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Abstract

This paper provides an overview of Systems Engineering education in the context of an Engineering Management program. This program has successfully integrated systems engineering into the broader perspective of engineering management. From a base of core strengths and competencies in engineering management, the systems engineering courses have grown in substance and acceptance in the marketplace. Combinations of these courses lead to Certificates and Master's degrees. Further study in systems engineering, together with research and dissertation activities, can lead to a doctorate degree. Aspects of the offerings discussed in this paper include: (1) system requirements, (2) the systems approach, (3) system architecting, (4) synthesis and analysis, (5) standards, (6) software engineering, (7) support elements, (8) modeling and simulation, (9) systems acquisition, (10) systems of systems, (11) systems analysis, and (12) systems engineering management. A summary includes a discussion of directions for the future. Topics of interest in this regard include (1) a possible paradigm shift, (2) partnerships of new shapes and sizes, (3) integrated ways of participating, (4) the global dimension, and (5) improving the state-of-the-art in this field of education.

Introduction

Approximately ten years ago, the University Department integrated systems engineering, in a formal manner, into its engineering management program. This change was all about emphasizing and featuring Systems Engineering as a major part of moving forward in the 21st century. This turned out to set the stage for major growth in the Department, much of that growth having to do with the demand for education programs in Systems Engineering. Looking at this matter historically, one could say that the engineering management program successfully integrated systems engineering into the broader context of engineering management. The integration occurred in several dimensions:

a. the offering of new programs that featured courses in both engineering management and systems engineering

b. the formal change of the Department's name to "Engineering Management and Systems Engineering", and

c. the outreach to industry and government with respect to the scope and content of the integration efforts.

Success may be measured, in part, by the very positive responses to (c) above, both in words and deeds. These, in turn, have brought new students and revenues to the University and Department.

From a base of core strengths and competencies in engineering management, the systems engineering offerings satisfied and indeed stimulated further demand and have grown in substance and acceptance in the marketplace. Evidence of this stimulation is the fact that an expanding group of industry and government representatives have signed on to the new programs which have grown in both size and direction. We are also able to see that other Universities have started new programs bringing aspects of engineering management and systems engineering together, in one form or another.

Certificate Program

An initial offering was a Certificate in Systems Engineering. It was configured as a set of six courses covering a variety of topics in both systems engineering and engineering management. It was both convenient and forward-looking to establish this program as a cohort offering that would be attractive to local industry personnel with degrees in science and engineering. The convenience lay mainly in bringing the courses and instructors to the physical facility of the students. It was also represented by distinct points of contact between industry and the University, facilitating early problem recognition and solution. We believe it was forward-looking in that it formed the foundation for major acceptance and expansion down the road, especially at the Master's level. Immediate actions involved presenting the program to local companies and ultimately signing a memorandum of understanding that established terms and conditions for the program. It was set up to provide the courses at the company's facility, usually starting at about 5:30 PM and running to 8:30PM. A time period of 12 weeks per course became a standard. A cohort of some 25-30 persons could complete the six courses in a period of two years. All students in the cohort went through the program in lock-step, and knew in advance what was being offered and when each course was scheduled. The content of the courses was nominally the same as those offered on-campus, but the instructor had the additional benefit of being able to bring specialized materials into the courses, when appropriate and approved.

Master's Degree Program

It became clear rather early that the Certificate Program needed to evolve into a Master's degree program whereby the students could move beyond the Certificate to obtain their Master's degrees. Thus, an additional six courses were added to the Certificate requirements, thus constituting a solid program at the Master's level. The same cohorts, and the supporting companies, found this expansion extremely attractive and responsive to their needs. The overall program thus consisted of twelve courses:

-- four core courses (to be taken in all Master's degree tracks)

-- five additional required courses for all students in the systems engineering major

-- three electives (agreed upon at the beginning in the case of the cohorts)

The systems engineering track has the greatest number of students at this time, and demonstrates how it is possible and desirable to bring systems engineering together with engineering management.

Doctoral Program

The Department has offered a doctoral program for many years. This program continues, and students study in areas of focus, including:

-- engineering and technology management

-- systems engineering

-- crisis, emergency and risk management

-- economics, finance and cost engineering

-- environmental and energy management

-- knowledge and information management

-- operations research and management science

The first two of the above list tend to encompass both engineering management and systems engineering disciplines and research areas. At times, students are able to "double-major", combining courses from two of the above focus areas. Some of these focus areas (e.g., economics, finance and cost) naturally affiliate with others.

Overview of Scope of Systems Engineering

The scope of the systems engineering program, of course, depends upon the level of education in question (i.e., certificate, master's, doctorate). A brief overview of some of the areas of special interest is presented below.

1. System Requirements

Many of the problems associated with building large systems are traceable to issues surrounding the requirements for those systems. Emphasis is placed upon examples of both good and bad requirement statements, as well as key aspects of requirements engineering and analysis. Areas of special concern include (a) high-risk requirements, (b) low performance requirements, (c) the formulation of derived requirements, (d) non-measurable requirements, and (e) inconsistent requirements.

2. The Systems Approach

This refers mainly to being able to see the "whole" of a system, to include all its elements, and both internal as well as external connections. Specific aspects of this approach can be articulated as [1]: (a) following a systematic and repeatable process, (b) emphasizing interoperability, (c) developing a cost-effective solution to the customer's problem, (d) assuring the consideration of alternatives, (e) using iteration as a means of refinement and convergence, (f) satisfying all final user and customer requirements, and (g) creating a robust system, i.e., one that can experience many modes of failure without crashing.

