SYSE 590 CLASS PROJECT  
(E-PORTFOLIO) 

Prepared for:  
Dr. Herman Migliore  
Systems Engineering Department  
Portland State University  

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Prepared by:  
Mohamed (Arif) Salam  
Torrance, CA
Table of Contents

1 Background ........................................................................................................................................3
2 Learning Objectives ..........................................................................................................................3
3 Coursework ..........................................................................................................................................4
  3.1 Systems Engineering Approach (SYSE 591) .................................................................................4
  3.2 Hardware Software Integration (SYSE 595) .....................................................................................6
  3.3 Requirements Engineering (SYSE 573) .........................................................................................8
  3.4 Operations Research in ETM (EMGT 540) .....................................................................................10
  3.5 System Dynamics (SYSC 514) .....................................................................................................11
  3.6 Discrete System Simulation (SYSC 527) .......................................................................................14
  3.7 Integrative Workshop (SYSE 590) ...............................................................................................16
  3.8 Project and Systems Engineering Management (SYSE 510MP) ....................................................17
  3.9 Reducing Risk in Decision Making (SYSE 575) ...........................................................................20
  3.10 Reliability Engineering (EAS 561) .............................................................................................22
  3.11 Master's Project (SYSE 506) ....................................................................................................26
4 Reflection on the SE Program and Future Study Plans ........................................................................26
5 Acknowledgment ................................................................................................................................29
1 Background

I started the PSU Systems Engineering Program in the fall of 2003. At the time I had been a systems engineer at a local company for a few years. I learned a considerable amount of systems engineering on the job since there was a formal role for systems engineers at this company. Having come to appreciate and value the role of systems engineers, I decided to get a formal training in the field.

After looking for a while for systems engineering (SE) courses, I decided to get a certificate in SE from PSU since the courses offered at PSU were quite relevant to my role. However, as I inquired into the requirements for the program, I was informed that the application process for the certificate program was about the same as the application for the Master's program. As a result, I decided to apply for the Master's program.

In the first year, I took the following courses:

- SYSE 591 – Systems Engineering Approach (Fall 2003)
- SYSE 595 – Hardware Software Integration (Winter 2004)
- SYSE 573 – Requirements Engineering (Spring 2004)

I suspended my studies in the Fall of 2004 since I had to relocate to California. Unfortunately, I did not resume my studies until the Fall of 2007. Since then I have taken the following courses:

- EMGT 540 – Operations Research in ETM (Fall 2007)
- SYSC 514 – System Dynamics (Winter 2008)
- SYSC 527 – Discrete System Simulation (Spring 2008)
- SYSE 590 – Integrative Workshop (Fall 2008)
- SYSE 510MP – Project and Systems Engineering Management (Winter 2009)
- SYSE 575 – Reducing Risk in Decision Making (Spring 2009)
- EAS 561 – Reliability Engineering (Summer 2009)
- SYSE 506 – Master's Project Part I (Fall 2009)
- SYSE 506 – Master's Project Part II (Spring 2010)

Although these courses were challenging, I thoroughly enjoyed them and learned a great deal. As a distant student, I appreciate the convenience and flexibility the program offers to working students like me.

2 Learning Objectives

Early in my career, I started gravitating to roles that required understanding the 'big picture' of projects. When the opportunity presented itself in 1999, I became a systems engineer for a company that manufactured opto-electromechanical products. Soon I began to grapple with the following questions and issues:

- How to write Engineering Functional Specifications
- How to write good requirements
- How to allocate system requirements to subsystems
- How to translate Marketing/Customer requirements to Engineering Requirements
- How to work with and lead inter-disciplinary team
- How to make sure subsystem designers exchange information and deal with interface issues
- Performing system level analysis and testing
I tend to be more analytical and process oriented and so I decided to get formal training in the areas I listed above. I received special training in Design of Experiments and Requirements Management but I wanted more comprehensive training. Fortunately, Systems Engineering discipline addresses these issues and much more.

My learning objectives were to get some answers to my questions without re-inventing the wheel. In addition to these learning objectives, I desire to learn how to help reduce product development risks due to, for example, technology injection that results in considerable cost and schedule overruns.

### 3 Coursework

The following sections will provide highlights of what I learned in the courses I have taken and my reflections on how I have been able to apply what I learned.

#### 3.1 Systems Engineering Approach (SYSE 591)

The Systems Engineering Approach course is one of the fundamental courses that are designed to define what systems engineering is as well introduce the major topics the field of systems engineering deals with. The major topics the course covered include:

- What and how of Systems Engineering
- Roles of SE's
- The four views of a system one must consider, namely, Function view, Requirements view, Architecture/Answer view, and Test view
- Decision making tools
- Reliability
- Simulation model development
- Design capture and requirements management tools

INCOSE defines systems engineering as an interdisciplinary approach and means to enable the realization of successful systems. The Encyclopedia Britannica defines it as the technique of using knowledge from various branches of engineering and science to introduce technological innovations into the planning and development stages of a system.

Therefore, systems engineering is an interdisciplinary approach and process for the engineering of systems throughout the life cycle of the design/product. The process involves defining, capturing and managing the systems requirements, goals setting, systems synthesis, systems analysis, systems approaches, and operational research.

