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Evolving the INCOSE Reference Curriculum for a Graduate Program in Systems Engineering

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ABSTRACT

This paper suggests an evolution to the graduate level systems engineering curriculum framework documented in an International Council on Systems Engineering (INCOSE) report in October of 2007 [Jain and Verma, INCOSE-PP-2007-001-01, Seattle, WA, 2007]. This evolution leverages the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 15288 Systems and Software Engineering—System Life Cycle Processes standard [ISO/IEC 15288, International Organization for Standardization, Geneva, 2008] as a guide. The evolved framework is presented and consists of six levels of course categories: prerequisite, introductory, technical system life cycle processes, project planning system life cycle processes, infrastructure processes and other broad areas, and capstone courses. Next, 18 systems engineering centric online masters degrees offered by 17 distinct universities are identified as part of a growing base of graduate level systems engineering degrees offered globally through distance education. Specific examples for applying the framework using three of the universities that provide online systems engineering masters programs globally are included. © 2009 Wiley Periodicals, Inc. 13: 381–388, 2010

Key words: systems engineering education; systems engineering curriculum; graduate level systems engineering framework; curriculum assessment; distance education; global systems engineering education

1. INTRODUCTION

The tremendous growth in systems engineering (SE) masters programs offered around the world over the last decade is indicative of the importance of systems engineering education to both industry and government. In 2000, Brown identified 23 universities in the United States that offered graduate programs in two broad categories of systems engineering: systems analysis and design, and industrial and manufacturing engineering, with one university also focused on control systems. Brown and Scherer [2000] estimated that these university programs were between 5 and 20 years old, and that about 250 masters and 50 doctorates were awarded each year. Five years later, Fabrycky and McCrae [2005] identified 56 universities in the United States that offered systems engineering focused graduate programs. Fabrycky and McCrae's 56 universities were inclusive of 20 of Brown and Scherer's 23 universities (missing were Kansas State University, Louisiana Tech University, and Ohio University). Fabrycky and McCrae divided the graduate degrees into two types: systems engineering centric programs, where systems engineering was the intended major area of study, and domain centric systems engineering, where systems engineering was applied

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to a specific domain. Of the 56 universities, 27 offered systems engineering centric masters degrees and 34 of the universities offered domain specific systems engineering masters degrees, where some universities offered masters degrees in both. Domains were divided into six areas: biological engineering, computer engineering, electrical engineering, industrial engineering, management engineering, and manufacturing engineering [Fabrycky, 2007]. Today, the International Council on Systems Engineering (INCOSE) currently lists 108 systems engineering academic programs on its website [ERTC, 2009]. These programs are located all over the world as shown in Tables I and II, which contain the number of programs listed by INCOSE both by country; and then by state for the United States [ERTC, 2009].

New systems engineering programs are typically put in place to meet a perceived opportunity or need based on a particular target group. Dependent on the time constraints and curriculum development resources available, a variety of approaches may be used to develop the needed curriculum to create a complete program. When the need is imminent, existing courses can be leveraged to the extent feasible to create an initial program, with additional content applied to fill in the gaps. Lessons learned based on course experience and assessments can then be applied as continuous improvement measures. This is akin to a "bottom-up" systemic approach to curriculum development [Bots and Thissen, 1996]. With more time, a "top-down" systemic approach can be applied that includes the mapping of course content to industry needs and systems engineering competencies [Bots and Thissen, 2000; Squires, Larson, and Sauser, 2010].

In order to assist in the development of new systems engineering curriculum and to provide a means to assess this curriculum against international guidelines for systems engineering, we suggest further evolution of the INCOSE adopted graduate systems engineering curriculum framework. This evolved framework can be used to compare and contrast existing systems engineering programs of interest, including those offered globally through distance education, as well as

Table I. INCOSE Directory of Systems Engineering Academic Programs

Country	# Programs
Australia	3
Brazil	1
Canada	6
China	11
England	7
France	2
Germany	2
India	1
Israel	1
Korea	1
The Netherlands	1
Saudi Arabia	1
Singapore	1
Turkey	1
United States	69
Total:	108

Table II. INCOSE Directory of U.S. Systems Engineering Programs

State	#Programs
Alabama	2
Arizona	2
Arkansas	1
California	11
Colorado	6
Florida	4
Georgia	3
Idaho	1
Iowa	1
Maryland	5
Massachusetts	3
Michigan	2
Minnesota	1
Missouri	2
New Jersey	1
New York	4
North Carolina	1
Ohio	5
Oregon	1
Pennsylvania	2
Texas	5
Virginia	5
Washington, DC	1
Total:	69

to identify areas where programs can be improved or new programs can be developed to fill in the gaps.

