Study and Analysis of Best Practices for the Development of Systems Engineers at a Multi-National Organization

by

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ACKNOWLEDGEMENTS

Firstly, I would like to acknowledge the guiding factor that Prof Janice Klein has been in the formulation and development of this thesis. With such an open-ended problem, it would have been very difficult to structure this thesis without her help and guidance. I thank her for keeping me on my toes which ultimately resulted in the timely completion of this thesis. Secondly, I would like to express my gratitude and sincere thanks to the employees of Alpha Company who agreed to be interviewed by me and openly expressed their opinions. Without their support, this thesis would not have been possible.

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TABLE OF CONTENTS

Study and Analysis of Best Practices for the Development of Systems Engineers at a Multi-National Organization

CHAPTER 1 ......................................................................................................................... 7
SETTING THE STAGE: VALUE OF SYSTEMS ENGINEERS?................................................ 7
Motivation .......................................................................................................................... 7
Thesis Statement ............................................................................................................. 7
What is a system? ............................................................................................................. 8
What is Systems Engineering? ....................................................................................... 8
What Are Systems Engineers And Why Are They Needed? .......................................... 11
Research Methods ........................................................................................................ 15

CHAPTER 2 ................................................................................................................... 18
A CASE STUDY: ALPHA COMPANY .................................................................................... 18
Company Background .................................................................................................... 18
Value of Systems Engineering at Alpha Company ....................................................... 21
Systems Engineering Process at Alpha Company ....................................................... 22
Impact of Systems Engineering at Alpha Company ..................................................... 25
Systems Engineers at Alpha Company ........................................................................... 26

CHAPTER 3 ................................................................................................................ 31
DEVELOPMENT OF SYSTEMS ENGINEERS AT ALPHA COMPANY AND OTHER COMPANIES ................................................................................................................................................................. 31
Existing Efforts for Development of Systems Engineers at Alpha Company .................. 31
Development of Systems Engineers at USAF and NASA .............................................. 35

CHAPTER 4 ................................................................................................................ 37
RECOMMENDATIONS ..................................................................................................... 37
Development of Systems Engineers at Alpha Company: Two potential complimentary options ...... 38
• SEED (Systems Engineering Early Development)....................................................... 38
• SE-LDP (Systems Engineering Leadership Development Program).......................... 42

CHAPTER 5 ................................................................................................................ 46
CONCLUSIONS ................................................................................................................. 46
Topics for further research ............................................................................................. 47

REFERENCES .................................................................................................................. 48

APPENDIX A .................................................................................................................... 51
SAMPLE JOB DESCRIPTION OF SYSTEMS ENGINEERS AT VARIOUS BUSINESS UNITS OF ALPHA COMPANY 51

APPENDIX B .................................................................................................................... 54
PROPOSED TEMPLATE FOR DEVELOPMENT OF SYSTEMS ENGINEERS BY MICHAEL B. HARRIS .............. 54
CHAPTER 1

SETTING THE STAGE: VALUE OF SYSTEMS ENGINEERS?

Motivation

With the rapid growth of outsourcing in various industries, coupled with the increase in the technical complexity of the modern day products; it has become extremely difficult to put all the pieces together in an efficient and proper way. Whereas the product complexity is increasing exponentially, the likelihood of all the components of the product being developed at one location is becoming very remote. Additionally, the aggressive time-to-market strategies have demanded the product development cycles to become more efficient and innovative. All these factors have spurred the growth in what is called the systems engineering and systems thinking in general.

Systems Engineering began to evolve as early as 1950s in the military and 1960s in the commercial sector. It is considered to be still evolving and encompasses various fields ranging from requirements development, system modeling and simulation, software engineering, various levels of regulations analysis, environmental and social implications, cost and risk analysis, tradeoffs and project management – to name a few. Often thought of a project management disciple, it involves a great deal of quantitative analysis involving tradeoffs, risk-benefit analysis and integration of product components coming out of various engineering vertical segments.

Such a broad scope of responsibilities needs to be handled by a systems engineer. But do the companies have enough skilled systems engineers? The most probable answer is no. If the companies are not ready with the people with the right skill sets in order to thrive in a fast paced, multi-faceted and geographically dispersed product development team, then, do they have a plan in place to develop such skills within the organization?

Thesis Statement

The purpose of this thesis is threefold:
- Define the role and need of systems engineers/integrators within a large organization.
- Analyze the system engineering procedures and availability of systems engineers/integrators to fill the need within multiple business units of a large multinational corporation and recommend best practices for development of system engineers/integrators.

This thesis will investigate a product oriented company which operates in various market segments. This company, a manufacturer with a history of producing reliable and scalable
products, places heavy emphasis on systems engineering. This, in turn, creates the need for highly experienced and efficient system engineers/integrators.

**What is a system?**

Although the definition of a system can vary from person to person, a system can be viewed as an integrated set of objects that perform their functions independently and in conjunction with each other to deliver a certain value.

*A system is a construct of collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected. (INCOSE definition of systems, and this references Rechtin 2000)*

A system can be as complex as a nuclear weapon system or as simple as a camera. Understandably, the more complex systems need meticulous planning, solid methodologies and techniques in order for the system to perform seamlessly. But at the same time, the smaller systems need to be looked at with proper attention as well. In each of the above case, the product positioning in the market place might be completely different. A highly complex system might not need to be competitive in price, at least not in the beginning if it is an innovative novel product. However, a simpler system might be competing against similarly priced products from other competitors. In such a scenario, even though the complexity of the smaller product is far less but it still needs to be developed with; among other factors; scalability, cost and time-to-market in mind. Therefore, although different but methodologies and techniques still need to be applied to smaller systems as well to ensure its success and longevity in the market place. Thus, irrespective of the complexity and size of the system, system engineering techniques can still be applied.

**What is Systems Engineering?**

INCOSE (International Council on Systems Engineering) defines systems engineering as follows:

*Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:*
Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

As shown in the figure 1.1, systems engineering is the “glue” that holds all the other engineering disciplines together. Sitting at a higher level, systems engineering is concerned with effectively and efficiently integrating all other engineering verticals to ensure a system that delivers the promised value to the customer. The functions of systems engineering range from upstream to downstream processes and everywhere in between in the product development cycle. Its involvement begins as early as collecting and defining requirements and ends with the product eventual phase-out and disposal. Given the nature of functions that systems engineering performs, it is often viewed as an engineering management role as well and can be applied through various industries.

Figure 1.1: Positioning of systems engineering (source: George Mason University, 1997)
As shown in the figure 1.2, the systems engineering process is an iterative process of technical management, acquisition and supply, system design, product realization, and technical evaluation – beginning at the top. Many possible alternatives are discussed at each level and in the end the best suited system solution is selected. The detailed design and implementation at each level is primarily the responsibility of the product development teams at that level. However, the systems engineering team works closely with the development teams at each level to guard against deviation from the selected system solution.

The INCOSE systems engineering handbook, version 2.0, July 2000 defines the basic steps in the systems engineering process as:

(1) Define the System Objectives (User’s Needs)
What Are Systems Engineers And Why Are They Needed?

Since its inception, INCOSE has been trying to define systems engineering, systems engineers and the roles associated with the systems engineers. In the past, people performing the “systems-oriented” functions have been called the systems engineers. For the last few decades, the medium and highly complex projects have been “glued” together by people known as the systems engineers. These people have been also been often thought of as the “Program Manager” or the “Technical Project Manager”. Sheard [published in INCOSE proceedings in 1996] outlined the twelve roles that each systems engineer might perform. It is worth noting that a systems engineer might perform one or more of the twelve roles mentioned below, either partially or fully. It is a fair possibility that a systems engineer might not perform all the twelve roles in his/her entire career. Table 1.1 shows the twelve roles of systems engineers as outlined by Sheard.

<table>
<thead>
<tr>
<th>Role</th>
<th>Abbr.</th>
<th>Short Name</th>
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<tbody>
<tr>
<td>1</td>
<td>RO</td>
<td>Requirements Owner</td>
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<tr>
<td>2</td>
<td>SD</td>
<td>System Designer</td>
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<td>3</td>
<td>SA</td>
<td>System Analyst</td>
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<td>4</td>
<td>VV</td>
<td>Validation/Verification Engr.</td>
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<td>5</td>
<td>LO</td>
<td>Logistics/Ops Engineer</td>
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<td>6</td>
<td>G</td>
<td>Glue Among Subsystems</td>
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<td>7</td>
<td>CI</td>
<td>Customer Interface</td>
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<td>8</td>
<td>TM</td>
<td>Technical Manager</td>
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<td>9</td>
<td>IM</td>
<td>Information Manager</td>
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<td>10</td>
<td>PE</td>
<td>Process Engineer</td>
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<tr>
<td>11</td>
<td>CO</td>
<td>Coordinator</td>
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<tr>
<td>12</td>
<td>CA</td>
<td>Classified Ads SE</td>
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</table>

Table 1.1: Twelve systems engineering roles (Source: Sarah Sheard, published in INCOSE proceedings, 1996)

The twelve roles are briefly explained below. The source of these explanations is again Sheard’s publication on INCOSE proceeding in 1996.
1. **Requirements Owner (RO)** – “...This role groups several requirements-related tasks together. The first is translating customer needs into specific, well-written requirements to which systems and subsystems (subelements, pieces, software and hardware, control items, etc.) can be architected and designed. Requirements duties include understanding all external interfaces and ensuring the functional architecture correctly captures the need. …”

