Incorporating Systems Engineering and Project Management Concepts in First Year Engineering Curriculum

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Abstract

During the first and second years of undergraduate engineering programs, most students focus their studies to build a solid foundation of mathematics, writing composition, engineering graphics, programming languages, economics, and other social science disciplines. Along with preparing students for discipline-specific engineering courses, these remedial classes aim to broaden their horizons and develop interdisciplinary skills for career success. However, neither the holistic views of interaction between different systems nor the complexity behind their management are provided to the engineering students. As a result, the engineering graduates very often find it challenging interacting and coordinating with different branches or sectors of their workplaces. It is important to mention that the number of engineering graduates pursuing career in other disciplines are also increasing.

Project management deals with planning and managing resources to implement real life solutions, and hence can provide future engineers a mindset to think like problem solvers. Early exposure of systems engineering and project management principles in the curriculum would be beneficial for all engineering and computer science students, because many of them will enter workforce and manage critical interdisciplinary systems and work with peers from various backgrounds. The scope of systems engineering and project management can range from missile defense to non-profit organizations and covers many aspects of our daily life.

In this paper, an outline of first year systems engineering and project management topics and their rationale are discussed based on industry standard bodies of knowledge (BoK) and recent graduate survey reports. Early exposure of both business and technical needs to solve real life problems and managing resources will not only motivate engineering students about their future career, it will also enhance their learning in perspective and help them think from various points of views.

Career of Engineering Graduates: A Case Study

Before discussing project management and systems engineering concepts for first year engineering students, let's first analyze which career tracks graduates enter after completing their undergraduate engineering programs. In order to get some facts and figures, we analyzed Undergraduate Career Plans Survey Reports from School of Engineering & Applied Science

(SEAS) at the University of Pennsylvania. The reports are published by the University of Pennsylvania Career Services and available on the World Wide Web. According to the 2011 survey results of newly graduate students, only 17% of the University of Pennsylvania 2011 SEAS graduates entered in engineering careers who went for fulltime employment (excluding graduates pursuing further studies or seeking employment). The 2011 report collected data from December 2010, May 2011 and August 2011 SEAS bachelor's degree recipients. Based on this survey, engineering career is further broken down into five categories such as research and development (36%), design (25%), project management (22%), manufacturing and production (11%) and quality assurance (6%). Percentages of the University of Pennsylvania SEAS graduates entering in engineering careers after undergraduate degree completion are provided in Fig. 1 for the years 2007 to 2011.

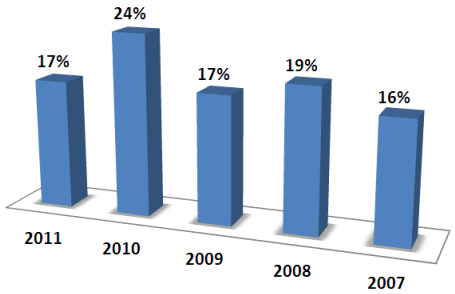

Figure 1: Percentage of the University of Pennsylvania SEAS graduates in engineering career after undergraduate degree completion

Now let's look at the overall job types of 2011 graduates as provided in Fig. 2 below. Information technology is the major career track for recent graduates followed by consulting, engineering and financial analysis. The reason for high percentage of engineering graduates seeking career in other fields for our case study could be impacted by the school's geographical location and other job related factors in the northeast United States. However, fields such as IT, consulting, technical management and finance require a high level of quantitative reasoning and analytical skills while offers competitive salaries. This could be some of many reasons why new engineering graduates are considering other non-engineering fields for their career choice.