2. BACKGROUND

The systems engineering curriculum framework presented in this paper is an evolution of a previous framework initially developed and summarized by Squires [2007] and documented in an International Council on Systems Engineering (INCOSE) report in October 2007 [Jain and Verma, 2007]. To develop an initial framework in 2006, Squires [2007] performed an iterative analysis of two hundred and three systems engineering courses selected across the graduate curriculum of 32 U.S. universities. Each course was categorized based on a detailed review of the course descriptions. Course groupings and category definitions were iteratively updated as new courses were added to the overall analysis. Through the extensive iterative process each of the 203 courses was eventually assigned to one of 16 primary course topic areas that were sorted into four levels of course categories as shown in Table III.

The final detailed results of the iterative effort are shown in Table IV. The course categories were comprised of prerequisite (Pre) courses needed to enter the systems engineering graduate program, introductory (Intro) and core courses that were required courses for the completion of the graduate degree, and specialization courses which were typically selected based on the student's interests.

As shown, the courses were sorted primarily based on recurrent themes in the course content, based on the course descriptions provided. The "Core" category contained the most frequently offered systems engineering courses across

Table III. Baseline SE Curriculum Framework Course Categories and Types [Squires, 2007]

Level	Category	Course Type
0	**Foundation Courses:** Pre-systems engineering courses. Students must be competent in these areas to enter the systems engineering graduate program.	Probability and Statistics
		Linear, Matrix, Differential Algebra
1	**Introductory Courses:** Fundamental systems engineering courses for the beginning graduate student. These are the first courses taken in the systems engineering graduate program.	Fundamentals of Systems Engineering
		Introduction to Systems Engineering Management
2	**Core Courses:** Required core courses towards the completion of a graduate degree in Systems Engineering. These are recommended as core courses in any systems engineering program.	Modeling, Simulation and Optimization
		Systems Design/Architecture
		Decisions, Risks and Uncertainty
		Quality, Safety, and Systems Suitability
		Systems Integration and Test
		Software Systems Engineering
3	**Specialization Courses:** Advanced courses which focus on systems engineering niches or special areas related to systems engineering. Students focus on specialization courses once the initial and CORE courses are complete.	Finance, Economics, and Cost Estimation
		General Project Management
		Manufacturing, Production, and Operations
		Organizational Leadership
		Engineering Ethics/Legal Considerations
		Masters Project or Seminar

the courses analyzed that were neither prerequisites, nor fundamental courses. The remaining courses were grouped into the "Specialization" category. Please note that not all courses for every school were included in the initial analysis, and only a subset of U.S. universities were considered. Furthermore, this subset included only universities that taught a systems engineering centric as opposed to a domain centric (as defined by Fabrycky [2007]) graduate program. The original goal was to develop an initial framework that could be evolved through vetting, collaboration, additional research, and other applicable means. As shown, therefore, this framework represented a baseline for comparing graduate systems engineering curriculum as part of a systems engineering centric (as defined by Fabrycky [2007]) graduate program, as it was being taught in the United States. This work was first presented to the INCOSE Academic Council at the INCOSE Symposium in July 2006 by Dr. Rashmi Jain and later documented by INCOSE in a 2007 report [Jain and Verma, 2007].

Since the development of this original framework, a few changes have occurred in the 32 universities included in the original study. Please note that most of the 32 universities currently offer either a Master of Science or a Master of Engineering degree in Systems Engineering; however, not all of the degrees are so named. For example, the Colorado School of Mines offers a Masters of Science in Engineering Systems, and the University of Southern California offers a Masters of Science in Systems Architecture and Engineering (founded by Eberhardt Rechtin). Also, California State University—Fullerton and Cornell University offer masters degrees with options offered in Systems Engineering. And two of the original 32 universities studied in 2006 no longer offer graduate Systems Engineering related degrees: In the case of the University of Idaho, the degree program is simply no longer offered; in the case of the Washington University in St. Louis, the degree has been more appropriately renamed to a Master of Science in Systems Science and Mathematics.