Systems engineering provides systematic approach for designing systems that involves the following steps:

- Define Goals
- Identify Alternative Systems
- Evaluate Alternatives
- Select Solution
- Document and Define Next Step

In my experience careful and methodical evaluation of alternative solutions is overlooked. Often times
the easiest or the most expedient solution that comes to mind is adopted.

Systems engineers assume many roles in a typical organization. Sarah Sheard in an article titled 'Twelve Roles and Three Types of Systems Engineering' [http://www.incose.org/educationcareers/PDF/12-roles.pdf](http://www.incose.org/educationcareers/PDF/12-roles.pdf) documented well the many roles systems engineers assume. I found this article comprehensive and true to my experience over the last 16 years. I have listed these roles in a table that I used for planning my coursework. I have assumed at least seven of the twelve roles at various points during new product development cycle.

Since a system consists of many parts, skills, and techniques, there are many ways it can be described. It is preferred that a complex system be described using a top down approach and at least four views be considered. These four views are a Function view, a Requirements view, an Architecture/Answer view, and a Test view. Also systems approach requires a functional description method to describe any system. Considering these four views that are called FRAT for short has proven extremely beneficial to me for analyzing a system as well as generating system requirements and specifications.

In addition to using at work the skills I learned in class, two classmates and I worked together on a class project in which we demonstrated all the skills we learned in class. The contents of the project are listed below.

Class Project: PDT Battery Life Predictor Requirements ver3

**Table of Contents**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Objective</td>
<td>3</td>
</tr>
<tr>
<td>Life Cycle Model</td>
<td>3</td>
</tr>
<tr>
<td>Team Man-hours</td>
<td>3</td>
</tr>
<tr>
<td>CUSTOMER REQUIREMENT</td>
<td>3</td>
</tr>
<tr>
<td>Program and Product FRAT Views</td>
<td>5</td>
</tr>
<tr>
<td>Program View FRAT for Developing PDT Battery Life Predictor and Optimizer System</td>
<td>6</td>
</tr>
<tr>
<td>Product View FRAT for PDT Eatery Life Predictor and Optimizer System</td>
<td>9</td>
</tr>
<tr>
<td>FRAT to CORE Mapping</td>
<td>9</td>
</tr>
<tr>
<td>System Product FRAT Views</td>
<td>9</td>
</tr>
<tr>
<td>Originating Requirements</td>
<td>14</td>
</tr>
<tr>
<td>1 Originating Requirements</td>
<td>14</td>
</tr>
<tr>
<td>Functional Behavior Models</td>
<td>15</td>
</tr>
<tr>
<td>2 Functional Behavior Models</td>
<td>15</td>
</tr>
<tr>
<td>Part I - Function List</td>
<td>15</td>
</tr>
<tr>
<td>Part II - Behavioral Models</td>
<td>16</td>
</tr>
<tr>
<td>Components</td>
<td>27</td>
</tr>
<tr>
<td>3 Components</td>
<td>27</td>
</tr>
<tr>
<td>Part I - Component List</td>
<td>27</td>
</tr>
<tr>
<td>Part II - Component Definitions</td>
<td>28</td>
</tr>
<tr>
<td>Interaction Matrix</td>
<td>31</td>
</tr>
<tr>
<td>Glossary</td>
<td>31</td>
</tr>
<tr>
<td>Power Profiling Equations</td>
<td>32</td>
</tr>
</tbody>
</table>
3.2 **Hardware Software Integration (SYSE 595)**

The Hardware Software Integration course is a course that deals with critical topics of integration and management of interfaces, specifically between hardware and software. There is hardly any product of substance anymore that does not have software. All the products I have worked on since 1993 have had software in them. So this is a very critical and relevant course. The major topics the course covered include:

- Technical Performance Measurements (TPM) and Resource Margin Management
- Interface Management
- Comparing hardware-software systems
- Software Development
- Hardware-Software Integration

Interface management is a critical SE role that requires understanding of interface related issues, resource margin allocation, and Technical Performance Measurement techniques. The interface between systems and subsystems must be decomposed along with the architecture decomposition. Interface specifications must be documented in Interface Control Document (ICD), which should provide the following:

- Definition of boundaries between subsystems
- Documentation of all interfaces such as -
  - External (system to user and system to system)
  - Internal (subsystem to subsystem)
  - Hardware to Software
  - Hardware to Hardware
  - Software to Software
  - System to Operating Procedures
  - System Test Facilities to Test Tools
- Description of common elements of hardware, software and procedures

Based on my experience, I could probably make a bold statement to the effect that over 80% of failures and design challenges are interface related. For example, mechanical stress and thermal stress related failures account for many failures that occur during product verification and qualification. Most if not all of these failures are caused by inadequate understanding or design of the physical interfaces. I have seen many failures during vibration testing, for example, that can serve as great examples.

In addition to the interface management topic, the course provided excellent tutorial on hardware and software interface issues as well as on software application development process. Hardware-software integration is an area that I have some experience in as an electrical/systems engineer, and I have learned a lot from the course. However, I don't have a good handle on interfaces other than electrical and software and I would like to see a course dedicated to mechanical or physical interfaces that would address mechanical stress and thermal stress issues, among others.

I have been able to use the course concepts in a class project. Unfortunately, I have not been able to
champion for the creation of ICDs that cover more than electrical and software interfaces. The table of contents of the class project and examples of ICDs are shown below.