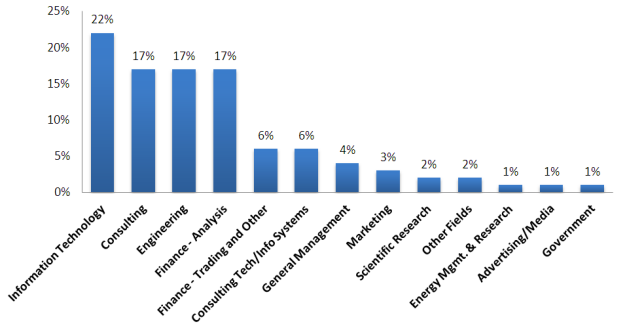

Figure 2: Job type breakdown of the 2011 University of Pennsylvania SEAS graduates after undergraduate degree completion

An industry wise breakdown of the above discussed data is provided in Fig. 3. According to 2011 survey, most recent graduates started a career in finance followed by consulting, technology and manufacturing. These four industries are represented by 84% of the new graduates of this survey.

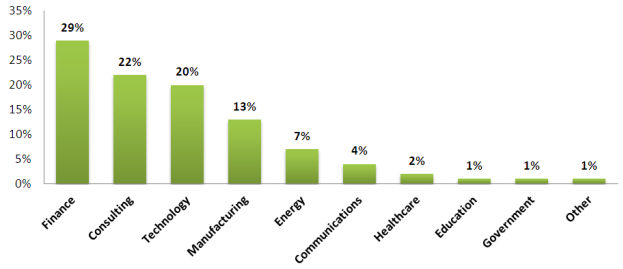

Figure 3: Job type breakdown of the 2011 University of Pennsylvania SEAS graduates after undergraduate degree completion

It is interesting to note that 22% of the recent graduates in 2011 survey who went for engineering career reported to be working in project management. Even though no breakdown is provided for the other job types, many of them can include direct project management work or related tasks of designing, developing and operating complex systems. When engineers are working in IT, consulting or finance, the three major non-engineering job types listed in the survey, they are working with peers who might have different educational background. Having some prior exposure in project management and systems engineering lifecycle can not only be an advantage during job interviews, it can also help to work better with others and develop a better understanding of interdisciplinary problems.

An Overview of Systems Engineering and Project Management

According to International Council on Systems Engineering (INCOSE), systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. INCOSE further defined a system as an integrated set of elements that accomplish a defined objective. Systems engineering focuses on the following problems while considering a solution:

1. Operations
2. Performance
3. Test
4. Manufacturing
5. Cost & Schedule
6. Training & Support
7. Disposal

According to the Handbook of Systems Engineering and Management, systems engineering is a management technology where management is the overlap between environment and organization and technology is between science and organization. Therefore, systems engineering is an overlap of all three elements and driven by information flowing through each

elements. The technical process of systems engineering involves defining system requirements, design, development and testing where the managerial process involves resource allocation, planning, monitoring, control, risk and change management.

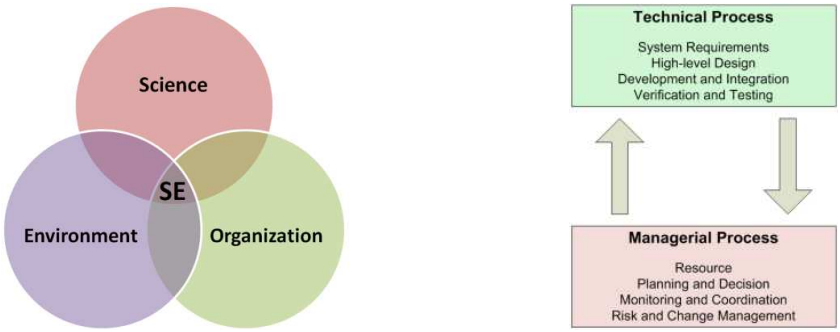

Figure 4: Systems engineering as a combination of science, environment and organization (a), technical and managerial processes of systems engineering (b)

