2006-1786: SYSTEMS ENGINEERING AS A FOUNDATION OF ENGINEERING MANAGEMENT EDUCATION

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Systems Engineering as a Foundation of Engineering Management Education

Abstract

The Department of Systems Engineering at the United States Military Academy (USMA) offers an undergraduate major in Engineering Management. This multi-disciplinary major is accredited by the Accreditation Board of Engineering and Technology (ABET) of the Engineering Accreditation Commission (EAC). All Engineering Management majors at USMA start their studies with an introductory course in Engineering Design and Systems Management. In this course, students are introduced to the Systems Engineering and Management Process (SEMP), which is the foundational problem solving approach used and reinforced throughout the curriculum. This paper describes the Engineering Management curriculum at the USMA, and shows how the sequencing of courses enhances students’ abilities as problem solvers using the SEMP. Students take courses in Systems Engineering, Engineering Management, another engineering discipline of their choosing, Financial Management and Personnel Management. The program of study culminates with students solving a real-world problem following the framework of the SEMP for a Department of Defense or industry client as part of a year-long Capstone Design course. Students work in small teams of four under the direction of a Ph.D. faculty member in applying the concepts learned throughout the curriculum.

Introduction

The United States Military Academy (USMA) at West Point has a unique role in our society among institutions of higher learning. Our mission is: “to educate, train and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country, and prepared for a career of professional excellence and service to the nation as an officer in the United States Army.” USMA fulfills this mission through rigorous military, physical and academic programs. The Dean of Academics (Dean’s) vision is that the academic program “educates cadets to be Army officers of character who anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world”. The USMA academic program is designed as a broad, multi-disciplinary education with an extensive array of required courses in the humanities and math, science and engineering disciplines. Students (cadets) also graduate with a major in a chosen discipline. The breadth of study provided in the required, or core, courses combined with depth of study in the majors program enables USMA to meet the Dean’s vision.

The USMA mission, the vision for the Academic Program and the reality of the worldwide operations of the US Army today imply that we need to graduate cadets with the background to understand, and solve, complex problems that are multi-disciplinary in nature. Andrew Sage describes systems engineering in many of these same terms; multi-disciplinary teams working with systems that are often large and complex. In the Department of Systems Engineering at USMA, we offer cadets five majors: Systems Engineering, Engineering Management, Operations Research (jointly run with the Department of Mathematical Sciences), Information Engineering and Systems Management. Systems Engineering education is central to all of these majors. The Engineering Management (EM) program of study is the focus of this
paper, which describes how Systems Engineering provides the foundation and framework for the curricular design of this highly successful major at West Point.

**Systems Engineering is Important to Engineering Management**

USMA is not the only university in which the Engineering Management major is run by a Systems Engineering (SE) department. SE is a central theme in several of the top undergraduate programs in Engineering Management. Three other undergraduate ABET accredited EM programs (University of Arizona, University to Missouri at Rolla and Stevens Institute of Technology) are integrated with departments that have large SE or Industrial Engineering programs. Many other non-ABET accredited EM or hybrids of EM programs co-exist in SE departments. This phenomenon also occurs at the graduate level at many universities and happens by design. This strongly indicates that an understanding of SE principles is critical to the success of Engineering Managers.

Engineering Management, as a discipline, evolved from the need to provide a link between the managers and engineers of all types. A quick review of undergraduate degree descriptions describes EM programs as providing a strong engineering core with additional studies in management, technology and business related courses. Two pioneers in the EM field, Dr. John Farr and Dr. Dennis Buede, attribute globalization and the increase of large-scale interdisciplinary problems to the expansion of using systems engineering as the platform for EM, especially earlier in the product lifecycle. The EM program at West Point recognizes the importance of systems engineering to the discipline and is reflected in the curricular design.

**The Engineering Management Curriculum at West Point**

The EM program at West Point provides cadets a nationally recognized major with a multi-disciplinary modern curricula supported by state of the art laboratory facilities. The program has been accredited by the Engineering Accreditation Commission (EAC) of ABET since 1996, with re-accreditation granted in 2002. The American Society of Engineering Management (ASEM) awarded our program the 2005 Founders Award for Academic Excellence for Leadership of Engineering and Technical Management for Undergraduate Programs. The EM Program received this same recognition as the best undergraduate program in the nation by ASEM in 1992, 1999 and 2002. The USMA Student Chapter of ASEM was also recognized as the outstanding student chapter in 2003 and 2004. Cadets find the program to be relevant and dynamic, as evidenced by the growth in enrollments from 15 majors in the Class of 2004 to 64 majors in the Class of 2008. Opportunities for applied research by both cadets and faculty ensure the program integrates the curriculum with real-world application.