Class Project

PROJECT TABLE OF CONTENTS
I.EXECUTIVE SUMMARY 3
II.PROBLEM STATEMENT ................................................................. 3
III.INTRODUCTION ........................................................................ 3
IV.PROJECT MANAGEMENT ........................................................... 3
  Schedule ................................................................................... 4
  Cost ......................................................................................... 4
  TPMs ...................................................................................... 4
V RESOURCE MARGINS .................................................................. 5
VI.HARDWARE-SOFTWARE INTERFACE MANAGEMENT .................. 6
VII.FUNCTIONS .......................................................................... 7
VIII.REQUIREMENTS .................................................................... 8
IX.ARCHITECTURE AND TEST ...................................................... 10
X.ANALYSIS OF RESULTS ............................................................ 12
XI.LESSONS LEARNED ................................................................ 12
XII.CONCLUSIONS AND RECOMMENDATIONS .............................. 12
XIII.REFERENCES ........................................................................ 12
XIV.APPENDICES ......................................................................... 13
  Appendix A ............................................................................. 13

ICD Templates

**Electrical Interface**

<table>
<thead>
<tr>
<th>#</th>
<th>Interface</th>
<th>Connection Type</th>
<th>Pinouts</th>
<th>Voltages</th>
<th>Power</th>
<th>Frequency</th>
<th>Temperature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Touch Screen &lt;&gt; Display PCB</td>
<td>Flex cable</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Physical Interface**

<table>
<thead>
<tr>
<th>#</th>
<th>Interface</th>
<th>Connectio n Type</th>
<th>Mechanical Properties</th>
<th>Mass</th>
<th>COG</th>
<th>Packaging</th>
<th>Temperature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stylus &lt;&gt; Touch Screen</td>
<td>Contact</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Communication Interface**

<table>
<thead>
<tr>
<th>#</th>
<th>Interface</th>
<th>Connectio n Type</th>
<th>Pinouts</th>
<th>Voltages</th>
<th>Power</th>
<th>Frequency</th>
<th>Temperature</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Display PCB &lt;&gt; Main PCB</td>
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3.3 Requirements Engineering (SYSE 573)

Requirements Engineering is one of those must take courses for every engineer. This course covers all aspects of requirements engineering from understanding customer needs to final product definition. Major topics covered in the course include:

- Understanding the context of requirements
  - Mission of the buyer and user
  - Origins of the need
  - Viewpoint of the stakeholders
- Prioritizing functional and performance requirements (QFD, WIN-WIN method etc.)
- Checklist for good requirements writing
- Classification of requirements
  - Functional Requirements of the Project
  - Performance Requirements of the Project
  - Quality and Robustness Requirements of the Project
  - Evolution Requirements of the Project
  - Interface Requirements of the Project
  - Key Constraints of the Project
- Communicating Requirements Effectively (six forms/techniques of requirements communication)
- Risk Management
- Change Management

Unfortunately, users and developers do not communicate requirements to each other very well. Users and developers make too many assumptions about how well each one understands the requirements. Hence, requirements management becomes critical. Here are the essential elements of requirements management:

1. Baseline the requirements
2. Discover new requirements from mission needs, customer needs etc. Add these discoveries to baseline
3. Manage changes to the requirements baseline
4. Ensure design and implementation follow baseline requirements
5. Verify that the final product/system meets the requirements

Some forms and/or techniques that can be used to communicate requirement include:

- Requirement Specification Document
- Quality Functional Deployment (QFD)
- Requirements Traceability and Verification Matrix
- Review Meetings
- Scenarios and Use Cases
- Use of Formal Specification Language

A requirement to be useful it must be verifiable/testable. The four typical ways to verify requirements are demonstration, test, analysis, and inspection. When a requirement is not clear or ambiguous, the major purpose of clarifying a common understating of the functions and capabilities of a product/system is not achieved. A requirement is vague or ambiguous if:

- It contains words such as often, frequently, occasionally, sometimes, as needed and as appropriate.
- It is open to more than one interpretation.
● It does not specify what data a given operation is to be performed on, or how often, or to what precision.
● It does not serve the intended purpose.
● It contains incorrect implicit assumptions.

The use of cross-function teams for formal inspection of the requirements can minimize or eliminate the vague and ambiguous requirements. Cross-functional teams can also reduce risk, which is another topic the course covered.

Requirements engineering is critical to my current position as a systems engineer for product development. The first responsibility I have as a systems engineer at the beginning of each project is to critique and translate marketing/customer generated product requirements into engineering functional specification (EFS) or systems requirements. After that, it is my responsibility to clarify the requirements for the engineering team and manage requirement changes throughout the product development cycle. This early stage of the project has been the most contentious stage of the product development cycle, in my experience. On the one hand engineering complains about vague marketing/customer requirements and questions if marketing understands the market needs, and on the other, marketing complains why engineering does not want to provide the market needs.

An aspect of requirements engineering that I would like to make more visible to a wider audience, is the requirements generated at the sub-system level that marketing/customer and system level engineering documents do not cover or specify.

Some of the failures of communication about requirements I have seen in my career include lack of understanding of customer needs, unrealistic schedule requirements, and lack of analysis of customer requirements. The consequences of these failures have been delayed product introductions and cost overruns. Apathy and cynicism in the product development process have also resulted from these failures.