As Table IV illustrates, the original baseline curriculum framework was developed by reviewing and categorizing a subset of systems engineering graduate courses offered as part of the 32 graduate systems engineering programs offered throughout the United States. This provided a method for comparing the types of courses offered as part of the systems engineering degrees of these institutions, and other institutions like these. However, the framework did not factor in available international standards or guidelines for the practice of systems engineering; nor was the complete graduate curriculum towards a Masters in Systems Engineering included—in most cases only the core courses for each graduate degree were selected for the analysis. These drawbacks are addressed in the newly evolved framework for graduate level systems engineering curriculum presented in this paper.

3. AN EVOLVED FRAMEWORK

In this paper, an evolutionary step is taken for developing an international systems engineering curriculum framework. This evolution combines two approaches—the original INCOSE graduate reference framework approach that was based on existing systems engineering centric curriculum offered in the United States and a standards-based approach that leverages two additional documents developed by systems engineering experts through domestic and international collaboration. First, the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) 15288 Systems and Software Engineering—System

Table IV. The Historical Record of the 203 Courses Applied in the 2006 Study#

	Category: Pre		Intro		Core						Specialization						
Results of analysis of 32 U.S. Universities (203 courses): Core systems engineering courses are categorized into sixteen primary topic areas within four primary categories	Foundation: Linear, Matrix, Differential	Foundation: Probability and Statistics	Fundamentals of Systems Engineering	Intro to Systems Engineering Management	Modeling, Simulation and Optimization	Systems Design/Architecture	Decisions, Risks and Uncertainty	Quality, Safety, and Systems Suitability	Systems Integration and Test	Software Systems Engineering	Finance, Economics, and Cost Estimation	General Project Management	Manufacturing, Production, and Operations	Organizational Leadership	Engineering Ethics/Legal Considerations	Masters Project or Seminar	**Grand Total**
Air Force Institute of Technology			1	1		1				1						2	6
Boston University					2												2
California State University,Fullerton	1	2			1		1										5
Colorado School of Mines					2											1	3
Cornell University			1		1							1				1	4
Florida Institute of Technology			1	1	1		2										5
George Mason University	1		1	1	1					1							5
George Washington University			2	1			2				1	1		1		1	9
Iowa State University				1		1											2
Johns Hopkins University			2						2	1		2				1	8
Loyola Marymount University			1			3		1		1		1	1		2	2	12
Naval Postgraduate School			1	3	1	1		1				1		1			9
Oakland University								1					3				4
Old Dominion University			3			1			1	1				1			7
Penn State Great Valley	2		1		2		1										6
Polytechnic University Farmingdale	3	2			1												6
Portland State University			1		1					1							3
Rochester Institute of Technology	2			2	1			1	1	1							8
Southern Methodist University			1	1	2				1								5
Southern Polytechnic State University			1	2	1	2		2	1		1					2	12
State University of NY - Binghamton		1	1		1		1										4
Stevens Institute of Technology		1	1	2	1	1		3	1		1						11
University of Alabama in Huntsville			1	1	1		1	1			1						6
University of Arizona	1	2	1		4												8
*University of Idaho**				*1*											*1*		*2*
University of Maryland				1	2			1	1		1					1	7
University of Missouri-Rolla**			2	2		3					1						8
University of Pennsylvania					2					1							3
University of Southern California			1	2		3			1	1	2						10
University of Virginia		1	1		3		2		2							1	10
Virginia Tech							1	1	1		1	1	1	1			7
*Washington University in St. Louis**	*5*	*1*															*6*
Grand Total	15	10	25	22	31	16	12	12	11	9	9	7	5	4	3	12	**203**

*These two universities no longer offer Systems Engineering focused graduate degrees.