The balanced EM program strives to produce graduates able to apply a disciplined problem solving process to complex, multidisciplinary problems. The program is designed to support the USMA mission and Academic Program goals. To meet the Dean’s vision for the USMA academic program and the accreditation criteria established by the ABET, the program is designed with specific outcomes (Table 1) in mind for our graduates:
<table>
<thead>
<tr>
<th>Outcome Number</th>
<th>Program Outcome</th>
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<tbody>
<tr>
<td>1</td>
<td>Identify and analyze a client's problem and manage the implementation of the solution.</td>
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<tr>
<td>2</td>
<td>Design and conduct experiments, as well as to analyze and interpret input and output data.</td>
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<tr>
<td>3</td>
<td>Design or re-engineer a system, component, or process to meet the needs of the client.</td>
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<tr>
<td>4</td>
<td>Apply knowledge of mathematics, science and engineering coupled with knowledge of contemporary issues to develop and implement a holistic solution to the client's problem.</td>
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<tr>
<td>5</td>
<td>Accurately and effectively report findings and recommendations both orally and verbally to the client.</td>
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<tr>
<td>6</td>
<td>Function as a contributing member of a multidisciplinary team.</td>
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<tr>
<td>7</td>
<td>Understand professional and ethical responsibilities of a military officer and engineer and the broad education necessary to understand the impact of engineering solutions on contemporary problems in a global and societal context.</td>
</tr>
<tr>
<td>8</td>
<td>Recognize the need for, and an ability to engage in life-long learning.</td>
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<tr>
<td>9</td>
<td>Use the techniques, skills, modern engineering tools and technologies necessary for service as an officer and for engineering practice.</td>
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These outcomes provide the focus for the EM curriculum.

The EM program model (Figure 1) offers a mix of engineering management, systems engineering, an engineering discipline of cadet choice, finance and organizational management courses. Methods courses provide the EM major the basic tools and techniques for the discipline. Cadets choose a specific engineering discipline (civil, mechanical, electrical, environmental or nuclear engineering) in which to develop a foundation in engineering principles. Project courses build on some of the methods courses and provide cadets specific applications useful for engineering managers. The organization, finance and management topics give cadets the multi-disciplinary exposure an engineering manager needs to understand the concepts of staffing, organizing, planning, leading and financing projects. Cadets have the opportunity to attend an Advanced Individual Academic Development experience during a summer training period to see the real-world application of their discipline. These are popular but voluntary limited summer internship programs primarily with Department of Defense (DoD) agencies. Finally, the integrative experience or capstone design courses provide cadets the forum to apply what they have learned in the program in solving a problem for a real DoD or industry client. They integrate concepts learned through all their USMA experiences to provide valuable analysis and recommendations concerning an issue for a project client. The Engineering Management Design courses are the culminating experiences of the major.
Cadets enrolled in the EM major start the program with a foundation course in systems engineering. The Introduction to Engineering Design and Systems Management course ensures all cadets start with a solid basis in systems thinking and the SE problem solving approach as they begin the major program of study. The problem solving approach taught in this course is reinforced throughout the program of study.

**Systems Engineering in the Engineering Management Program at West Point**

The SE problem solving approach taught at West Point is the Systems Engineering and Management Process (SEMP) (Figure 2). The SEMP provides a four-phased framework for identifying, analyzing, deciding on and implementing solutions to engineering design problems. The SEMP is comparable to other problem solving processes such as the SIMILAR Process (State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate) used in systems engineering. The SEMP framework can be applied to a broad array of large scale, complex ‘design problems’, from new product to organizational design. The ‘methods’ courses in the EM program, discussed in the previous section, provide cadets the techniques and best practices used in specific phases of the SEMP. The ‘projects’ courses take this a step further by applying course content to applications limited to specific phases of the SEMP. The extensive required humanities and basic sciences courses provide cadets the knowledge to understand the environment surrounding an engineering
problem, such as the economic, cultural and historical perspectives to problem solving. The Engineering Management Design (Capstone) courses have cadets apply the overall SEMP while incorporating other course concepts in solving a real-world problem.

**Figure 2. The Systems Engineering and Management Process (SEMP) at West Point.**

The Problem Definition phase of the SEMP is critical to successful problem solving. EM majors learn methods and techniques such as stakeholder analysis, functional analysis, system decomposition, value hierarchy creation, brainstorming and affinity diagramming in the basic Introduction to Engineering Design and Systems Management course, and an elective Decision Analysis course. These techniques are used to identify and define the correct problem for resolution and identify any subsystems that need to be integrated. The systems engineer also develops an initial model for determining the value of alternative solutions during this phase. The methods listed above are reinforced in project and capstone courses when cadets work on applications. Both cadets and project clients quickly see the value of the methodical problem-definition process that systems engineers use in working a problem. The process and products of this phase of the SEMP enable stakeholders to understand the issues more deeply and clearly, and to provide better guidance when forming alternatives for problem resolution. This process also helps in team building among both the stakeholders and the project team because it is very inclusive.

The Design and Analysis phase of the SEMP focuses on generating, modeling and analyzing alternatives for the given design problem. Besides the introductory course in SE, EM majors get extensive exposure to modeling and analysis through analytical methods and simulation courses. The information systems and technology courses in the major also support modeling and analysis of alternatives. They also gain background for alternatives generation through their courses in discipline-specific engineering principles. The courses in Engineering
Economics and Production Operations Management also provide information useful in modeling and analysis of alternatives.