3. System Architecting

This step in the systems engineering process is perhaps the most critical in terms of building a system that is ultimately responsive to the needs and requirements of all the stakeholders. Several approaches to the architecting of a system are explored, including the DoD Architectural Framework (DoDAF), Enterprise Architecting, Service-Oriented Architecting (SOA) and an approach, formulated by this author, based upon a strict and quantitative cost-effectiveness analysis of alternatives.

4. Synthesis and Analysis

The processes of architecting as well as subsystem design are strongly dependent upon the systems engineering team being able to appropriately synthesize and analyze alternatives. This needs to be performed in both short and longer formats appropriate to the phase of the effort. Specific synthesis examples and companion analysis processes are explored and tried in order to develop understanding and proficiency. More often than not, the resultant examples are placed in the context of a comparative assessment of the cost and effectiveness of alternatives. These alternatives can be at both the architectural level as well as at the subsystem level of design.

5. Standards

Emphasis is placed upon standards for both systems and software engineering, both current and historical. Special emphasis is placed upon EIA 632 and ISO/IEC 15288, both of which are “process” oriented and apply to systems engineering. On the software side, IEEE/EIA 12207 is of particular interest. The CMMI is also an important part of exploring this overall topic and its influence and impact.

6. Software Engineering

Software engineering is viewed as a critical part of systems engineering. Areas of special concern and interest include [1]: (a) software management strategies, (b) key management indicators, (c) the COCOMO approach to cost estimation, (d) software reliability, and (e) an overview of what the systems engineer needs to know about software engineering.

7. Support Elements

One can view many of the elements of systems engineering in their support roles to the mainstream of designing and building large-scale systems. These include, but are not limited to: (a) mission engineering, (b) life-cycle costing, (c) risk analysis, (d) interface and configuration control and management, (e) integrated logistics support, (f) reliability, maintainability and availability, (g) integration, (h) verification and validation, (i) specialty engineering, and (j) test and evaluation.

8. Modeling and Simulation

This activity is crucial, especially for large systems. It is necessary, in the main, to be able to predict the performance of systems during their architecting phase, clearly before one is able to test real hardware and software. The principal way to do this is through modeling and simulation. This is achieved largely by either building a new set of models and simulations, or using existing commercial simulation tools, adapted to the problem at hand. At times, combinations of these two approaches can be used to great advantage.

9. Systems Acquisition

Special attention can be paid to the point of view of the acquirer of the system in question, who follows a set of procedures that might be called the systems acquisition process. The "5000 series" of documents in the Department of Defense define the important features of this process, and deal with a variety of topics that need to be known to the systems engineer. These topics include: (a) integrated plans and capability roadmaps, (b) a management framework, (c) integrated architectures, (d) evolutionary acquisition, (e) advanced technology, and (f) the total systems approach.

10. Systems of Systems

As systems have grown in size, complexity and scope, we have been developing what has come to be called "systems of systems" and "federations" of systems [2]. In examining this topic, we have looked at: (a) examples of systems of systems, (b) the rationale for such a description, (c) the special features of systems of systems, (d) a taxonomy for developing systems of systems, and (e) how to approach the building of such systems that might be different from the more conventional approach to systems engineering.

11. Systems Analysis

This overview topic deals with special "analysis" topics that might be borrowed from other fields, such as linear and non-linear systems analysis, operations research methods (e.g., linear programming), demand analysis, thermodynamics, probability and statistics, and other topics drawn from companion engineering disciplines.

12. Systems Engineering Management

All of the elements of systems engineering need to be appropriately managed. As an integral part of defining and exploring systems engineering, careful attention is paid to the ways on which "management" can either help or hinder the processes. Students of systems engineering need to appreciate and understand that there are different approaches to "technical" and "management" issues and problems. Indeed, one might say that systems engineering and engineering management come together in this area known as systems engineering management.

Summary

This paper has briefly discussed systems engineering education programs within the context of engineering management. These have included certificate, master's and doctoral programs in systems engineering. This is a quite strong area within the Department, as measured by technical content as well as demand in both industry and government.

In the design and delivery of these programs, we have noticed what might be called the beginning of a "paradigm shift", from open enrollment offerings, to cohort-based programs. In this context, one might say that both industry and government have been taking a more proactive role in determining the programs that they will sponsor, at the certificate, master's and doctoral levels.

In the context of the above, we also see more definitive stances within the three conventional communities (academia, industry and government) in the direction of new "partnerships", so that each is more responsive to the needs and contributions of the others. As part of this shifting of positions, agencies, groups, offices and departments are looking for, and finding, new and more powerful ways of participating and interacting with one another. It would seem that this direction will be reinforced in the years to come.

We have been able to respond to an expanding global dimension where we see interest in our programs, and in partnerships, outside of the United States. Although there are some limits as to the extent to which we can do this, we see it as a possible trend that will continue for some time. Cost of delivery and availability of resources are obviously serious issues in this regard.

Finally, we continue to look for ways to improve the state-of-the-art in systems engineering education, while assuring that we have the requisite connections to the overall field of engineering management. In this regard, we hold a weekend review session, every year, bringing together both full-time and part-time adjunct faculty to discuss what we have learned, and what adjustments need to be made going forward. That is only one concrete example of the "continuous improvement" approach we have taken to this important part of our program offerings. Systems engineering itself is a dynamic field, and it both influences, and is influenced by, the engineering management perspectives that that we have developed over a period of many years.

References

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