2. **System Designer (SD)** – “... An engineer in this role creates the high-level system architecture and design and selects major components. Possible ways of building the system from pieces are investigated and compared to the system requirements, the system design is selected and fine tuned, needs for the next lower subsystems are described in detail, and it is confirmed that subsystems that can meet the specifications are available or can be developed. Because of the complexity of projects employing systems engineers, the emphasis tends to be on architecture, high-level design, integration, and verification, rather than on low-level development. …”

3. **System analyst (SA)** – “…System analysts confirm that the designed system will meet requirements. Typical analyses include system weight, power, throughput, and output predictions for hardware systems, and memory usage, interface traffic, and response times for software systems. Usually the more complex parts of the system need to be modeled in order to demonstrate that they will work properly and interface properly with the external world. Modeling also helps the systems engineer and others understand how the system will be operated. …”

4. **Validation/Verification Engineer (VV)** – “…VV engineers plan and implement the system verification program to ensure the system, as designed and built, will meet the specified requirements. In some organizations, systems engineers also write the detailed system test plans and test procedures. During the system verification process, questions usually arise as to what was supposed to have happened during a scenario. VV engineers are responsible for answering these questions in real time and, to the extent possible, for predicting such behavior in advance. VV engineers also are required to respond to anomalies with the best possible understanding of the system design. They must also know which experts to call when needed. …”

5. **Logistics/Operations Engineer (LO)** – “…This role captures the back end of the "cradle-to-grave" or "lust-to-dust" system life cycle. During the operational phase, systems engineers sometimes operate the system for the customer; more often, they serve "on call" to answer questions and resolve anomalies. … In addition to owning primary responsibility in the later phases of programs, LO engineers are usually expected to bring maintenance, operation, logistics, and disposal concerns to the requirements, design, and development phases. As creators of users’ manuals, they need to understand most design aspects and all operational aspects of the system, and determine what users do and do not need to know about the system. …”
6. **Glue Among Subsystems (G)** – “...In this role, the systems engineer serves as a proactive troubleshooter, looking for problems and arranging to prevent them. Since many problems happen at interfaces, this role involves a very close scrutiny of interfaces, particularly internal, subsystem-to-subsystem interfaces. While the designers of the subsystems struggle to make their subsystems do what they are supposed to, the G systems engineer is watching to ensure that each subsystem is not going to interfere with the others. ...

7. **Customer Interface (CI)** – “...Systems engineers can be asked to represent the point of view of the customer, and to see that it is properly respected throughout the program. They can also serve as the interface to customer technical personnel in this role, striving to ensure the "right" system is built, and that the details are as customer-friendly as possible. ... The CI (Customer Interface) role includes only the role of the engineers building a customer-deliverable product, not the full marketing process of a business or organization. ...

8. **Technical Manager (TM)** – “...Technical management is one part of program management, which also includes controlling cost, scheduling resources, and maintaining support groups such as configuration management, computer network staff, and finance. The technical management part is sometimes assigned to a program systems engineering manager or to engineers responsible for the customer-deliverable system. ... As the reach of systems engineering extends to commercial companies, a type of systems engineer called the Product Manager or Product Engineer appears. This role is similar to a Systems Engineering Manager role, with authority over a much smaller group of engineers, maybe only one. On a small project, the Product Manager or Product Engineer may wear more of a marketing hat and more of a cost and schedule hat than technical managers on large programs wear. ...

9. **Information Manager (IM)** – “...Historically, some authorities have considered configuration management to be a systems engineering role. These are generally the authorities who lean toward the "program management" view of the systems engineering task. As information systems become more complex and more pervasive, it becomes more important for someone to view the overall information needs of the system, and even of the business. Thus, this role may grow to include data management and process asset management. ...

10. **Process Engineer (PE)** – “...This is a fairly recent systems engineering role. Those who do systems engineering are also expected to document, follow, own, and improve the projects and the organization’s systems engineering processes. This role also calls for defining and capturing systems engineering metrics. ... Recently the "reengineering" of industry has called for a cadre of "reengineers" to be developed, and those trained in systems engineering have sometimes been asked to participate, because the skills of designing a complex product can be applied to designing business processes as well. ..."
11. Coordinator (CO) – “...Because systems engineers have a broad viewpoint, they are sometimes asked to coordinate groups and resolve system issues, at least to the point of seeking consensus, or making recommendations, when consensus cannot be achieved among the participants. Even if there are no "systems engineers," coordination can be considered vital to the engineering of a complete system. This role may be permanent, defined in terms of team or discipline coordination, or transitory, established to solve a specific problem and then dissolved. …”

12. Classified Ads SE (CA) – “...This role was added to the first eleven in response to frustration encountered when scanning the classified ads, looking for the INCOSE-type of systems engineering jobs. Approximately half of the advertisements for "systems engineers" in a recent newspaper seemed to be asking for other things. For example, ‘... skills must include shell scripting, SQL, performance analysis, and network integration...’, ‘... five years of solid analytical & debugging expertise in a telecommunications environment...’, ‘... To analyze and develop systems level software in C/C++ and UNIX scripts’. …”

As previously mentioned, INCOSE has found it difficult to define systems engineering and systems engineers. The primary reason behind that difficulty is difference of opinion among subject experts and the resultant lack of consensus among them. Table 1.2 shows different roles of systems engineers as it appears in various INCOSE papers. It is presented here to depict the difficulty of defining systems engineers’ roles.
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▲=Primary assumption, ✓=Secondary Assumption

Table 1.2: Systems engineering roles apparently assumed in various INCOSE papers (Source: Sarah Sheard, published in INCOSE proceedings, 1996)

Research Methods

The majority of research was obtained through literature reviews and personal interviews. Various key personal at several business units of the organization were interviewed. The goal was to interview around five people from each business unit. The actual target fell a little short of the numbers goal but seemed adequate. The target personals have responsibility in hiring and/or mentoring systems engineers. Examples of such positions include Director/Manager in the Systems Engineering, Product Management, Systems support and services, and Human Resources. Several others, with similar responsibilities, were interviewed outside of Alpha Company, especially companies in other industries, to understand the development/training of systems engineers in that industry. A total of 60 interviews were conducted over the course of approximately 7 months. The first round of interviews started in October 2005 and continued until April 2006. Some of the interviewees were interviewed more than once during this time. In general, the number of interviews was roughly equally divided between the two segments of markets that Alpha Company operates in, i.e. Aerospace and Building Management. In addition, some people from the corporate and the central research unit were also interviewed which are not directly part of any aforementioned business segments.
A concise and highly structured questionnaire was prepared for the purpose of the interviews. A sample set of questions appear below:

- Nature of the product/business that you are involved in or have been involved with, with respect to system engineering?
  - Current role of interviewee

- Evolution of system engineering within the business -
  - How long has system engineering been in practice? What was the impetus for the creation of system engineering roles?
  - How it was before and how has it changed now?

- Role of system engineers/integrators –
  - What is the primary function that systems engineers/integrators perform? What are some examples (get them to be as concrete as possible) of issues systems engineers address?
  - How have the system engineers/integrators progressed in their careers? Did they start in some vertical segment first and then moved to system engineering/integration or did they start in system engineering/integration itself?
  - What other cross functional roles might they have held prior to becoming a system engineer? For example, business management roles, operations, marketing, finance? Also, do they move between businesses?
  - How does this role overlap/differentiate itself with technical product management?

- Staffing needs of system engineers/integrators –
  - Number of system engineers/integrators (per engineer or per major component, etc.) required? Is there a difference for new products vs. redesign or modifications to existing products?

- Background/training of current system engineers/integrators –
  - What is the background (education/experience) of current system engineers/integrators? Additional demographics would be useful, e.g., educational background, years of experiences, age, etc.
- What is the organization doing for continuous training of current system engineers/integrators? New junior system engineers vs. senior ones? Formal courses or on-the-job training?

- Desired qualifications for future system engineers/integrators –
  - Do the current system engineers/integrators seem well qualified or should the future system engineers have different qualifications?
  - What are the selection criteria for new system engineers? What is the source pool – internal or external?
  - What is the organization doing to hire well qualified system engineers/integrators?

- Impact of system engineering on product/business, in other words, has it made a difference? Could the product/business have done better/worse without system engineers/integrators?

This thesis is broken into 3 major categories. Chapter 2 discusses the existing systems engineering practice and the required skills by the systems engineering practitioners at Alpha Company. This chapter researches the need of systems engineers and their current availability at Alpha Company. Chapter 3 analyzes the methods already in place for development of systems engineers at Alpha Company. This chapter tries to establish the need for further actions for the development of systems engineers in the company. Chapter 4 proposes recommendations towards the goal of providing Alpha Company with a sufficient supply of well qualified systems engineers. Finally, the thesis concludes with chapter 5 which lists potential questions for further research.
CHAPTER 2

A CASE STUDY: ALPHA COMPANY

The following case study is presented to illustrate the usefulness of systems engineering and the complexities of developing systems engineering practitioners in a large multi-product multinational company. Today, there is a constant challenge of increasing the productivity through innovative means. Systems thinking has come to be identified as one such mean. However in diverse companies such as one presented here, a standard systems engineering process – the absence of which impedes the adoption - needs to developed and defined for it to be able to contribute towards increase in productivity. Additionally, the implementation and practice of systems engineering requires skilled systems engineers who should possess rare technical and multi-disciplinary skills. The case study will examine the evolution of both systems engineering as a practice and systems engineers at Alpha Company.

Company Background

Alpha Company is a multi-national diversified technology company. It provides products and services in the building and aerospace industries to customers around the world. The company operates as a holding company having several business units (BU), with each BU operating independently. As shown in figure 2.1, the President of each BU reports directly to the CEO of the company.