#The number of courses shown in each column is in no way reflective of the total number or type of systems engineering courses offered by the university. Instead, this table is the historical record of the number of courses from each area that were applied to the original 2006 study, totaling 203 courses.

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Life Cycle Processes standard [ISO/IEC, 2008] guides the evolution of the original framework. Second, the *Systems Engineering Handbook: A Guide for Systems Life Cycle Processes and Activities*, Version 3.1 [INCOSE, 2007], which incorporates the previous version of this international standard [ISO/IEC, 2002] and is used to prepare for the INCOSE Certified Systems Engineering Practitioner (CSEP) exam, is used to continue the evolution process.

To begin the evolution process, the original INCOSE graduate reference curriculum framework is leveraged for its proven list of topic categories that reflect the various typical combinations of course content offered as a subset of graduate level systems engineering centric masters programs in the United States. That is, the original framework provides a basis for establishing course categories that systems engineering curriculum can be mapped to. Additional categories are then added to the framework as needed to provide a complete mapping to both the international systems engineering standard and the INCOSE handbook in systems engineering. Thus, the original curriculum framework is extended using ISO/IEC 15288 [ISO/IEC, 2008] and version 3.1 of the INCOSE handbook [INCOSE, 2007]. The new framework is outlined in Tables V and VI.

Together, the original and added course topic areas incorporated into the framework fully address the System Life Cycle Processes of the ISO/IEC 15288 standard published in 2008, an earlier 2002 version of which also forms the basis for the most recent version 3.1 of the INCOSE Systems Engineering Handbook [INCOSE, 2007]. As shown in Table V, the original four levels are extended into six levels that more readily map to the standard's System Life Cycle Stages. In the same way, course types within each of the levels are expanded as well. For example, the system life cycle process standards per ISO/IEC 15288 include a set of Agreement Processes (Acquisition and Supply) and Organizational Project-Enabling Processes that, in turn, include Life Cycle Model, Infrastructure, Project Portfolio, Human Resources, and Quality Management Processes. Process guidelines within the System Life Cycle Processes are included for the set of Project Processes and Technical Processes. Each set of ISO/IEC 15288 System Life Cycle Processes are mapped to the evolved systems engineering curriculum framework as shown in Table VII.

The result is an evolved framework that incorporates an ontology that current systems engineering programs can be mapped to, which addresses the complete systems engineering life cycle set of processes in use worldwide. This full set of topic categories should ideally be covered at least at a basic level in a university's graduate systems engineering curriculum in order for the graduate to be familiar with all areas required to meet the internationally defined standard in the field. The framework provides the ability to complete an up to date validation of the systems engineering curriculum for universities that have well-established systems engineering programs, and also provides an international basis for systems

Table VI. Evolved SE Curriculum Framework Course Categories and Types

Level	Category	Course Type
0	**Pre-Requisite Courses**	Probability and Statistics
0		Linear, Matrix, Differential Equations
1	**Fundamentals: Generic or Domain Specific**	Fundamentals of Systems Engineering
1		Fundamentals of Software Systems Engineering
1		Introduction to Systems Engineering Management
1		Introduction to Domain Specific
2	**System Life Cycle Technical Processes**	Mission Needs, System Concept, System Requirements, Requirements Analysis
2		Systems Architecture, Systems Design and Development
2		Modeling, Simulation and Optimization
2		Systems Integration and Test, Field Testing
2		Manufacturing, Production, Operations, Retirement
2		Systems Suitability: Quality, Safety, Reliability, Supportability
3	**System Life Cycle Project Processes**	Decisions, Risks and Uncertainty
3		Configuration Management, Information Management
3		Project Management, Finance, Economics, Accounting
4	**Other System Life Cycle Processes**	Enterprise Systems
4		Acquisition and Supply
4	**Other Broad Areas Applicable to Systems Engineering**	Systems Thinking
4		Creativity and Problem Solving
4		Subject Matter Expert Domain Specific
5	**Capstone**	Masters Thesis, Project or Seminar