According to Project Management Institute (PMI), a project is a temporary endeavor undertaken to accomplish a specific task or objective. By definition a project is time framed and must create a unique product or service, thus it is different than business operations. For example, establishing a customer service website for a large internet company can be considered a project where serving actual customers is business operations. The project is unique in the sense that it addresses specific needs of the internet company to serve their customers better. Repetitive tasks such as resetting password or answering common billing questions is not considered as projects. PMI defines Project management is a combination of knowledge, skills, tools and techniques and their applications in order to meet or exceed project goals defined at the beginning. Do these goals change as project goes along? Yes they often do, and that can make managing projects complex and challenging. In order to better organization of tasks and address uncertainty, a project lifecycle is divided into following five phases as illustrated in Fig. 5:

1. Initiation
2. Planning
3. Execution
4. Monitoring and Control
5. Closing

Each of these phases requires a combination of knowledge in the following nine areas:

1. Integration Management
2. Scope Management
3. Time Management
4. Cost Management
5. Quality Management
6. Human Resource Management
7. Communications Management
8. Risk Management

9. Procurement Management

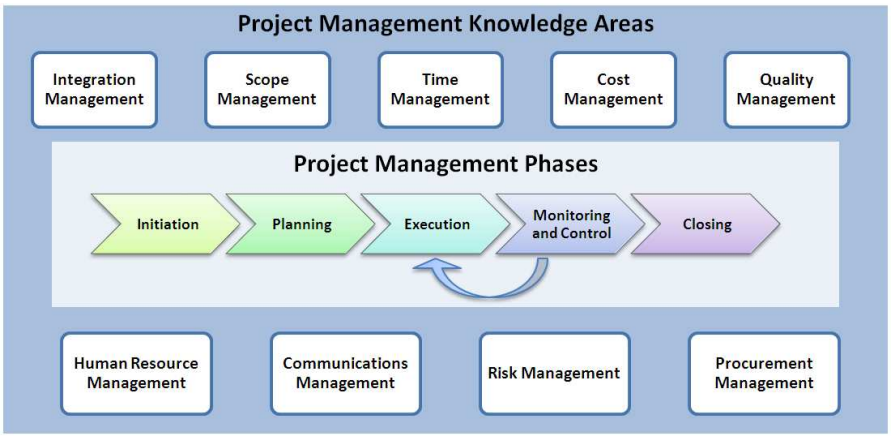

Figure 5: Phases of projects and knowledge areas as defined by Project Management Body of Knowledge (PMBOK)

Systems engineering and project management have some similarities as well as differences. As Considine describes in his article "Systems engineering & strategic project management", systems engineering focuses more on improving the product and process where project management emphasizes on delivering the product or service in time and maximize profit. Project management has been used for a long time in construction work before the knowledge was formalized.

Additional Helpful Tools

Many software tools are used in managing tasks and resources throughout development lifecycle. Once a large project or system is broken down into smaller sub-systems, task, sub-tasks and activities, they are sequences using Gantt chart. Gantt chart shows dependencies among project activities and very useful for estimating cost and duration of projects. Numerous free and licensed project management software are available for creating Gantt charts. Figure 6 shows a sample Gantt chart screenshot using Microsoft Project software package.

Another important method in critically reviewing project task dependencies and identify potential problem areas is called PERT (Project Evaluation and Review Technique). PERT chart help identifying the critical path of a project which is the longest path between tasks that a project might require. PERT chart is important for anyone responsible for on time and budget project completion as delay in any task in the critical path will delay the project. An example of PERT is given in Fig. 7 with the critical path marked in red. PERT is usually created from the same information as Gantt chart and also helps identifying important scheduling data such as the earliest start, latest finish, and slack time for each project activity.