![Figure 2.1: Alpha Company top-level organization structure](image-url)
Each BU has organized itself independent of the other, depending entirely on its business needs. Therefore, the organization structure at and below the top management level varies from company to company. All of the companies have global presence, making them organize keeping the geographical locations in mind. Alpha Company operates at more than 4000 locations worldwide and does business in more than 180 countries. In fact in 2005, out of the total worldwide employee force of 220,000, 67% were located outside of United States. Another important consideration in the organization of each company is the business segment that it caters to. The 2005 business numbers reveal that 61% of the total 2005 revenues are generated outside of United States. All this, combined with the reality of ever changing labor costs, have forced companies to staff very differently from one another even though they are all part of one umbrella organization of Alpha Company.

Broadly, the company’s products range from air-conditioning/heating systems, elevators/escalators, electronic and fire safety, jet engines to aerospace systems. One can imagine the importance of reliability in all of the products; given the nature of the functions that each is expected to perform. Each product touches the aspect of human safety and therefore it comes as no surprise that Alpha Company takes the quality and reliability of the products very seriously. The company has a very clear vision on quality which states, as published in the quality mission statement and presented on the company website:

"...  
  o A quality-first mindset governs all Alpha Company employee actions.  
  o External and internal customers receive innovative products and services that completely satisfy life cycle requirements.  
  o Quality improvement is the job of every Alpha Company employee."

Traditionally, engineering has played a vital part in the company’s product strategy. The reason is not only the aforementioned quality and reliability but a long term focus of serving the customer better by delivering superior products and improving profit margins on each product.

As mentioned earlier, Alpha Company is a holding company with several business units. However, most of the businesses can be divided into two categories: Aerospace and Commercial building management. It is worth noting that the company started off in the aerospace sector in its early days. It grew in the aerospace segment jointly by organic growth and acquisitions. On the other hand, the entry and growth into the commercial building management business has been led by acquisitions. However, it must be mentioned that currently there is a strong emphasis on organic growth with acquisitions to help plug the gaping holes in the product/services offerings. Formation of a new business unit in the commercial building management segment through acquisition is such an example. Given the different nature of the businesses in the two broad businesses; aerospace and commercial building management; the need for the practice of systems engineering has also been different.
Aerospace companies have very strong business relations with other companies such as NASA, Boeing, Raytheon, Rolls Royce, GE and Lockheed Martin etc. in the same sectors as partners, customers and competitors. These Alpha Company businesses need to cater the needs of large systems integrators such as Boeing and have to be flexible in their product/solutions offerings so that interoperability with competitors is not an issue. This has made the systems engineering practice at the aerospace businesses at Alpha Company a necessity. Although adopted as a practice, interviews indicate that systems thinking in these businesses have been far from satisfactory. One interviewee who works in one of the aerospace businesses said: “[we] took a long time to realize that the most beneficial business model was to offer jet engine solutions comprising of low to nil upfront costs, better warranty and lower repair costs along with reliable engines and not necessarily selling the most powerful and highest performing engines”. Although the above example does not necessarily illustrate the problems with systems engineering but more on the systems thinking, it is evident that it took some time before the systems thinking culture sunk in at the aerospace sector of Alpha Company. Even after the realization and adoption of systems thinking in general and systems engineering in particular, the businesses are still trying to find the best practices in the area of systems engineering.

The businesses in the commercial building management segment have adopted and implemented the systems engineering practice as needed. Perhaps driven by the business need, there is an example of the one of the commercial building businesses pursuing systems engineering almost in the same mould as the aerospace companies. On the other hand, there are examples where systems engineering has not been adopted until very recently. One of the reasons that Alpha Company has been slow to adopt the systems approach could lie in the fact that the company itself never thought itself as a systems integrator. It grew through several acquisitions and each acquired company had its own culture. Most of them thought themselves of selling products rather than services. This culture prevailed long enough to delay the adoption of systems thinking into the organization as a whole. Given that the company now takes systems engineering very seriously, all that seems to be a thing of the past. There appears to be a growing realization of the importance and need for systems engineering across all the businesses in both the aerospace and building management sectors.

One of the identified problems has been thorough knowledge of the systems engineering procedure and systems engineers’ role across all the businesses. With that in mind, Alpha Company has published a “Alpha Company Systems Engineering Guidebook” with a goal to define and recommend the necessary and sufficient systems engineering processes and practices for implementation - to help achieve Alpha Company’s enterprise productivity goals. As an interviewee from one of the aerospace businesses pointed out “[A documented standard systems engineering process] was needed to have it serve as a training aid in some of the business units. At the time [when efforts were underway to prepare the Alpha Company systems Engineering Guidebook], only a few of the BU had real system engineering positions and the other BUs were attempting to get started. It became a method of familiarizing the BU with the best practices and helping them instantiate the practices. The process also provided the opportunity for System Engineering to get ‘kick started’ more effectively within Alpha Company.”
Value of Systems Engineering at Alpha Company

Addressing an internal engineering conference in 1997, Alpha Company President and CEO stated that:

“…Alpha Company is more than just a financial enterprise...They [the financial numbers] are results of everything else we that we do. Many management teams focus on the results and don’t pay attention to the causes. We are where we are because we paid attention to the causes, one of which is engineering. If engineering is not right, it’s over. That’s why your [engineering] function is so critically important ...”

Expressing the challenge he made at another conference in 1992, Alpha Company President and CEO said:

“… We are big, powerful, effective spenders, but I think we can do better than we do in terms of time to market and engineering productivity, and in terms of really perfect products that work right the first time, every time, which has to be the goal of engineering. And so my challenge to you is to talk...about the issues of productivity, time to market, and rework. And you tell me how to make, for all of us, significant, significant gains. I don’t mean something as little as 10% or even 20%. We need to increase engineering productivity a great deal because the real issue is competition from people who are potentially dramatically better than we are today....”

In 2000, Alpha Company came up with the first of its series of volumes describing the various aspects of systems engineering as applicable to Alpha Company called “Alpha Company Systems Engineering guidebook”. It states that:

“…Alpha Company SE Process describes the SE Process as one of the three system processes, the other two are integrated Product Development and Program Management. All three are required for successful product development, operations, support and disposal. …”

As stated in the “Alpha Company Systems Engineering Guidebook, 2000”, Alpha Company has promoted systems engineering in particular to realize the above goals. In turn, systems engineering realized the above business goals by ensuring to:

- Build better products – A product’s performance and life can be enhanced by adopting systems engineering methodologies and management as well as performing root-cause analysis during problems to ensure the solution of the problem at the root level.
• Reduce product development and time-to-market – Systems engineering can use several techniques available, such as domain engineering, re-use and platform engineering – to name a few, to expedite the process of product development and reduce the development costs as well without compromising the product quality and reliability at any stage.

• Reduce overall product cost – By reducing the overall product cost through reduced product development and product lifecycle costs, the product can be made more competitive in the marketplace without sacrificing profit margins. Systems engineering can reduce manufacturing costs by proper architecture and design, use of standard parts and processes, and appropriately sizing system complexity.

• Reduce warranty costs – When a product fails to perform as per the specification, the company has to spend money to fix the problem(s), thus, hurting the operating profit margins. These costs can be reduced by better product design and proper testing at the component as well as at the system level.

• Reduce field (installation/service) costs – Designing systems that can be easily installed and are easy to service in the field reduce the time that the engineers have to spend in the field on each product. Thus, systems engineering again plays an important role in achieving this goal by designing more modular and easily replaceable system.

**Systems Engineering Process at Alpha Company**

The importance of systems engineering in the company’s revenue and profit margins has already been discussed earlier. However, systems engineering adoption really began to pick up only in the 1990s. Also, there was a lack of understanding about the systems engineering process and how to maximize its use for increase in engineering productivity. Therefore, given the relative newness of the concept and lack of a structured procedure, it was important to suggest standardized systems engineering process. As discovered during the interview process, most if not all the groups responsible for systems engineering follow a similar process described in this section. That’s not to say that the groups do not have the flexibility to change the process to suit their needs. In fact, most of the groups have made the necessary modifications and use the suggested process as a guideline.

As shown in figure 2.2, Alpha Company Systems Engineering Guidebook 2000 suggests the systems engineering at Alpha Company as a seven-step process:

1. **Process Inputs** – Process inputs are the key ingredients to the iterative steps embedded in the systems engineering process. It is divided into two categories:
   a. The first is the initial set of product requirements. It may contain inputs from sales, marketing, customer surveys, benchmarking activities, regulatory and environmental bodies, strategic and tactical teams.
b. The second set of inputs is developed from the iteration of the earlier set. Thus, the input of the next set of inputs is generally the output of the previous set of inputs with the addition of new requirements.

Consider the 12 roles of the systems engineers described earlier. The person performing this role could either be the Requirements Owner (RO) or the Customer Interface (CI).

2. Requirements Analysis – Requirements analysis defines the boundaries and constraints of the system and is the first step of formal requirements definition. It is the process of collecting requirements as driven by the various aforementioned factors. The key step is to provide a set of traceable requirements, the fulfillment of which will become the baseline for the program success. It’s important to note that the requirements analysis will determine *what* the system will do, not *how*. Therefore, the functional and performance requirements are defined, negotiated and refined in this step. A good requirements analysis will also identify the criticality and sensitivity of each requirement. The Requirements Owner (RO) systems engineer is expected to don this role, although certain overlap with the Customer Interface (CI) can not be ignored.