Table V. Level Definitions for International SE Curriculum Framework

Level 0: Pre-Requisite Courses	Pre-systems engineering courses; students must be competent in these areas to enter the systems engineering graduate program.
Level 1: Introductory SE Courses	Fundamental systems engineering courses for the beginning graduate student. These can be in systems engineering, systems engineering management, or other domain specific systems engineering fundamental courses.
Level 2: Core SE Life Cycle Courses	Systems related technical courses that cover the system life cycle from a technical perspective, from the identification of the mission needs and the development of the initial system concept to the retirement or replacement of the system.
Level 3: Core SE Management Courses	Systems related project planning courses that cover the system life cycle from a systems engineering management perspective including project management, decision, risk and opportunity management.
Level 4: Broad SE Related Courses	Courses that deal with broad areas related to systems engineering including enterprise systems, systems thinking and creativity and problem solving.
Level 5: Capstone - Masters Thesis, Project or Seminar	Capstone courses where the student demonstrates the culmination of their learning and experience gained throughout the graduate program.

Table VII. Mapping of Evolved SE Curriculum Framework to ISO/IEC 15288 [ISO/IEC, 2002, 2008]

Level	System Life Cycle Technical Processes	ISO/IEC 15288 Technical Processes
2	Mission Needs, System Concept, System Requirements, Requirements Analysis	Stakeholder Requirements Definition, Requirements Analysis
2	Systems Architecture, Systems Design and Development	Architectural Design, Implementation
2	Modeling, Simulation and Optimization	Architectural Design, Implementation
2	Systems Integration and Test, Field Testing	Integration, Verification, Transition, Validation
2	Manufacturing, Production, Operations, Retirement	Operation, Maintenance, Disposal
2	Systems Suitability: Quality, Safety, Reliability, Supportability	Across all Technical Processes
Level	**System Life Cycle Project Processes**	**ISO/IEC 15288 Project Processes**
3	Decisions, Risks and Uncertainty	Decision and Risk Management
3	Configuration Management, Information Management	Configuration Management, Information Management
3	Project Management, Finance, Economics, Accounting	Planning, Assessment and Control, Measurement
Level	**Other System Life Cycle Processes**	**ISO/IEC 15288 Enterprise and Agreement Processes**
4	Enterprise Systems	Organizational Project-Enabling Processes
4	Acquisition and Supply	Agreement Processes

engineering, for universities who anticipate launching a program in systems engineering in the future.

4. USING THE EVOLVED FRAMEWORK

Several examples of applying the evolved systems engineering curriculum framework follow. Due to the proliferation of systems engineering programs worldwide, and the importance of distance education in providing education to the global citizen, we select universities from those that offer systems engineering programs to the global student, through distance education, as example cases. The idea is that global students can complete systems engineering curriculum offered remotely from any country and this capability supports an international approach to systems engineering curriculum development. While the authors were unable to locate a university outside of the United States that offered systems engineering curriculum remotely, the Penn State online program is offered as part of the World Campus program. Based on an updated evaluation of the original 32 universities researched in the United States in 2006, and additional up-to-date secondary research, 17 U.S.-based universities were identified that offer masters degrees in systems engineering curriculum through remote online education (accessible anytime, from anywhere). The universities and the online masters degrees offered are shown in Table VIII. Three new universities identified over and above the previous researched universities are bolded in the table.

As shown in Table VIII, 18 systems engineering masters degrees are offered online by the 17 universities listed. A detailed analysis of the full graduate curriculum from three universities was performed in order to demonstrate the application of the evolved framework. The three universities chosen were: Air Force Institute of Technology (AFIT), Penn State—World Campus, and Stevens Institute of Technology (SIT). Each university's degree was evaluated as a complete online program. In cases where electives were involved, core

Table VIII. Universities Offering Online Remote Systems Engineering Masters Degrees

Institution	Degree
Air Force Institute of Technology	M.S. in Systems Engineering
Colorado State University	M.E. in Systems Engineering
Cornell University	M.E., Systems Engineering Option
Iowa State University	M.S. in Systems Engineering
Missouri University of Science and Technology	M.S. in Systems Engineering
National University	**M.S. in Systems Engineering**
Naval Postgraduate School	M.S. in Systems Engineering
Penn State - World Campus	M.E. in Systems Engineering
Portland State University	M.E. in Systems Engineering
Rensselaer Polytechnic Institute	**M.E in Computer and Systems Engineering**
Southern Methodist University	M.S. in Systems Engineering
Southern Polytechnic State University	M.S. in Systems Engineering
State University of NY - Binghamton	M.S. in Industrial and Systems Engineering
Stevens Institute of Technology	M.E. in Systems Engineering
University of Alabama - Huntsville	M.S.E concentration in Systems Engineering
University of Southern California	M.S. in Industrial and Systems Engineering, M.S. in Systems Architecture and Engineering
Walden University	**M.S. in Systems Engineering**