Failures in communication between members of a product design team occur all the time. Many of these failures have been due to lack of understanding of the requirements. This problem usually surfaces when the design fails a Quality and Reliability test and the design team challenges the well-established product qualification tests.

I have seen many system integration problems. A few years ago, we discovered that the pinout assignment of a physical connector to a device was prone to cause damage if two pins are shorted in the process of connecting the device to a cable or another device. This was the result of not defining all critical requirements at the interfaces and sub-system levels of the system.

Since requirements documents are the primary tools in which engineers communicate, I think the skills taught in this course are essential for every engineer.

I worked on class project in which I analyzed company processes with regard to requirements engineering. I am not able to attach the class project report since it dealt with sensitive company processes. As the outline below shows, all aspects of requirements management were covered in the project. It was useful report that shed light on company processes that require improvements. This report was especially well received by the local company quality organization.

1 EXECUTIVE SUMMARY
3.4 Operations Research in ETM (EMGT 540)

Operations Research course provided an in-depth coverage of most of the decision making tools introduced in SYSE 591 class. Specifically the course dealt with mathematical modeling and decision analysis using spreadsheets. Major topics covered in the course, based on 'Spreadsheet Modeling & Decision Analysis' text by Cliff T. Ragsdale, include:

- Optimization and Linear Programming
- Modeling and Solving LP Problems in Spreadsheet
- Sensitivity Analysis and the Simplex Method
- Network Modeling
- Integer Linear Programming
- Goal Programming and Multiple Objective Optimization
- Nonlinear Programming
- Queuing Theory

The course introduced systematic methods of defining, formulating and solving problems. Emphasis was placed on defining and formulating the problem more than solving the problem. This approach worked very well since it was much easier to solve a well defined and formulated problem than an ill-defined one.

In addition to this approach, the course dealt with broad range of problems that I did not deal with in my daily work. I realized the value of this tool for decision making at the managerial level and quite often wondered why I have not seen it used very often in my circles. In summary, this course expanded
my analysis tools a great deal and introduced me to various optimization tools that are necessary to conduct effective trade studies.

For my class project, I worked on a work related design optimization problem. The goal of the project was to explore how to optimize motor controller efficiency, weight, cost and reliability from a user prospective and to create spreadsheet tool. In order to achieve this goal, requirements, inputs to the system (controller), and relationships between inputs and the optimization parameters had to be defined with the support of company experts. Gathering the critical relationships proved to be difficult because of time constraints and the difficult nature of the problem. This kind of topic could become a Master's Project.

Class Project: Design Optimization of Motor Controllers

The project report could not be provided but the table of contents is shown below.

Project Table of Contents
Purpose ............................................................................................................................................. 3
Background ....................................................................................................................................... 3
Analysis ................................................................................................................................................ 3
  Project Requirements .................................................................................................................... 3
  Controller Requirements and Input Data ....................................................................................... 4
  Definition of Decision Variables .................................................................................................. 11
  Definition of Goals ....................................................................................................................... 12
  Definition of Objective Functions ................................................................................................. 13
  Definition of Constraints ............................................................................................................. 13
  Implementation Strategy ............................................................................................................. 14
  Implementation Results .............................................................................................................. 15
Summary of Results .......................................................................................................................... 15
Conclusion .......................................................................................................................................... 15
References .......................................................................................................................................... 15

3.5 System Dynamics (SYSC 514)
The System Dynamics course also provided an in-depth coverage of simulation modeling tools introduced in SYSE 591 class. Specifically the course dealt with mathematical modeling of system dynamics using VENSIM modeling tool. Major topics covered in the course, based on 'Business Dynamics' text by John D. Sterman, include:

- Challenges of Complex Systems
- The Modeling Process
- Structure and Behavior of Dynamics Systems
- Causal Loop Diagrams
- Stocks and Flows
- Positive and Negative Feedback
- S-Shaped Growth
- Instability and Oscillation
- Model Testing

I expected the course to cover typical linear controls topics but turned out to be more general dynamic system simulation course. More than any other course, the System Dynamics course challenged my
narrow conception of dynamic systems that can be modeled. As an engineer, I felt I had been conditioned to think that only physical systems can be modeled with confidence. The course forced me to think about non-physical systems such as social and financial systems, among other. One of the key concepts the course taught was how as human beings we are unequipped to predict the behavior of dynamic systems beyond first order systems and how it is critical to model dynamic systems.

The course emphasized using systematic approach to system modeling that address these topics:

- Problem Definition
- Model Setup
- Model Debugging
- Model Verification
- Model Validation
- Documentation

Example of a VENSIM model (Thermostat) is shown below.
3.6 *Discrete System Simulation* (*SYSC 527*)

Discrete System Simulation is a course based on Arena simulation application for discrete systems. The course taught both the theory and mathematics behind Arena analysis tools and provided hands-on experience on the tool. Major topics covered in the course, based on 'Simulation with Arena' text by W. David Kelton, Randall P. Sadowski, and David T. Sturrock, include:

- Introduction to Simulation and Simulation Concepts
- A Guided Tour Through Arena
- Modeling Basic & Detailed Operations and Inputs with Arena
- Statistical Analysis
- Entity Transfer

Arena is a powerful tool for simulating discrete models. Discrete models deal with wide range of problems such as queuing, work flow, and business processes. Model verification and validation are critical to success of any simulation. Through numerous class exercises, we learned the importance of systematically approaching simulation problems and addressing these topics:

- Problem Definition
- Expected Learning
- Reference Behavior Pattern (RBP)
- Problem Formulation
- Model Setup
- Debugging
- Analysis

Discrete models depend on statistical data and require knowledge of statistical analysis.