3. Functional analysis and allocation – Functional analysis is the early examination of the requirement specification, as defined during the requirements analysis. One can think of this step as the high level feasibility study of the requirements. This leads to the composition of sub-functions (with the required internal and/or interfaces) required to perform the functions defined in the requirements. Functional analysis should investigate all aspects of system, including development, production, deployment, support, logistics, maintenance and operations. The latent benefit of performing functional analysis at this stage is uncovering or unearthing of missing, unclear or unrealistic requirements. Among the 12 systems engineers, the one most likely to perform this role is Systems Designer (SD) with possible assistance from the Technical Manager (TM).

4. Synthesis – Synthesis helps create the system architecture to the satisfaction of the requirements and known constraints. The Alpha Company Systems Engineering Guidebook 2000 states:

> “...Synthesis transforms the functional system to a physical system composed of elements called configuration items (CIs). Synthesis supports design and test engineering, system integration following component and sub-system development, and “logistics” activities for downstream engineering and deployment.”

Systems Designer (SD) appears to be the logical choice for this role too. Again, a senior systems engineer such as a Technical Manager™ could very well perform this role too.

5. System analysis and control – The system analysis and control serves to provide the risk assessment of the system and offers a way to monitor the progress of the
program. It also provides an opportunity to continuously measure the program objectives against the requirements, especially cost and take corrective action(s) if needed. The analysis ranges across most if not all aspects of the system, including development, production, deployment, support, operations, disposal, training, and life-cycle-cost.

The System Analyst (SA) and Process Engineer (PE) could be the two obvious choices among the systems engineers to perform this role.

6. **System Verification** – This is a major part of the entire systems engineering process. System Verification is performed inspection, analysis, demonstration and test methods. This step ensures whether the system meets all the specified requirements agreed upon in the initial stages or not. System verification plays an extremely important role in determining the success of the program. Even though the individual components or modules may be performing to their specified requirements, it is possible that the system as a whole is not. No wonder every organization should give high importance to this stage in systems engineering process.

Without a doubt, the most obvious choice for this function should be the Verification/Validation (V/V) systems engineer.

7. **Process Outputs** – At the culmination of the systems engineering process, there is a series of technical as well as management outputs that need to be captured regardless of the success of the program. Ideally, it should include the program requirements, mission requirements, constraints, obstacles during the program and their resolutions, lessons learned, etc. It is essential to capture such information in order to plan for the next related program. Sometimes, the end point of one program may simply act as the start point of another. In such a case, such process outputs are of extreme value.

Most if not all systems engineers could be involved in this activity. The Technical Manager (TM) is the one who is certainly expected to be its part, perhaps along with others such as Information Manager (IM).

It is worth noting that systems engineers such as Glue among subsystems (G), Coordinator (G) and the Technical Manager (TM) are expected to be involved in multiple, perhaps all of the program.
Impact of Systems Engineering at Alpha Company

Everyone interviewed felt that the systems engineering has made a tremendous impact on the organization. In a company such diverse and geographically dispersed as Alpha Company, one common language of systems engineering has worked well to develop systems of increasing complexities and performance. Not only the technologies have grown exponentially in complexity but the businesses themselves have grown extremely
complex. Systems thinking in general and systems engineering in particular has helped the company to realign itself from being a seller of multiple products to seller of systems and services. In the age where partnerships and collaborations are essential to success, systems engineering helps define and manage the interfaces with external partners. Combine all these with the fact that the corporations need to reduce cost, time-to-market and improve product offerings with better, more reliable and higher performing products while still improving profit margins. Systems engineering at Alpha Company has helped achieve all of the above goals to increase revenue and reduce operating costs.

Systems Engineers at Alpha Company

Systems engineers at Alpha Company are considered to be among the top engineering talent available in the company and have the rare multi-disciplinary skills. At Alpha Company, systems engineers do not necessarily have to be staffed in a group called “systems engineering” to be a systems thinker. In fact, although many business units have such groups called “systems engineering”, the systems engineers are spread in multiple different groups as well. Even in the other departments such as components, controls, etc. the systems thinking is encouraged. It’s not uncommon to find a components or a controls engineer calling himself a systems engineer at Alpha Company. Such thinking can be positive for the quality and reliability of the system/product. If there is system level thinking even at the component and the sub-system level, the chances of success of the system as whole increases.

However, there is a general consensus within the company about the value and dearth of the good systems engineers. Although most of the business units have a set of 30-50 systems engineers to boast, there are a couple of business units who can not make that claim. In general, people have expressed concerns about lack of genuine systems engineers in the company at each business unit. One interviewee from one of the commercial building businesses said that “Even components engineers in the controls, belts etc. division think that they are systems engineers. While it’s good that people think about systems even at the component [subsystem] level but what we really need are people who understand the products at the system level”. Another interviewee from a company in the aerospace sector said “We lack quality systems engineers so much that we are reluctant to let them take time off to pursue full-time school for a higher degree while still being employed, although we know that that’s [letting them pursue higher education] the right thing to do.” Some businesses give it more importance than others. The aerospace companies are seen to care more about system engineering and system engineers; although the same can also be said about the commercial building BU that has embraced system engineering. The ratio of a system engineer vs. an engineer is seen to be inadequate at current level. For example, in one business unit operating in the aerospace sector there are around 40 system engineers/integrators in a total engineering workforce of 2000. Of course the ratio varies between different business units but it falls short in comparison to other companies in same industries. Comparing with Lockheed Martin for instance, another systems integrator operating in the aerospace sector, the corresponding ratio is nearly one system engineer/integrator per every four engineer. The late adoption
to formal systems engineering practice at Alpha Company could be one of the reasons for insufficient pool of systems engineers as compared to some other system integrators such as Lockheed Martin, Raytheon and Boeing. Systems engineering began to be taken seriously in the 1990s at Alpha Company while it was prevalent much earlier at the aforementioned competing aerospace companies. In fact, some of the businesses within Alpha Company have not taken systems engineering very seriously till even today although it should be mentioned that none of them operate in the aerospace sector of business. However, the signs are emerging that the thinking is changing at these business units and a sincere effort is being made to adopt systems thinking at these business units.

Given the nature of the job function that a systems engineer needs to perform, it’s not hard to understand why there is a huge difference between the demand and supply of the system engineers/integrators. Table 2.1 lists some of the characteristics of a systems engineer.

<table>
<thead>
<tr>
<th>EDUCATION:</th>
<th>ON-THE-JOB TRAINING:</th>
<th>MANAGEMENT SKILLS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ability to Understand Multiple Disciplines</td>
<td>1. Hands-on Hardware Experience</td>
<td>1. Ability to See &quot;Big Picture&quot;</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>RESPONSIBILITIES:</th>
<th>ATTITUDES WITH PEOPLE:</th>
<th>ATTITUDES TOWARD WORK:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Early Responsibility</td>
<td>1. Good Communicator and Listener</td>
<td>1. Learns Independently</td>
</tr>
<tr>
<td>2. Work in Several Technical Areas</td>
<td>2. Can Communicate to all Management Levels</td>
<td>2. Willing to Take Risks</td>
</tr>
<tr>
<td>3. Ability to Produce a Product (On Time, In Budget)</td>
<td>3. Patient, Curious, Honest, Friendly</td>
<td>3. Willing to Take Responsibility</td>
</tr>
</tbody>
</table>

Table 2.1: Characteristics of a systems engineer (Source: George Mason University)

Some sample job postings for the systems engineering positions at various business units at Alpha Company are shown in appendix A. It should be noted that the positions are for
different levels of responsibilities, therefore, the experience required for each may vary significantly from one to another. As can be seen from these postings, none of them are entry-level positions, something that everyone agreed upon during the interview process. All of the people interviewed were of the opinion that the systems engineering positions are not meant to be entry-level engineering jobs. They are considered to be highly responsible and viewed with a fair degree of respect. The systems engineers, before being hired as one, are expected to have spent a few years in at least one application. Some interviewees suggested more than one, at least two applications experience before being tasked with the responsibilities of a systems engineer. Although some of the interviewees did not rule out the possibility of hiring a fresh engineering graduate for the role of systems engineering, but that percentage is a very low number. Thus, it is very common to see an engineer start his/her career in a vertical segment of engineering before donning the systems engineer’s cap. One interviewee even suggested that “Software engineers often make a good systems engineer. ...The reason being the complexity of the software systems. ...Someone who starts dealing with as complex system as software system early in his/her career develops the skills needed to be a systems engineer.”

As described earlier, the systems engineers are the set of engineers who wear different hats at different times. One such hat is having the ability to interact with several others, including non-engineering people. They may be expected to develop and foster relationships and be socially active if needed to maintain that relationship. Of course, this is in addition to being very strong technically and functionally. Apart from this aspect, the systems engineer should be someone who is capable of looking at the “big picture”, something that not everyone is even capable of. Moreover, the systems engineers need to have certain degree of leadership skills. Considering everything, it is felt that a good engineer with a few years of experience and the exposure can then make a more successful transition into the systems engineering role than the one without experience.

Table 2.1 can be expanded to reflect the characteristics of a systems engineer at Alpha Company, as shown in Table 2.2. Expectedly (not shown in the table 2.2 but in appendix A), on-the-job training section differs among different businesses with some differences in the basic educational requirements as well, but the characteristics in the areas of management and people skills remain largely the same across all the businesses.