Table IX. AFIT Space Systems Track [AFIT, 2008–2009]

Course #	Course Name	Course Type	Level	Course Category
SENG 520	Systems Engineering Design	Core	1	Fundamentals of Systems Engineering
CSCE 590	Engineering of Software-Intensive Systems	Core	1	Fundamentals of Software Systems Engineering
SENG 640	Systems Architecture	Core	2	Systems Architecture, Systems Design and Development
SENG 610	Systems Engineering Management	Core	2	Mission Needs, System Concept, System Requirements, Requirements Analysis
MECH 532	Intro to Space Flight Dynamics	Specialty	1	Introduction to Domain Specific
SENG 631	Spacecraft Systems Engineering	Specialty	1	Introduction to Domain Specific
PHYS 519	The Space Environment	Specialty	4	Subject Matter Expert Domain Specific
STAT 583	Intro to Probability & Statistics	Math	0	Probability and Statistics
QMGT 680	Project Risk Analysis	Quantitative	3	Decisions, Risks and Uncertainty
SENG 799	Thesis Project (3 courses)	Thesis	5	Masters Thesis, Project or Seminar

Table X. Penn State—World Campus [Penn State, 2009]

Course #	Course Name	Course Type	Level	Course Category
SYSEN 510	Engineering Analysis I	Core	0	Linear, Matrix, Differential Equations
SYSEN 550	Creativity and Problem Solving I	Core	4	Creativity and Problem Solving
SYSEN 505	Technical Project Management	Core	3	Project Management, Finance, Economics, Accounting
SYSEN 531	Probability Models and Simulation	Core	3	Decisions, Risks and Uncertainty
SYSEN 552	Creativity and Problem Solving II	Core	4	Creativity and Problem Solving
SYSEN 530	Systems Optimization	Core	2	Modeling, Simulation and Optimization
SYSEN 533	Deterministic Models and Simulation	Core	2	Modeling, Simulation and Optimization
SYSEN 520	Systems Engineering	Core	1	Fundamentals of Systems Engineering
SWENG 586	Requirements Engineering	Core	2	Mission Needs, System Concept, System Requirements, Requirements Analysis
SWENG 587	Software Architecture	Core	2	Systems Architecture, Systems Design and Development
SYSEN 536	Decision and Risk Analysis in Engineering	Core	3	Decisions, Risks and Uncertainty
SYSEN 594A	Master's Paper Research	Project	5	Masters Thesis, Project or Seminar

Table XI. Stevens Institute of Technology [SIT, 2009]

Course #	Course Name	Course Type	Level	Course Category
SYS625	Fundamentals of Systems Engineering	Core	1	Fundamentals of Systems Engineering
SYS650	System Architecture and Design	Core	2	Systems Architecture, Systems Design and Development
EM612	Project Management of Complex Systems	Core	3	Project Management, Finance, Economics, Accounting
SYS605	Systems Integration	Core	2	Systems Integration and Test, Field Testing
SYS660	Decision and Risk Analysis	Quantitative	3	Decisions, Risks and Uncertainty
SYS640	System Supportability and Logistics	Specialty	2	Systems Suitability: Quality, Safety, Reliability, Supportability
SYS645	Design for Reliability, Maintainability, and Supportability	Specialty	2	Systems Suitability: Quality, Safety, Reliability, Supportability
SYS611	Modeling and Simulation	Specialty	2	Modeling, Simulation and Optimization
SYS655	Robust Engineering Design	Specialty	2	Systems Suitability: Quality, Safety, Reliability, Supportability
SYS800	Special Problems in Systems Engineering	Thesis	5	Masters Thesis, Project or Seminar

courses, or courses in line with a systems engineering focus, were selected. This approach resulted in a complete set of courses for each degree that would best demonstrate the mapping of the university's systems engineering curriculum into the international framework. The results of the mappings are shown in Tables IX, X, and XI.