Example of an Arena model (Simple Process) is shown below.
I worked on a work related problem for my class project. The purpose of the project was to model a generic product development process and estimate the duration of the development cycle for a typical new product. The development process was defined and simulated in Arena. The process was divided into six major phases, namely, requirements phase, preliminary design phase, critical design phase, procurement phase, manufacturing phase and qualification phase. Using discrete simulation model, I was pleased to demystify and understand why typical new products, in my experience, take about 2 to 3 years to develop. Discrete System Simulation is another great tool that can be used to explore possible solutions for cost and schedule overruns that most engineering organization deal with on a regular basis. 

Class project Contents

Table of Contents

Executive Summary .................................................................................................................. 3
Introduction ............................................................................................................................ 4
3.7 Integrative Workshop (SYSE 590)

Reviewing and reflecting on all the SE courses I have taken so far as part of the SYSE 590 class requirement was extremely beneficial. I considered the following three approaches to prepare for the class:

Approach I
- Read all materials from courses taken already
- Summarize each course
- Reflect on the application of each course
- Assess how remaining courses will fit into my study plan

Approach II
- Based on memory and experience summarize what I learned in each course
- Reflect on how I have been able to apply concepts of each course
- Assess knowledge gaps and propose courses to take to close the gaps

Approach III
- Read as much as possible 'what's size got to do with it?' book by John E. Blyler and Gary A. Ray since the book discusses all the major SE topics
- Review courses materials selectively and write a summary of each course
- Reflect on course work and write about applicable projects and experiences
- Assess knowledge gaps and how the courses I plan to take will fill the gap
- Address any needs not covered in the program courses

I opted to use Approach III as much as possible. This option was the best in terms of balancing effort and learning opportunity. However, as a self-study course, it was difficult to stay on plan. I enjoyed the opportunity to reflect on the SE program courses and to plan ahead.
3.8 Project and Systems Engineering Management (SYSE 510MP)

The Systems Engineering Management course provides excellent overview of project management and system engineering and management topics. Major topics covered in the course, based on 'Essentials of Project and Systems Engineering Management' text by Howard Eisner, include:

- **Project Management**
  - Project Plan
  - Schedule, Cost, and Situation Analysis
  - Project Manager and Leadership
  - Team Building and Team Interactions

- **Systems Engineering and Management**
  - Thirty Elements of Systems Engineering
  - Requirements Analysis and Allocation
  - Systems Architecting
  - Software Engineering

- **Trends, Perspectives, and Integrative Management**
  - Systems/Software Engineering and Project Management Trends
  - Selected New Perspectives
  - Integrative Management

In addition to providing practical step-by-step tutorial on these major topics, the text contains a great deal of useful references. It focuses on what a Project Manager (PM) and Chief System Engineer (CSE) need to know to manage projects effectively. The PM and CSE have to work closely and provide leadership to the technical team and often times some of their roles are intertwined.

**Project Management**

Most of the essential elements of project management as listed above were covered in depth. For example, the following seven essential elements of a project plan were discussed:

1. *Needs, goals, objectives, and requirements*
2. *Task statement, statement of work (SOW), and work breakdown structure (WBS)*
3. *Technical approach*
4. *Schedule*
5. *Organization, staffing, and task responsibility matrix*
6. *Budget*
7. *Risk analysis*

Other useful project management topics covered include:

- Schedule analysis and monitoring using tools such as PERT charts
- Cost analysis and monitoring – Earned Value Analysis (EVA)
- Situations Analysis

**Requirements Analysis and Allocation**

The requirements analysis and allocation is an extremely important systems engineering task. This is a task that deserves a sign that reads, “It is the Requirements Stupid!”

In my experience, there is never enough time to analyze and document requirements properly. I have seen many cases were designers have to work directly from customer requirements rather than from system requirements document that analyzes and allocates requirements to subsystems. However, I seldom see a software development organization that does not demand software requirements
document upfront, as they should. Maybe the rest of the subsystem designers (hardware) should learn from the discipline that software development organizations have developed over the years.

System Architecting
The key to systems architecting is the systematic evaluation of alternatives. These three alternative architectures discussed in the text for the purpose of reducing the solution space were very valuable:

1. A low-cost, minimum-effectiveness alternative
2. A “baseline” alternative
3. A high-performance, (high-cost) alternative

It is a simple and elegant way of bounding the solution space to three practical architectures.

Software Engineering Process
As much as software is prevalent in today's products, it is surprising to see the lack of in depth knowledge of the software engineering process outside of software development organizations. The text introduced several major software standards such as Mil-Std-498 and ISO 12207. These standards continue to evolve and provide critical processes for software development. In addition to providing a survey of software standards, the text introduced major topics such as software management strategies, capability maturity, and metrics. The three major software management strategies of Grand Design, Incremental, and Evolutionary are discussed. The Incremental and Evolutionary strategies are preferred. I found the cost estimation tools like the COCOMO very interesting and eye opening. Like the EVA, I am disappointed that I have not seen rigorous software cost estimation tools like the COCOMO used by the software development organizations I have dealt with. Definitely, systems engineers should be well versed in this whole subject matter of software engineering.