<table>
<thead>
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<td>1. Ability to Understand Multiple Disciplines</td>
<td>1. Hands-on Hardware Experience</td>
<td>1. Ability to See &quot;Big Picture&quot;</td>
</tr>
<tr>
<td>3. At least B.S. degree (higher degree like M.S. / M.B.A. preferred) in the related technical field</td>
<td>3. Knowledge of / Experience with understanding customer requirements,</td>
<td>3. Understanding of Program Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Risk assessment and mitigation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Ability to take</td>
</tr>
</tbody>
</table>
defining system requirements, and validating those requirements

4. Knowledge of / Experience with functional decomposition, system design, reliability and sensitivity analysis

5. Experience with requirements management tool such as DOORS and simulation tool such as Matlab / Simulink

RESPONSIBILITIES:

1. Early Responsibility
2. Work in Several Technical Areas
3. Ability to Produce a Product (On Time, In Budget)
4. Ability to document and present various levels of details depending upon audience

ATTITUDES WITH PEOPLE:

1. Good Communicator and Listener
2. Can Communicate to all Management Levels
3. Patient, Curious, Honest, Friendly
4. Ability to work well in team(s)
5. Ability to interact with outside partners, suppliers and customers

ATTITUDES TOWARD WORK:

1. Learns Independently
2. Willing to Take Risks
3. Willing to Take Responsibility
4. Disciplined
5. Not Parochial
6. Pragmatic
7. "Can Do" Attitude
8. Adaptable
9. Flexible to travel as needed

Table 2.2: Characteristics of a systems engineer at Alpha Company

As seen from table 2.2, the systems engineer is expected to have such an extensive set of skills. Such skills can be “home-grown” within the organization or can be hired from outside. The “home-grown” option has an obvious advantage of reducing or even eliminating the learning curve of the application(s) when compared to outside hire. At the same time, this option means that organizations, including Alpha Company, will need to develop certain methods to develop systems engineers internally, a topic of discussion in the following chapters.
This chapter discussed the needs in terms of systems engineering capabilities for each market segment of the organization, aerospace and building management. Although the needs have generally been found to be the same across both the segments, the aerospace sector seems to have taken a head start in implementing systems engineering practices. The implementation varies in the building management sector. While one company has nearly competed with its counterparts in the aerospace sector, another one has been slow to adopt and is beginning to start the process now. Obviously, this means that although most of the businesses are nearly at par with each other in terms of implementing systems engineering capabilities and developing systems engineers for future, one particular business unit lags behind.

Chapter 3 discusses the efforts that Alpha Company has already taken to grow the systems engineers internally and areas where these efforts fall short. Chapter 3 also recognizes that Alpha Company is not alone in facing this problem but others such as NASA and US Air Force are in similar situation.
CHAPTER 3

DEVELOPMENT OF SYSTEMS ENGINEERS AT ALPHA COMPANY AND OTHER COMPANIES

Systems engineers are considered to be among the most valuable engineering talent available at Alpha Company. Given the importance, it is imperative that the company creates an atmosphere where systems engineers can be developed and groomed. As seen previously, the company’s current strength of systems engineers falls short of the desired number. Although the units in the aerospace sector seem to be doing better than the building management units, the interviews indicate that a more structured method for the development of systems engineers needs to be in place. This chapter will discuss the existing efforts in the development of systems engineers at Alpha Company. It will also discuss some efforts in other organizations such as United States Air force (USAF) and NASA and try to apply the learning from them.

Existing Efforts for Development of Systems Engineers at Alpha Company

Alpha Company recognizes the importance of having an educated workforce. Perhaps that’s why it has a widely acclaimed program called the “Employee Scholar Program” that pays 100 percent of registration and tuition at qualifying schools, required academic fees and course-required books. Not only this, the company also allows the working students to receive up to 50 percent of the total credit hours for all courses taken in an academic period as paid time off for studying, to a maximum of three hours per week. The company further rewards its employees by granting them company stocks, with varying numbers depending upon the degree. "Our goal is to have the best educated workforce on the planet" said Alpha Company Chairman announcing Alpha Company's Employee Scholar Program – clearly demonstrating the willingness of the company’s top management to fund employee education.

At Alpha Company, the efforts have been continuously made for the development of systems engineers for the past decade. Part of the continuous includes interactions among the systems engineers in the company and between the systems engineers and academic scholars outside. The Systems Engineering section of the Alpha Company learning portal\(^1\) states that:

> “This [systems engineering] area brings together numerous resources from across Alpha Company and external sources to facilitate exchange of System

\(^1\) Alpha Company Learning Portal is an internal web-site designed to fulfill the learning needs of the employees. It is a one-stop site for employees to manage their participation in the Employee Scholar Program and take on-line courses on a variety of topics.
Engineering information, educational offerings and related opportunities of interest.

As a competency area of strategic advantage for Alpha Company, the Alpha Company Technical Council, System Engineering Curriculum Team, and Alpha Company Learning and Development team have collaborated on educational solutions to strengthen, drive best practices, and promote cultural change in this discipline through education.

Our curriculum team consists of subject matter experts from each Alpha Company business unit, and partners with high caliber educational partners like MIT, RPI and USC to offer a unique blend of educational opportunities which maximize impact and best practices for our workforce.”

Alpha Company also makes efforts to train its engineers in the field of systems engineering. It has teamed up with some of the best institutes in US\(^2\) to make courses on systems engineering available to its interested employees. Employees can choose between a M.S. degree and a certificate program, some of which are also available via long distance education. The different programs offered are:

- **Degree Programs**
  - Massachusetts Institute of Technology (MIT)’s MS in System Design and Management – An available long distance program, jointly sponsored by MIT’s Sloan School of Management and the Engineering System Division within MIT's School of Engineering with 20 industry partners.
  - University of Southern California (USC)’s MS in System Engineering and System Architecture - Web based Master's program in System Engineering and System Architecture within the aerospace industry.
  - Rensselaer Polytechnic Institute (RPI)'s custom MS in Engineering Science - A customizable Master's program in engineering disciplines tailorble to Alpha Company student’s needs to allow for interdisciplinary study.

- **Certificate Programs**
  - Massachusetts Institute of Technology (MIT)’s Certificate in System Engineering - A one year, three course program which combines curriculum from MIT’s School of Engineering and Sloan Business Schools.
  - University of Southern California (USC)'s Certificate in Systems Architecture and Engineering – A five course online certificate program with an aerospace focus.

\(^2\) According to US News 2007 ranking of America’s best graduate school in engineering
Note: The above mentioned schools are not the only available choices. Alpha Company employees have chosen other educational institutions; such as Stanford, University of Virginia, George Mason University as well for further studies in systems engineering.

Although evident from above, the company has made available some facilities for the development of the entire workforce. Also is evident from above that some special attention has been paid to the development of systems engineers as well and consequently programs such as the ones mentioned earlier have been put in place. However, issues still remain.

**Issues:**

- **Going back to school is not an option for everyone:**

It is worth noting that the availability of such programs alone does not make it possible for candidates to pursue education in systems engineering. There are various other factors, the two most important of which are family and work-school balance. Although all the offered programs are career compatible, the organizations may not always be willing. In the time of economic downturn in the US economy, organizations were less willing to let the employees take time-off for education. This is evident from the fact that company-sponsored candidates participation fell dramatically during 2000-2005. As one interviewee, who is an engineering manager, said “...[I] can’t afford to send someone off to MIT for one full semester at this time [of economy] ....” It is worth noting that although promoted as a distance learning program, MIT SDM degree program requires students to attend at least one full semester on campus, apart from requiring them to attend six business trips which are one-week long each. The employees themselves may find it hard to go back to school while working full-time and may find it hard to adjust in the new environment. Senior engineers, who would be the best suited to pursue one of these programs, may have families. An engineer who wanted to pursue the SDM Master’s program but settled on the certificate program said “...I am not sure if I can go through the rigors of a [MIT] degree at this stage [of life] – with a working wife and kids. ... Instead the certificate program looks more doable” Although those who have succeeded in completing the program provide positive feedback about the experience and the opportunities after graduation but as can be felt in the above example; sufficient deterrents exist to join one of the aforementioned educational programs.

- **Lack of a structured grooming process for systems engineers:**

As one interviewee, who is involved in the development and learning of all Alpha Company employees at the corporate level, said “A lot of people want to move into systems engineering. Although there is no defined roadmap for systems engineering career path yet, it is seen as a stepping stone for getting into the roles of technical managers.” This was confirmed by most of the people interviewed who noted that they have been developing their skills in systems engineering on the job. Engineers working in vertical departments admit to having a desire to move to systems groups.
They see that transition becoming a possibility by trying to over-perform in their current role and assume leadership tasks wherever possible. One interviewee said “...I think of myself as a systems engineer even though I work in the belts department. While working on [this] component I think of the product as a whole which enables me to capture better requirements.” Similarly, another interviewee recently hired as a systems engineer who worked for six years in a component manufacturing plant in one of the aerospace companies, said “...[Even though not a systems engineer] I wrote such good requirements for the [current] project that it impressed the interview panel [of the system engineering job].” As discussed previously, Alpha Company learning portal offers a few courses on the subject as well which people have used to gain the preliminary knowledge. But there is a lack of a process under which systems engineers can be further groomed in their skills or components engineers can be groomed and transitioned into systems engineering.