The Decision Making phase generates a valuing of the alternatives in meeting the stakeholder needs. In addition to the introductory course in SE, all the ‘methods’ courses in the EM major support the scoring of alternatives. The organizational management and leadership courses in the major also provide the theory and concepts inherent in good decision making. The engineering economics and finance courses provide the EM major a framework for applying cost-benefit analysis in comparing alternatives.

The EM major as a project manager is the focus of the implementation phase. The Project Management course provides the methods for planning, executing, controlling and assessing the implementation of a problem solution. The information systems and technology courses in the major expose cadets to the integration issues that systems engineers must be cognizant of when implementing system solutions. The organizational management and leadership courses also expose EM majors to the human resource issues associated with project implementation.

The concepts discussed in each phase are integrated through the year-long capstone design courses. Cadets apply the SEMP as they work through the issues of a problem for an actual client. Cadets gain valuable lessons in SE and EM education as they interact with their clients and stakeholders on the interim process and products of their analysis. In their final semester, cadets attend a professional seminar course that provides a forum to learn about the application of Systems and Engineering Management methods to real-world issues, such as the NASA space program, by practicing professionals in industry and government. Cadets are also exposed to professional standards for SE, such as the Institute of Electrical & Electronics Engineers (IEEE) standard 15288-2004 (Adoption of International Organization for Standardization (ISO) / International Electrotechnical Commission (IEC) 15288:2002 Systems Engineering - System Life Cycle Processes). These courses bring the application of Systems Engineering to life for the cadets.

An Example Student Capstone Project Using the SEMP

Each summer approximately 1,300 young men and women (new cadets) enter the gates of West Point aspiring to be cadets and future Army officers. These new cadets undergo a rigorous 6-week basic training program that inculcates them into the Army and cadet life. The day they arrive at West Point is known as Reception (R-) Day and USMA processes each new cadet through a series of tasks that facilitates transforming them from civilian life by nightfall of R-day. This day is filled with such activities as receiving haircuts, medical checks, military uniform items, and training in basic drill and ceremony skills among other tasks. All new cadets have to complete these tasks before the oath ceremony that takes place in the early evening. To accomplish all these tasks for 1,300 new cadets in a few short hours requires “military” precision.

While R-Day has been successfully run for many years now, the people responsible for planning, organizing and executing all the myriad of tasks asked for help in making the process
more efficient. This became a capstone project for a group of four cadets who majored in Engineering Management or Systems Engineering. Figure 3 provides a snapshot of the key activities the capstone team performed in each phase of the SEMP as they worked this problem for their client. The remainder of this section provides a very brief overview of some of these activities to illustrate how SE concepts taught in the EM curriculum are pulled together in Capstone projects.

During the Problem Definition phase of the SEMP, the cadets received the following initial problem statement:

To streamline R-Day activities for in-processing candidates into the Corps of Cadets from the initial arrival of cadets at Thayer Hall until the start of the Oath Ceremony to ensure all critical tasks and training are completed prior to the Oath Ceremony.

The cadets immediately started to diagnose their problem and met with their stakeholders so they could conduct a thorough needs analysis. The end result of the needs analysis was a values hierarchy to reflect what the stakeholders valued in a solution to this problem. The cadets also developed a revised problem statement.

![Figure 3. Depiction of R-Day Capstone Project Work using the SEMP framework.](image)

After conducting an in-progress review with the clients to gain approval of the values hierarchy and revised problem statement, the cadets worked on activities in the Design & Analysis phase. The cadets generated multiple alternatives for streamlining the R-Day activities.
and started to model and analyze each of them. The cadets used the skills they learned in their simulation elective course as they modeled and analyzed their alternatives in the Pro Model© simulation software. In the Decision Making phase of the SEMP, the cadets evaluated their alternatives using a decision matrix and checked the sensitivity of their recommendation to changes in their value hierarchy weights. The cadets recommended an alternative to their client that included modifications to the number of workers manning each activity site, flow control times to speed processing, information requirements for each activity, key leader locations, and decision points for controlling the rotation of groups of new cadets through the activities.

Throughout the project, cadets used the concepts from their Project Management course to plan and control their work. For this specific capstone project, the implementation phase of the SEMP could not be fully executed because the cadets graduated before the Execution and Assessment & Control steps of this phase could be performed in the summer. However, their recommendations were incorporated by the client in restructuring the R-Day activities (haircuts, uniform issue, basic drill and ceremony skills, etc) making the arrival day for new cadets a much more efficient, if not entirely pleasant, experience.

Conclusion

Understanding the processes in Systems Engineering is important for engineering managers. Engineering managers often lead multi-disciplinary teams working on large-scale, complex problems requiring integrated solutions, exactly the types of issues for which systems engineering is designed. Engineering managers should gain an understanding of SE in their formal programs of study at the undergraduate or graduate level. The nationally recognized Engineering Management major at USMA uses Systems Engineering processes and concepts as the foundation and framework for the curricular design of the program. The SE problem solving approach, the SEMP, taught at the introductory level is reinforced throughout all engineering management and systems engineering courses in the major. The EM major at West Point sends graduates out to the technologically, politically, economically and socially complex operating environment they will face in a deployed Army with the practical education they need to succeed.

Bibliography