Systems/Software Engineering and Project Management
Topics covered include:
1. Systems engineering trends
   1. INCOSE
   2. Systems of Systems
   3. CMM for SE
   4. Systems Architecting
   5. Sustainable Development
   6. The Structure of SE
   7. SE Environments and Tools
   8. Education
   9. Acquisition Practices
   10. Systems Integration
2. Software engineering trends
   1. National Software Council
   2. Commercial Practices
   3. Reuse
   4. Development Methods
   5. Acquisition Practices
   6. I-CASE
   7. Architecting
   8. Re-engineering
   9. Other trend areas
3. Project management trends
   1. General Management Trends
   2. Project Management Tools
   3. DoD Initiatives

All these excellent topics were cursively covered. It does illustrate the dynamic nature of systems/software engineering and project management and the importance of education in order to keep up with these trends.

Other topics of special interest covered include:
1. Role of INCOSE: the important and the vision of INCOSE were discussed. INCOSE is highly regarded and is doing effective job of shaping the future of SE
2. Acquisition of Systems: DoD 5000.1 Directive and 5000.2 Instruction were discussed. These directive and instruction documents provide sound guidelines that should improve acquisition of systems. The Kadish Report, Capability-Based Acquisition, and Defense Acquisition Guidebook were other topics discussed.
3. Problems in Systems and Software: Top on-going problems in systems and software engineering were discussed. Some of the problems mentioned were inadequate requirements engineering, inadequate qualified resources and poor planning and management.
4. Integration of Systems: Several key issues that pertain to integration were discussed. The major topics covered include:
   1. Systems of Systems
   2. Integration of Stovepipes
   3. System Complexity
   4. Horizontal Fusion and Netcentric Notions
   5. Joint Capabilities Integration and Development System
   6. List of Suggestions

Integrative Management
Chapter 14 discussed integrative management. Here is a concise definition given in the text:
“Integrative management is defined as a set of practices whereby people, processes, tools, and systems are brought together into harmonious interoperation so as to maximize their efficiency and effectiveness.”
The following domains are discussed in depth:
   1. Managers as integrators
   2. Teams as integrators
   3. Plans as integrators
   4. The systems approach as integrator
   5. Methods and standards as integrators
   6. Information systems as integrators
   7. Enterprises as integrators

In addition, excellent suggests on various topics are given on how to think outside the box.
I found the 12 integration suggestions and the eight TOTB ideas very helpful. The move to capability-based acquisition by the DoD was something new to me. I think it makes a lot of sense and aerospace industry in general should adopt this.
3.9 Reducing Risk in Decision Making (SYSE 575)

The Reducing Risk in Decision Making course provides systematic approach to decision making. It provides excellent introduction to the field of decision analysis. Major topics covered in the course, based on 'Making Hard Decisions' text by Robert T. Clemen, include:

- Introduction to Decision Analysis
- Elements of Decision Problems
- Structuring Decisions
- Making Choices
- Sensitivity Analysis
- Creativity and Decision Making
- Probability Basics and Subjective Probability
- Theoretical Probability Models
- Using Data and Monte Carlo Simulation
- Value of Information
- Risk Attitudes

Decision making can be difficult, but it does not have to be done by guess work. Ones chances of making the best decision under uncertainty can greatly be improved by following decision analysis techniques.

Elements of Decision Problems

The basic elements of a decision problem according to text are:

1. Understand the values and objectives
2. Identify the decisions to make
3. Identify all uncertain events
4. Identify the consequences

Structuring Decisions

A decision model requires three steps, namely, identifying and structuring the values and objectives, structuring the elements of the decision, and refining and precisely defining the elements of the decision model.

The text explains well how to evaluate/refine values and objectives using conceptions of 'fundamental objectives' and 'means objectives'. It also introduces influence diagram and decision tree tools for structuring decision elements into a logical framework.

Decision tree is used when all the details of the problem need to be seen explicitly. The decision tree shows every decision path and every chance event explicitly. On the other hand, the influence diagram is more concise and good for high-level presentations and during initial stages of decision analysis. Although the two methods complement each other, decision trees are easier to use for specific variable evaluation and sensitivity analysis.

Influence Diagram Structure:-
Decision Tree Structure:

Making Choices
Once the decision is modeled, means of making choices between alternatives have to be established. One method is to pick the alternative with the highest expected value (EV). Expected monetary value (EMV) is used when the consequences of the decision involve only money.

Sensitivity Analysis
Sensitivity analysis answers the fundamental question of how variations in the input variables of a decision problem/model affect the outcome. It is essential to determine what parameters have most and least impact to the outcome of a decision problem so that appropriate focus can be placed on the critical few.

Probability Basics, Subjective Probability, and Theoretical Probability Models
Good summary and introduction to probability basics and methods of assigning probabilities to subjective statements. The text also examines how various theoretical probability models can be applied to specific types of problems.