- **Lack of development of systems engineers in multiple applications:**

The problem of lack of systems engineers has been discussed previously. What makes this problem more acute is the fact that there is no pool of qualified systems engineers who have experience in both the aerospace and building management industries – who could be called upon as and when needed. Of course, the first step is to fill the gap between the demand and supply of the systems engineers within a particular industry segment, rather particular business unit, first but the overall vision should be to develop a pool of systems engineers who can fit in both the industries well. Although the product lines differ within the two industries that Alpha Company operates in, the exposure and experience of working in both the industries will help them be better systems engineers in whatever industry they are chosen to work on at any given time. As an interviewee from an aerospace company said “...[a building management company] is going to find it hard to implement systems engineering in the beginning (something that this company is looking to start). [It] will probably look to systems engineers from other [Alpha Company companies]. They [systems engineers in other companies] can not be expected to be productive at once.” When queried further, the interviewee further said “The experience gained by [the transferred] systems engineers at the new company will broaden their systems engineering skills. They not only will apply the skills [they learnt] from their current companies to the new ones, they will be more useful if they come back to the old organization as well.” This is an example to illustrate that having an approach of developing systems engineers for multiple applications serves two purposes: It produces better systems engineers and provides a pool of qualified systems engineers to rely upon whenever needed.

The aforementioned broad issues mean that Alpha Company is unable to fill the gap between the need and supply of the systems engineers. As one interviewee in the building management business noted that “... [The current] rate of ‘graduating’ engineers into systems engineers is lower than desired. ... more can be done”. Similar concerns were voiced by people interviewed across both the business segments. Thus, this problem is
seen as one sweeping the entire company as opposed to any particular business or business segment.

**Development of Systems Engineers at USAF and NASA**

The problem at Alpha Company is not unique. Others have either been in the situation before or are beginning to be in one now. Several renowned organizations today understand the need to develop technical leadership skills within the organizations. Most of them are starting to realize the importance – with some of them already prepared with plans – to develop the next generation of engineering workforce to take over the technical leadership roles. US Air Force (USAF) and NASA have faced this problem and have attempted to solve it; something that a company like Alpha Company can learn from and possibly adapt with necessary modifications. The efforts at USAF and NASA are described briefly below:

- **US Air Force Center for Systems Engineering (CSE) Rotational Systems Engineering Development Program** –

  The USAF CSE states the following about the above program (obtained from the website: www.afit.edu/cse)

  “The Rotational Systems Engineering Development program has been established to help advance development and cross fertilization of systems engineering throughout Government, Industry and Academic institutions.

  In this program, parent organizations agree to establish Operating Locations at the Center for the rotational candidates. Personnel assigned to rotational positions will participate in all aspects of the CSE and will propagate systems engineering knowledge and experience between the parent organization and the CSE.

  These rotational positions are career broadening positions that are intended to increase the knowledge and experience of the participant, provide a systems engineering clearinghouse for USAF program offices and to infuse the parent organization with future systems engineering expertise. The targeted personnel for this rotational program are mid-level professionals, typically between 7-15 years of experience, typically General Service grades 13 to14, military grades O-4 to O-5 and industry equivalents are sought. While the exact length can be variable, it will be expected that the participant will typically be assigned to this program for 12-24 months.

  This program provides a mutually beneficial Systems Engineering experience to the participants, their sponsoring organization, and the Air Force.”

- **NASA Systems Engineering Development Process (SEDP)** –

35
At the agency level, NASA is currently attempting to put together a plan called the Systems Engineering Development Process (SEDP). As stated on NASA’s Academy of Program Project and Engineering Leadership website (appel.nasa.gov):

“The Systems Engineering Development Process (SEDP) is a roadmap to provide career training and development opportunities for agency program and project managers through a sequence of professional experiences, courses, and other strategies that support individual career goals and Center activities....

The overall objective of the Systems Engineering Development Process (SEDP) is to provide a strategic and tactical approach for systems engineering development for individuals, Centers, and the Agency....

The SEDP career development process is one in which employees develop and implement individual development plans based on an assessment of themselves within the context of the organization. Successful career development involves a partnership between the employee, the manager, and the organization. In order for SEDP to be effective, employees will need the support and involvement of their managers and mentors, Center leadership, and others throughout the Agency...

From the practitioner’s perspective, there are five steps in the NASA career development process which are: 1) self-assessment; 2) exploring the NASA environment; 3) setting goals; 4) planning development strategies; and 5) executing....”

The SEDP is still under development and according to the systems engineer responsible for its implementation, the first phase is expected to be rolled out around October 2006. Therefore, it is too early to know its advantages and disadvantages. But NASA’s three individual centers; Goddard Space Flight Center, Jet Propulsion Laboratory and Ames Research Center; have implemented similar programs in the recent past. Although the success of these programs is confidential information, it is probably safe to assume that the lessons learned and best practices out of each will be best utilized for SEDP.

As seen from above, Alpha Company is among a few large organizations trying to find a suitable solution to this growing problem. Alpha Company has some options for the development of systems engineers but fall short of the desired goal. Others, as discussed earlier, have taken a few proactive steps that Alpha Company can learn from and leverage. Chapter 4 addresses the issues identified in this chapter at Alpha Company and makes a couple of recommendations.
CHAPTER 4

RECOMMENDATIONS

Alpha Company realizes that being primarily a high technology product driven company, it needs an excellent engineering workforce - which it can boast of. Among the talented and experienced workforce are the systems engineers who – a previously discussed - have been established as key members to introduction of new products as well as sustaining of existing products. It’s the availability of the systems engineers that has been demonstrated as a source of concern. Given the different kinds of skills set required to perform the duties of a systems engineer, it is not surprising to see the company struggle to reach the desired number of systems engineers. As seen earlier, a systems engineer not only needs to be strong in the technical/functional area of the application but he/she needs to possess the multidisciplinary skills as well as the rare skill of being able to see the “big picture” while still paying attention to details.

Alpha Company realizes the need for need for having an educated workforce and strives hard to fulfill that. Also discussed is the company’s unmatched policy of providing educational assistance to all its employees for their continuous growth. The company also has partnered with several top-notch educational institutions to help its employees gain access to the relevant courses, including in the area of systems engineering, while still working. Additionally, the company has on-line offerings of some systems engineering coursework.

Despite these efforts, the company still faces a shortage of systems engineers for all its needs. Several reasons for this have been discussed. One way for developing systems engineering capabilities is to enroll into school offering courses on the subject but a lot of people find it difficult to pursue the option of enrolling into school while being employed full-time, foreseeing the difficulties in balancing work-school-family life. Apart from this option, currently there is no other structured infrastructure in place for the grooming of systems engineers. Therefore, although some pursue the school option and migrate into systems engineering while some others make this transition based on their experience in their respective vertical segments but this number is too small to fulfill the current and future needs. There is an urgent need for a program to be put in place to help the interested engineers transition into the field of systems engineering. During the design of such a program, factors like the development of systems engineers in multiple applications should be kept in mind.

The current situation where there is insufficient number of qualified systems engineers available needs to be addressed quickly. While putting together an aforementioned infrastructure will speed up the process of grooming experienced engineers into systems engineers, the company also needs to seriously look at the option of developing fresh engineers into systems engineers. During the interviews, the fact that a systems engineer needs to be an experienced engineer came into focus. While some were adamant that recent engineering graduates should not be hired into the systems engineering positions,
some others reluctantly agreed that it can be tried. An interviewee from an aerospace company said “[Although] I am not for pushing a [fresh] engineer into systems engineering [role], but sharp graduates can be properly trained and groomed. He [/she] can begin with some systems engineering roles – not the systems designer types but analyst types”. Given the need, this option is worth pursuing at least to test its feasibility.

Development of Systems Engineers at Alpha Company: Two potential complimentary options

The current process for development of systems engineers at Alpha Company is laudable. Moreover, it is providing some of the best available coursework on the subject to its employees – at no cost to them in most if not all cases. However, it’s pretty obvious that more could be done. Systems engineers are needed at level in the organizations. The challenge is to recruit as well as further develop the systems thinking in the current crop of systems engineers in an organization. Given two different types of problem – recruitment of entry-level and development of experienced systems engineers, two different approaches might be more prudent. While one option deals with methods to prepare fresh engineers into systems engineering, the second option is useful for further development of experienced systems engineers.

- SEED (Systems Engineering Early Development)

This is a proposed method for recruitment and development of fresh engineers to fulfill the current and future needs of systems engineers at Alpha Company. The proposed method is inspired by a paper titled “Development of Systems Engineers: A Structured Approach Based Upon International Experience” by Michael B. Harris. In this paper, the author suggests a structured method of developing systems engineers. This thesis bases the methods of developing systems engineers at Alpha Company on the methods suggested in the aforementioned paper. The aforementioned paper by Michael B. Harris itself is inspired by a program already in practice by the U.K. Ministry of Defense (MoD) “Graduate Engineer Trainee Programme”. According to the paper, MoD recruits Honors engineering graduates into its program. The selected graduates are in the disciplines that interest MoD, such as electrical, electronic, communication, aeronautical, mechanical, naval architecture or computer systems. Apart from looking at the strong track record of academic excellence, MoD bases its selection upon extracurricular activities and leadership qualities/potential. The selected candidates are inducted into a two-year professional development scheme. U.K. follows the European Union guidelines called the Standards and Routes to Registration (SARTOR) scheme to accredit the engineers. MoD takes it a step further by adding its training to provide the engineers with the people, management and communication skills needed to be a competent systems engineer in the MoD. MoD breaks the program into three phases: 1) Induction phase, 2) Work Experience phase and 3) Transfer phase. One notable feature of
this scheme by MoD is the option to have one of the work assignments overseas during the Work Experience phase, in Germany, USA or Australia. According to Harris, such an assignment accelerates personal growth and assists with the artificial “ageing” needed for a systems engineer. The paper cites that about 80% of the trainees take up the option of overseas training. Harris also cites the example of another in-house systems engineering development program meant for development of recent engineering graduates at Lockheed Martin. In this example, he discusses the importance of personal development and mentoring, both considered important elements in the suggested model.