5. FINDINGS

Given that courses were listed in the general suggested order of completion, there was a large variety in the three systems engineering programs chosen, based on how they mapped to the international systems engineering standard and evolved curriculum framework. This could indicate an issue with the baseline systems engineering framework, the evolution process selected, or the lack of a consistent philosophical perspective towards the discipline of systems engineering in general, and the education of systems engineers, specifically.

Also, while the task was not too difficult to map the courses, in some cases, courses could have spanned more than one course category and, in those cases, only the primary category was selected for the mapping. Additionally, it was noted based on both provided course descriptions and personal experience, duplication of course content may result from one course to the next within the same program, for several reasons. First, in order to adequately cover a particular topic, duplication of fundamental material may occur, second, there is a need for review due to a potential time lag from one course completion to the next course, and, third, experienced faculty with diverse backgrounds may have differing approaches or perspectives on similar topics. A more thorough analysis of the courses would uncover these types of considerations and should be addressed when updating or creating new framework-based curriculum.

In general, a complete mapping of every existing systems engineering programs would potentially result in the revamping of certain areas of the framework to accommodate courses not currently addressed. These additional courses would most likely impact the framework in the area of level four: "Other Broad Areas Applicable to Systems Engineering" and possibly in the first two levels of the framework that address pre-requisite course topics and introductory or fundamentals courses. However, the hope is that the essential structure of the framework would hold and be of use for new systems engineering programs in development or as a framework to compare existing curriculum against for identification of potential gaps in the desired curriculum.

Also of note, the initial examples uncovered two potential areas that were also not addressed by any of the systems engineering programs analyzed in the original analysis, and that was the area of "enterprise" and "agreement" processes covered in level four of the framework. This gap includes the absence of focus on the acquisition process of large systems and systems of systems, a primary concern of government and defense. INCOSE has acknowledged the importance of the acquisition perspective through the development of an INCOSE Certified Systems Engineering Practitioner (CSEP) in Acquisition (-Acq) certification process which requires the understanding of such processes outlined in the interim version of the Defense Acquisition Guide (DAG) [DAG, 2009]. Given the importance of an acquisition perspective to the systems engineering life cycle process, and to industry and government, this area may warrant additional attention by universities when performing systems engineering curriculum development or reviews.

And, finally, the analysis also uncovered the fact that none of the programs were likely to cover the entire system life cycle. Most programs, like these provide a broad brush of the system life cycle and focus in on the front end of the life cycle, most specifically in requirements, architecture, and design. This may be due to the combination of an inability to cover the broad, multidisciplined process of systems engineering in the shorter masters graduate program timeframe and the resultant focus on the front end of the process, which is the phase where the success or failure of a project is typically determined.

Further research is needed to review lessons learned from historical work in this area as well as consideration of other, perhaps more viable, approaches to developing a useful systems engineering curriculum framework.

6. SUMMARY

This paper covers the extension of a baseline systems engineering curriculum framework to the next step in evolution. The framework was initially developed based on a review of 203 systems engineering courses offered across 32 U.S.-based universities [Squires, 2007]. The framework is extended to include the international standards and guidelines outlined in the ISO/IEC 15288 Systems and Software Engineering—System Life Cycle Processes standard which provides the basis for version 3.1 of the *INCOSE Systems Engineering Handbook* [INCOSE, 2007]. An application of the framework is demonstrated by mapping three existing online systems engineering masters programs, including one that is part of the World Campus, to the evolved framework. Findings indicate that while existing systems engineering programs vary widely, there are some commonalities in areas that are covered (fundamentals, requirements, and architecture design) and areas that are missing (enterprise and agreement processes as defined in the standards). Further use of the framework would likely uncover additions in other broad areas applicable to systems engineering curriculum. The framework appears to be useful for comparing existing programs and would also be beneficial as a guideline for the development of new systems engineering based programs and the associated curriculum; however, a new approach may be needed to develop a more usable systems engineering curriculum framework going forward.

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