Value of Information
The expected value of information helps one determine if 'expert' information can improve one's decision and what this 'expert' information is worth. In some cases, no amount of information can improve the outcome and in others a little bit of information can make a big difference in the outcome.
Risk Attitudes
Risk attitude of the decision maker is a critical factor in decision making. An individual can be risk-averse, risk-seeking, or risk-neutral. In addition to the risk attitudes, the test covers other fundamental concepts such as expected utility, certainty equivalence, risk premiums, and risk profiles and dominance.

This is a challenging course that is extremely important for not only making engineering and design decisions but for managerial and personal decision making as well.

3.10 Reliability Engineering (EAS 561)
The Reliability Engineering course provided an excellent and broad introduction to the field of reliability engineering. I highly recommend the course to every engineer. Major topics covered in the course, based on 'Practical Reliability Engineering' text by Patrick D. T. O'Conner, include:

- Introduction to Reliability Engineering
- Reliability Mathematics and Probability Plotting
- Load-strength Interference
- Reliability Prediction and Modeling
- Reliability in Design
- Reliability of Mechanical, Electronic and Software Systems
- Reliability Testing and Data Analysis
- Reliability in Manufacturing
- Maintainability, Maintenance, and Availability
- Reliability Management

The text defines engineering reliability as:
"The probability that an item will perform a required function without failure under stated conditions for a stated period of time."

This definition ties three critical aspects of reliability, namely, chance outcome, performance under predefined conditions, and performance for a given period of time. Failures occur when designs do not adequately address any one of these.

I found worth repeating the Objectives of Reliability Engineering as stated in the text.
1. To apply engineering knowledge and specialist techniques to prevent or to reduce the likelihood or frequency of failures.
2. To identify and correct the causes of failures that do occur, despite the efforts to prevent them.
3. To determine ways of coping with failures that do occur, if their causes have not been corrected.
4. To apply methods for estimating the likely reliability of new designs, and for analysing reliability data.

The above objectives in order of priority taken from the text are explored in depth in the text. A few concepts that standout will be discussed here.

Prior to the course my understanding of the role of reliability engineers was limited to performing some statistical analysis based on system knowledge and historical information to come up with MTBF numbers and generating FMEA reports. However, after emphasizing the limitations of statistical methods, the author concludes that ultimately reliability engineering is effective management of engineering.
Reliability Mathematics
In Chapter 2 the text tied various distributions to the reliability topic and challenged the typical assumption of s-normal distribution for most engineering data. The author made good arguments to challenge this assumption. The author also challenged the validity of the 6-sigma approach that is heavily pushed in most industries. Here are some reasons why normal distribution assumption, often used as part of 6-sigma approach, may not be accurate:

1. Tails of engineering parameters like resistance, for example, do not extend out to infinity but are truncated.
2. Engineering parameters are sometimes skewed because of physical limitations. For example, the size of a screw hole has a hard lower limit. Below this limit, the proper screw will not fit.
3. Variation could be multi-modal. Components like resistors and capacitors can be sorted into different bins based on measured value rather than throwing them away.
4. Environmental conditions like heat or cold either expand or shrink material, creating one sided distribution.

Load-strength Interference
Load-strength topic covered in Chapter 4 was extremely useful in explaining the statistical nature of failures. It is critical to understand the distribution of the load and the strength of the material as shown in the figure below.

Some of the difficult product failures I have seen can be explained by the lack of understanding of how much overlap there is between load and strength. However, I am not certain that both the load and strength distributions can be determined for majority of complex designs that are subjected to more than one type of stress.

Reliability Prediction and Modeling
The text illustrated how to model and predict the reliability of simple models using reliability block diagrams and the reliability mathematics covered in Chapter 2. In addition, analysis tools such as
BDA, FTA and Markov were introduced. The 'Fundamental Limitations of Reliability Prediction' section surprised me in the way it emphasized the difficulty of modeling system reliability and how unreliable some of the typical sources of reliability data are. Although I should not have been surprised considering the statistical nature of reliability and of failures, this caution went against my perception of reliability analysis. Reliability analysis in my recent experience was made to look deterministic and fairly straightforward by reliability engineers that have provided input to the programs I worked on. This experience reinforces the role of SE as an 'information broker' and the importance of understanding the fundamentals of all the major disciplines that contribute to a system design.

Reliability in Design
Design for reliability is not an afterthought activity but rather critical process throughout the product design cycle. The text introduced analysis methods that are used both for design analysis and reliability analysis. The most common methods include QFD, load-strength analysis, and FMECA. Although the material on these major methods and the lesser known methods was brief, it was a good refresher. The material on design reviews brought back many memories of ineffective reviews. It is unfortunate that a critical activity such as this is handled so carelessly. This topic reminded me of how limited interaction there is, in my experience, between reliability engineers and design engineers. It is as though they only meet around the formal review periods. I wonder if some of design decisions that have resulted in qualification test failures could have been prevented had the two worked together closely.

Integrated Testing, Accelerated Testing, CERT, and FRACA
Although I have not seen an integrated testing program as described in the text, it would be extremely useful to any organization. In most organizations there isn't a single person or entity in charge of all the tests. MIL-HDBK-781 was sighted as the main source for most the environmental tests encountered in product development. I found many familiar tests and topics that I have encountered during qualification testing of aerospace products.