The paper by Michael B. Harris suggests the following four steps (presented with modifications to suit Alpha Company needs in figure 3.1) in the development of entry-level systems engineers.

![Figure 3.1: SEED Process](image)

Note: This thesis uses the same four steps but adapts the details to the needs of Alpha Company. The original method by Michael B. Harris in the paper is attached in appendix B.

1. **Introduction Phase (Michael B. Harris calls it Undergraduate):**
   An introductory systems engineering course can be offered at one of the Alpha Company’s partner universities (MIT, USC, RPI) in the final year of the undergraduate engineering degree. This course would
serve as an introduction to systems thinking and the importance of why engineers should be willing to think beyond their chosen vertical engineering field. It should be noted that these universities already have degrees/certificate programs in the area of systems engineering and thus should have no problem tailoring an introductory SE course to the undergraduate level. The only limitation in this arrangement is that such a course is offered only at handful of universities (assuming an agreement is reached between Alpha Company and these universities); thus limiting the avenues where the entry-level systems engineers can be hired. Such an experiment can be run on these universities - before expanding the partnership with a few more universities (to offer such an introductory course) or offering the course internally through the Alpha Company learning portal – to assess the success of this method of recruitment and development of entry-level systems engineers. Typically, an undergraduate engineering student in his/her final year at one of these universities will be hired by Alpha Company (through campus recruiting or otherwise) and be required to attend this introductory course.

2. Induction Phase:
A short 3-month induction phase should be arranged once the newly recruited systems engineer starts at Alpha Company. The purpose of this induction phase is to familiarize him/her with the company, as would be the case with any other new hire, but to also familiarize him/her with the engineering process in the company. The induction phase should also include introduction of the systems engineering process of the business unit, along with the review of the Alpha Company SE Guidebook. It is highly recommended that each newly recruited systems engineer is assigned a mentor at the beginning of the Induction phase who plans the assignments in this as well as the subsequent phases.

3. Training Phase:
A rigorous 15-month of training phase should be follow after the completion of the induction phase. With the help and the guidance of the mentor, the newly hired systems engineer should be given a systems engineering project for the duration of nearly the same as the training phase. In this phase, the assigned project should force the systems engineer to dig deeper into the practices of systems engineering. The Alpha Company SE Guidebook should act as the starting point for this person in trying to understand the process of systems engineering to be followed in his/her project. As is evident from the description, the idea of this phase is to give the newly recruited systems engineer a flavor of real work experience in systems engineering. Recalling the 12 roles of a systems engineer discussed earlier, it should be noted that not all the systems engineers will get to
perform all the roles in their professional careers. Keeping this in mind, the newly recruited systems engineer should be given exposure to the roles he/she is most suited to keeping in mind his/her desires. Thus, the training phase for one systems engineer might be focused on the system design and analysis while for someone else it might be on a completely different area, for example defining requirements and verification/validation.

Another important component of this phase should be developing the new systems engineer’s interpersonal skills. While it comes naturally to some, others take more time to groom in this area. If possible, the project chosen in this phase should involve multiple groups, even better if geographically dispersed. As a systems engineer, collecting the information from all the concerned parties and keeping them in the loop of the project is an important step. If exposed to such an experience in this phase, this will form a solid base for this person’s development as a systems engineer.

4. Professional Working Phase:
This phase is the normal professional working phase of a systems engineer. The newly hired systems engineer in the SEED program will end up in this phase after successful completion of the above three phases. It is worth noting that this phase should differ for the SEED participant than the other systems engineers. The SEED participant has been through some exposure of systems engineering, having gone through one real project in the previous phase. The situation with others is likely to be different, most of them likely to be having more experience but not likely in the field of systems engineering. Remember that a lot of systems engineers are those who worked in different vertical disciplines first. Thus, at this stage one set of people might have more professional work experience although not necessarily in systems engineering while the other will have significantly less professional work experience with some exposure in systems engineering.

It would probably make sense for both, although definitely for the SEED participants to continue their further education in formal systems engineering. It is advisable for them to pursue a Master’s degree in systems engineering. If this is not possible, a shorter version (e.g. the certificate program in systems engineering) should be pursued. For SEED participants, it probably makes sense to pursue the certificate option first. Once he/she has gained some more experience, the person can pursue the Master’s program. This would be a logical progression as well given that the Master’s programs (e.g. the System Design and Management program) focus a lot of leadership aspect as well. Thus, people with some professional experience stand to gain more. Also as discussed earlier, Alpha Company as a corporation encourages continuing education for its employees. Therefore, the
The company’s policies and its current efforts should be fully utilized by SEED participants in this phase. They have an opportunity to choose three world class institutes (MIT being one of them) to pursue their further education in systems engineering with full corporate support structure and apply their learning in everyday life at work. This continuing education not only helps in the evolution of the engineering capabilities of the person but also helps in the professional “ageing” of that person helping him/her become a better systems engineer in the process.

- **SE-LDP (Systems Engineering Leadership Development Program)**
  This is a proposed method for development of systems engineers, who are ready to assume the technical leadership positions at the successful completion of this program. The program will enroll 5-15 promising engineers and put them through two rotational programs of duration of one year (with a possibility to extend by six-months) each. The length of the rotations can be varied depending upon the nature of the assignments.

Currently, no such program exists within Alpha Company. The company, however, offers several leadership development programs aimed at graduating students, both undergraduate and graduate including business majors like MBA. Some of such programs offered by Alpha Company are (obtained from the career section of the company website):

- **Undergraduate Level** – These programs are more of entry-level rotational programs, designed to provide exposure of the corporate world to the recent college graduates. A few of such programs, offered at the corporate level, are:
  - Financial Leadership Program
  - IT Leadership Program
  - Operations Rotational Program

- **Graduate Level (for MBAs)** – These programs are offered for graduate students especially those with business degrees. Examples of such programs are:
  - Corporate Human Resources Rotational Program
  - Leadership Associate Program at one of the building management companies
  - General Management Leadership Rotational Program at another building management company
  - Leadership Development Program at one of the aerospace companies

As seen from above, the company encourages leadership programs in various disciplines such as the ones shown above. However, all these programs are meant to be for entry level or near entry level positions. It should, however, be
mentioned that the placement positions after completion of such programs (especially the graduate level) are important leadership positions. But the fact cannot be denied that these programs are primarily meant for people graduating from school, although Alpha Company does make an attempt to enroll its own employees too.

The purpose of SE-LDP is to prepare mid-career people for leadership positions in the discipline of engineering. The targeted personnel for this program are mid-level engineering professionals with an experience of 5-10 years. As shown in figure 3.2, the SE-LDP process will be five-step (could be four for some):

1) Selection of candidates at each BU – The first step shall be to select promising candidates to be sent to this program. Initially, each business unit could select one candidate each. Depending upon the program’s success, this number could be increased over time. Selection from each BU would ensure wider participation which in turn ensures more diversity within the program. Each BU shall have the flexibility to select the type of candidate it wishes to send to the program. The selected candidate could be an engineer with some experience in any vertical segment or it could be someone with systems engineering work experience. The idea is to prepare someone who is seen as a capable person who, given the exposure, can come back and provide technical leadership to the BU or be seamlessly portable to other BUs if needed. The BUs will be expected to keep the selected candidate’s position open to enable him/her to return back if the situation arises. The BUs will also be expected to pay for the time that the candidate is away from regular work as well as the associated costs to participate in the program.

2) First Assignment – The first assignment will kick-off the program initiation. Since this program is not meant to be the “one-size-fits-all” kind, therefore, the assignments will be customized to maximize the participant’s time during the program. The first assignment shall be in another application but within the same industry. Thus, the participant from the aerospace industry will work on systems engineering project for another aerospace company while the participant from the building management industry will work on project for another building management company. This ensures applying their knowledge of the industry but on another application, thus, easing the participants into the program. Each participant’s performance shall be reviewed by the Project/Program Manager at the end of the project.

3) Second Assignment – As expected, the second assignment shall not be in same industry as that of the participant’s BU. Thus, everyone will get to work on systems engineering projects of broadly both the major industries that Alpha Company operates in. Each participant’s performance shall be reviewed by the Project/Program Manager at the end of the project.
4) Master’s SE Degree program (optional) – This step is optional for all the participants. While it’s entirely possible that some participants already have advanced degrees (although not necessarily related to Systems) while others do not. By making this step optional, the program shall give freedom to the participant’s to assess their backgrounds and determine the need to pursue such a degree. If opted for, the entire expenses regarding the degree shall be paid through the “Employee Scholar Program”.

5) Graduation – This is the final step of the program. Upon successful completion of program, the participants shall be ready to go back to their original positions to be better engineers. It is however, fair to expect that the organization (each BU) will note the hard work during this grueling program and give each participant a chance to showcase their learning by giving them more responsibility in the areas of technical leadership.

![Figure 3.2: SE-LDP Process](image)

The recommendations made here should be treated as a starting point and by no means can this be viewed as the exhaustive options available for the purpose of the development of systems engineers. Other methods and options should be explored. Additionally, as
discussed later in Chapter 5 further research should be made into the areas of software and other high-tech hardware industries.
CHAPTER 5

CONCLUSIONS

This thesis began with a goal of investigating the development process at a large multi-national organization. With the adoption of systems engineering as a practice by organizations, there is a growing need of systems engineering practitioners called the systems engineers. Given the fact that traditionally companies have focused on developing high-quality components to deliver high-quality systems and that systems engineering has only taken off rather recently, there is a dearth of systems engineers. Companies are slowly beginning to realize the importance of systems engineering as a practice for producing better and more reliable products. It assumes even more importance in a multi-national multi-product company such as Alpha Company which operates in 62 countries and produces several different products, where efforts have to be coordinated across several geographical locations and the resultant products touch everyday human life.

