning. Relevant course information of these classes were integrated into a relational database where they could be easily cross-referenced to the systems engineering concentrations and competencies

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 Systems Engineering 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 Engi-

neering¹. 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, information technology companies and utilities.

For working engineers, the path to Systems Engineering education presents some challenges.

System Engineering (SE) Survey												
Co	mpany Name											
Individual Name Title/Position					Date							
		Stro Dis	ong agr	ly ee				Stro: Agre	ngly e			
Ce	anal Naada		1		2	3	4	5				
1	SE is greatly needed by my company		Т	-					٦.			
2	Sustam Engineering can be taught		누	÷	H	님	H	H	-			
3	All engineers should have some SE training		ᅣ╞	11	H	H	H	H	-			
4	System Engineers should be certified (tested)		忭	t	H	H	H	H	1			
Ger	neral Competencies and Background				<u> </u>				-			
5	Systems Thinking (i.e. a mind-set) is a key element in SE.		П						٦			
6	Practical SE experience is needed to become a System Engineer		ᅣ╞	i i	Ħ	Ħ	Ħ	Ħ	1			
7	System Engineers need to be knowledgeable in project management		忭	ii	Ħ	Ħ	H	Ħ	1			
8	System Engineers need to be knowledgeable in business administratio	n	忙	11	T	П	T	T	1			
9	System Engineers need to be knowledgeable in system architecting		忭	ii	Ħ	Ħ	Ħ	Ħ	1			
10	System Engineers need to be knowledgeable in the full system life cyc	le				Π			1			
11	System Engineers can come from any engineering or scientific discipl	ine		11		Π			1			
Spe	cific Knowledge and Capabilities Needed by System Engineers					_			-			
12	Technical Management								1			
13	Program Management		TE						1			
14	Requirements/specification Management								1			
15	Risk Management		TC						1			
16	Influence Management		ΙC						1			
17	Contract and Sub-contract Management								1			
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								1			
27	Cost Estimating											
28	Organizational Structures, Environments, & Psychology											
29	Marketing		1Ľ						1			
30	Economics		10			\square			-1			

Figure 1. Systems Engineering Industrial Survey.

There are currently seventy-five institutions of higher education in the United States that offer 130 undergraduate and graduate degree programs that incorporate Systems Engineering². Many of the Systems Engineering curricula provided by academia require a constrained time commitment, e.g. semesters-long courses taught during working hours, or weekslong, 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.

System 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 em-

Proceedings of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference Copyright © 2008, American Society for Engineering Education ployers 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 Engineering³ and to various academic references for Project Management / Systems Engineering⁴. These SE Competencies form the organizing foundation for a distributed SE curriculum.

Curricular Guidelines

Creating an entire Systems Engineering postgraduate degree for working professionals is an extremely challenging and expensive undertaking and it not within the scope of this effort⁵. 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 project. 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 no monitoring of progress, exit exams, certifications or degrees awarded under this program. While this may lack the perceived coherence and control of a more formal program, in this instance, 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 (<u>Core Concepts</u>) plus three Systems Engineering Concentrations: <u>SE Management</u>, <u>SE Processes</u>, and <u>SE Techniques</u> (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.

<u>SE Techniques</u>

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.



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 industryrecognized standards in areas related to Systems Engineering⁶.

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 week-end 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+ classes from nominally 20 providers in a delivery format suitable for working professionals. These courses are listed as individual pages in the catalog (Figure 3).

Course ID: 17	nt Principles and Practices								
Course Description:	DeliveryMethod:	Online	Credit	2.5					
Businesses use project management projects and achieve outcomes typic	Regoinal Locatio	Non-Specific	Length	8 meetings					
limited resources and under limited constraints. This intensive, hands-o	SEConcentration	SE Management	Provider	UC Irvine					
provides an overview of the princip underlie project management and co	Course Number:	MGMT X442.2	Fee:	690					
fundamental skills needed to enhan of any project. Gain a working know nine major areas of the Project Mar	ce the outcome wledge of the agement Body	WebLink							
of Knowledge (PMBOK as defined by the Project		Course Skille & Competencies							
Management Institute) including hu									
ranagement, communications management, scop	agement, scope								
Course Notes:	Program/Project Ma								
		Quality Tools and M							
		Risk Management							
		Schedule Managen							

Figure 3. Example Course Listing.

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 (1'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 Concentra-

tion. 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.



Figure 4. Catalog Matrix.

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.

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- 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).