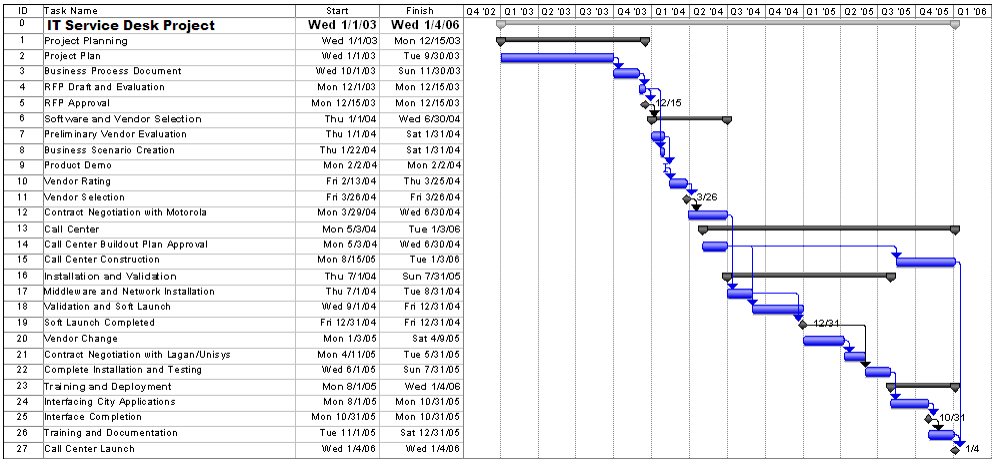

Figure 6: A Gantt chart screenshot displaying project task dependencies

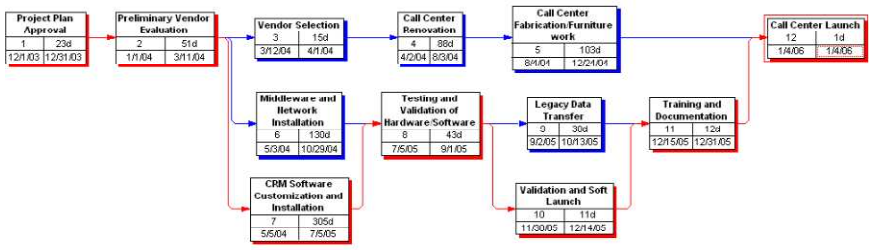

Figure 7: An example of PERT chart with critical path marked in red

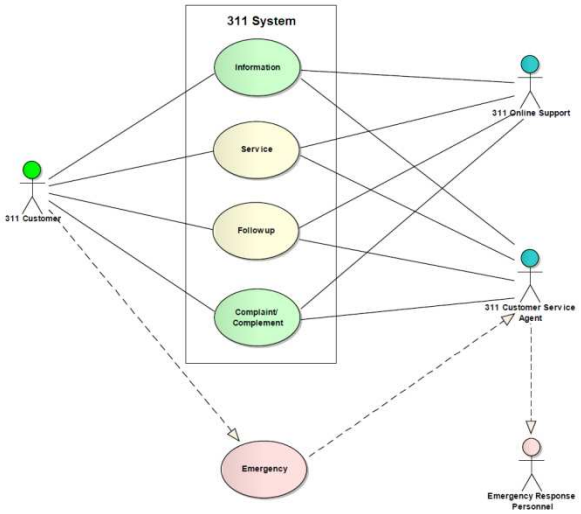

Figure 8: A use case diagram to illustrate user interactions with a system

Defining good requirements is a critical pre-requisite for any good system. There are many approaches for requirements generation depending on what type of project or system development is undertaken. Use case is a commonly used technique in systems engineering and

project management which illustrates how users interact with a system as given in Fig. 8. High level requirements are drafted from these interactions which are refined later to develop complex business and technical specifications.

There are many free and commercial software packages to create use case diagrams. NetBeans, and UML Pad are some open surce software tools for creating use case diagrams. Some examples of licensed ones are Enterprise Architect, Microsoft Visio, Rational Rose and Software Architect.

Conclusion

We aimed to highlight the fact that many engineering graduates are entering in other non-engineering fields as well as working in project environments. Early exposure of systems engineering and project management skills will provide freshmen students a sense of what real world problems will look like one they enter into the workforce. Classes can be designed with specific topics focusing on various engineering majors. Short projects or case studies can also enhance help freshman learning these concepts.

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