During the research for this thesis, it was found that the systems engineers needs within the organization is much greater than the supply. At the same time, it was also found that the skills required for performing the role of a systems engineer are multi-disciplinary. The systems engineer is expected to be strong not only in the technical/functional area of his/her expertise but should have various other skills such as the ability to see the “big-picture”, ability to work with multiple functional groups and have good interpersonal skills. Such requirements have made systems engineers a rare and prized commodity in Alpha Company.

Engineers from various disciplines try to move to systems engineering since it is seen as a stepping stone for technical management positions. Therefore, engineers try to develop their skills in the area of systems engineering, mostly by taking upon themselves to develop ‘system level’ thinking and going to various schools for pursuing further studies in systems engineering/management. The research for this thesis has shown that more can be done at the organization level to develop systems engineers.

As the research indicated, there is a short supply of qualified systems engineers within the organization to fulfill current and potential future needs. Therefore, a plan needs to be put in place soon to fill that gap between the demand and supply. This thesis looks at the problem holistically and presents recommendations at developing systems engineers at both the entry level and the experienced level.

One recommendation (of grooming fresh engineering graduates into systems engineering through the SEED program) is against the popular belief that an engineer needs to gain experience in certain vertical engineering discipline in one or more applications before he/she could transition into systems engineering and become a good systems engineer. Organizations such as Alpha Company owe it to themselves to invest in other ideas of
developing systems engineers and test its feasibility. The success of such an idea could keep the organization’s supply pipeline of systems engineers running for a long time.

The other recommendation (of developing experienced engineers into systems engineers through the SE-LDP program) is based upon the success of other leadership programs, especially in other engineering disciplines and IT. Again, such an idea needs to be tested for its feasibility since its success ensures ‘homegrown’ systems engineers.

Several other organizations have already or are now realizing the importance of putting an infrastructure in place for the development of systems engineers. It may be helpful for some of these companies to learn from others and port the learning into their own organizations. Some amount of collaboration among them, especially under the umbrella of INCOSE can also be very helpful in developing such an infrastructure. But these organizations have to answer the question whether they want to simply maintain the status quo or are willing to take the extra step and do something proactively about this problem?

**Topics for further research**

While this thesis attempted to answer several questions facing the organizations today with respect to development of systems engineers, but several more still remain unanswered. It would be interesting to extend this research into other companies and industries. The industries studies within the context of Alpha Company are aerospace and building management. Perhaps more companies within the same industries or some other industries could be studied to further enhance this thesis.

One of the initial scopes of this thesis (which was later dropped) was to study the portability/applicability of systems engineering skills and capabilities from an organization such as Alpha Company to other industries such as software. How would a systems engineer transition his/her career into a software/telecommunication company such as Microsoft Corporation and Cisco Systems? What position(s) could he/she be hired in such a company? Could it be technical management, product management or some other, etc, etc.?

Also, recalling the INCOSE definitions of systems engineering roles, the twelfth role was not clear and was more related to the software industry. It would be interesting to study how that role compared against the remaining eleven. Also interesting would be to study a feasibility plan for INCOSE to partner with leading software companies to arrive at a common roles definitions for a systems engineer and thus remove the ambiguity related to the INCOSE twelfth systems engineering role.
REFERENCES


Interviews of 60 employees at Alpha Company, 2005 and 2006.


APPENDIX A

Sample Job Description of Systems Engineers at various business units of Alpha Company

DESCRIPTION:

Looking for person with knowledge/experience with aircraft electrical generation or distribution systems. Responsibilities may include requirements design and development, system testing and product support of aircraft electrical products. We have a wide range of needs focused around systems requirements, detail modeling and design, test procedure development and testing, and system documentation. Systems engineers are required to work with a broad range of functional disciplines including electrical, mechanical and data communication interfaces. Projects are team-based and require good communication and interpersonal skills. Experience with requirement management tools such as DOORS and simulation/modeling tools such as MatLab is a plus. Occasional travel will be required.

EXPERIENCE:

- BSEE or MS EE/BS in Computer Science or physics will be considered
- 4-7 years experience desired
- Applicant should have the ability to apply basic electrical and/or mechanical principles to design, analyze and conduct engineering investigations on electronic products
- Applicant must have good interpersonal skills with the ability to work in a team environment
- Strong written and verbal communication skills required

DESCRIPTION:

Work with Marketing and Engineering Managers to understand customer needs, technology trends, and strategy for product differentiation. Define and document system requirements (architecture, interfaces, functional and performance) for next generation security and fire protection systems. Decompose system level requirements into embedded hardware and software requirements. Write plans and procedures for system development. Create system level models and simulations, work with embedded firmware and hardware Engineers to complete hardware/software integration testing, product field trials, product certifications and write associated reports. Support interactions with key technology partners (including outside suppliers, academic institutions, etc.) as needed to accomplish program objectives. Facilitate timely resolution of technical issues through participation in weekly project team meetings and disciplined project phase gate reviews.

EDUCATION:

- B.S. in Electrical Engineering with 15+ years applicable experience, M.S. in Electrical Engineering with 10+ years applicable experience.

EXPERIENCE:

- Recognized technical expert in electronic system engineering (requirements, design, test, integration). Additional technical expertise desired in one or more of the following technical areas required: electronic system modeling (Rhapsody, Matlab/Simulink), embedded firmware development (C++), embedded hardware design (analog and/or digital circuits), network communications including wireless LANs, WANs, and/or Internet protocols, digital video technology, wireless sensor networks, biometrics. Working knowledge
of advanced Quality Systems, lean manufacturing and modern electronic manufacturing methods extremely beneficial. Proven track record of technical accomplishments and ability to produce results. The ideal candidate for this position is a strong team player who possesses a rare combination of technical and interpersonal skills.

DESCRIPTION:

Looking for an opportunity in Systems Engineering? This is an excellent opportunity to gain front to back engine experience in a highly visible, dynamic work environment! Candidate will be responsible for supporting the initiatives and objectives of the Program Management Team for successful launch of the [large program]. This individual will be required to establish and lead ad hoc cross-functional teams for resolution of system level issues associated with engine module interfaces while being cognizant of budget, metrics and schedule constraints. In addition, coordination will be required with Component/Airframe Integration Teams for resolution of issues that can have system level impacts. Specific responsibilities may include, but are not limited to, engine cost & weight management, system level product review participation and [important] technical documentation. Interfacing with both in-house and out-house customers will be required.

EXPERIENCE:

- Typical qualifications include a Bachelor of Science Degree in Engineering and a minimum of 5 years of related design and development experience.

- This individual will possess a highly positive attitude with a strong background in mechanical design, project, structures or analysis and a good understanding of the engine validation/development process. An understanding of overall engine external system design is a plus. Strong leadership, including excellent communication/presentation skills and experience leading cross-discipline teams, is required. Candidate should be knowledgeable in the use of iMan, Microsoft Word, Excel & PowerPoint. In addition, a working knowledge of the Product Review Process and Engineering Change System is desired.

DESCRIPTION:

Work closely with our engineering teams around the world to define global component and elevator system concepts and requirements enabling [BUs] products to be the most competitive and robust in the market.

Support elevator system and component development teams by:

1. Work closely with both the SITs and global component development teams to define technical requirements.
2. Perform system and component trade-studies to identify cost/performance optimal configurations and break-points.
3. Support elevator system verification and validation.
4. Manage global component requirement and interface change.
5. Support the definition and analysis of new elevator system concepts.
6. Utilize state-of-the-practice modeling and simulation tools to help reduce product development cycle time.
7. Creation of elevator system engineering standards and standard work.
8. Mentor and train future elevator system engineers.

EDUCATION:

- MS in Mechanical or Electrical Engineering (preferred) with more than 3 years industrial experience
- BS in Mechanical or Electrical Engineering

EXPERIENCE:
• Previous experience as an Engineer or Senior Engineer
• 5 years of mechanical or electrical design experience
• Command of disciplinary processes and tools
• Advantageous: 1 year or more of mechanical or electrical system application experience, field installation and or maintenance of elevators
• More than 3 years industrial experience required.
• Strong teaming skills
• Self driven

DESCRIPTION:

Responsible for the design and analysis of the rotorcraft dynamic system, specifically the main and tail rotor blades and blade retention. Candidate will partake in all phases of composite helicopter blade design - conceptual through detail- with the goal of exceeding customer requirements such as Performance, Weight, Producibility and Cost. Job function shall also include involvement in ground test, flight test, aftermarket activities and blade manufacturing process. Knowledge in CATIAV5 CAD (or equivalent) and/or ANSYS or NASTRAN/PATRAN (or equivalent) is necessary. Experience with processing, manipulating, and analyzing digital structural data is also desired to accompany the design and analysis process.

EDUCATION:

Requires a minimum of a BS in mechanical or aerospace engineering.

EXPERIENCE:

Requires a minimum of 5 years experience in mechanical design and/or structural analysis, preferably in the aerospace industry. Experience with design of composite structures and/or composite helicopter blades is desired. Experience with creation of Catia advanced surfaces is considered a plus.
APPENDIX B

Proposed Template for Development of Systems Engineers by Michael B. Harris

(Harris, MB 2000, "Development of Systems Engineers: A Structured Approach Based Upon International Experience", in proceedings INCOSE 2000: 10th Annual International Symposium of INCOSE, Minneapolis, MN, INCOSE)