Analyzing Reliability Data
Tools such as Pareto analysis, CUSUM charts were covered among others. Important topics such as stress-life models, probability ratio sequential (PRST), and Duane method were also covered in depth.

Maintainability, Maintenance, and Availability
These are topics that I see all the time during requirements reviews but seldom ever see anyone spend any effort addressing. Perhaps I don't have visibility to it since it is part of the quality organization. The text covered two types of maintenance, namely, corrective type and preventive type. The systematic approach of addressing maintenance (RCM) that takes into account reliability aspects of maintenance was very useful. The important of FMECA as an input to maintenance planning was reinforced as well. I found most helpful the discussion on the pros and cons of Built-in-Test (BIT). I realized how I could have reduced reliability in the past while attempting to achieve very comprehensive BIT in software. There has to be a conscious effort to balance between failure detection for unit protection and potential false alarms that the detection schemes can produce.

Reliability Management
The text covered many useful aspects of reliability management, including, integrated reliability program, standards for reliability, methods of specifying reliability, contracting for reliability, and managing lower-level suppliers, to mention a few. Unlike military standards and the popular ISO9000,
the author recommends an integrated reliability program. This is a program that becomes an integral part of the product development and spans across the many phases of product development life cycle.

I was surprised that the author did not think some of the quality processes, like ISO9000, ensure reliable product. The integrated approach and TQM were considered more effective because of the 'freedom' these techniques provide to the individual contributor.

The section on managing lower level suppliers, I think, is extremely important and fairly accurate. I had an experience where purchasing selected a supplier solely based on price and with little engineering involvement. This turned out to be very expensive experience for all parties involved. I agree that engineering should make the decision with some purchasing organization support rather than the other way around.

I do not quite agree with the author about not writing detailed specification for lower level suppliers but rather giving them general statements. This can only work if there is joint development phase in the schedule for the purpose of generating detailed specifications and evaluating alternative solutions.

Other Topics
1. Project reliability plan: several elements that must be in plan were discussed.
2. Specification tailoring: alternatives that can improve reliability or build on proven technology should be recommended to customers.
3. Use of external services: the size of an organization and the frequency of new product development will dictate whether or not an organization should have dedicated reliability engineering staff. For those that cannot afford or don't need services frequently can use external services.
4. Customer management of reliability: Customer should manage reliability judiciously without overburdening the supplier. The purchaser should specify in a reliability program the expectations. It may be necessary for the purchaser's staff to monitor and observe the suppliers' design reviews etc.
5. Selecting and training for reliability: I agree with the author about the necessary pedigree of reliability engineers. I have not dealt much with reliability engineering organizations and can't say much about what type of people they hire, but I can see how statisticians may be favored. I think reliability engineers should be design engineers with special training. From what I learned in the class and from the class project, it is critical that reliability engineers understand the design details, to some extent, of the system they are evaluating.

Other topics covered include managing production quality, quality audit, and quality management approaches.

Class Project
The objective of the project was to estimate the reliability of an electric motor controller for a typical More Electric Aircraft (MEA) application.

The objectives of the project were to:
1. Define the reliability requirements of a motor controller for aircraft application
2. Determine the typical reliability of each component in the system
3. Use special knowledge about motor controllers to address the following:
   - Critical parameters that affect reliability of high power motor controllers
   - Understand the effect power electronic switching devices have on reliability since these components are considered to have major impact on reliability
   - Propose methods to improve reliability
4. Estimate overall system reliability
5. Compare estimated system reliability against requirements and recommend improvements if system reliability does not meet requirements.
6. Fully utilize knowledge gained in class throughout the project

I used MIL-HDBK-217F to predict the reliability of a motor controller for MEA application. Here is the conclusion taken from the project report:

As O'Connor pointed out, using MIL-HDBK-217F reliability prediction methods has many flaws. Some of these flaws include:

1. Part Count Method is basically useless. Reliability of systems cannot be generalized easily. Identical systems can result in drastic reliability failure rates because of differences in environmental conditions, for example.
2. Handbook does not address stresses due to EMI and power quality environment induced stresses.
3. Stress Analysis method is more useful in the sense that it factors in some environmental and stress conditions. However, it does not address stresses mentioned in bullet (2) but also does not address improvements being made in the manufacturing of electronic components.

With the exception of failure rates of capacitors and resistors for Controller A, the overall MTBF is within the expected range of 20k to 30k hours. The key take away from this analysis is that each system is unique and should be evaluated carefully.

The next step in the analysis is to explore the difference redundancy would make in the overall system reliability.

3.11 Master's Project (SYSE 506)
For my Master's Project, I picked the topic of Electric Power Generation for aerospace application. Here are some thoughts about the project:

1. Initially I thought that I should apply SE training on unfamiliar topic but later realized the importance of domain knowledge. Although it would have been exciting and challenging, I may not have been able to achieve much in two terms. The downside to picking a familiar topic, as I did, is the tendency to jump around. As I detailed in the attached Master's Project report, I have jumped around with some justification.
2. Doing a project was an excellent way of re-enforcing the SE approach and training.
3. Although I would have liked to have explored several areas in-depth, I have a good starting point and an overall structure to build on in the future.
4. I was able to simulate part of the system in the first term. This was a great learning opportunity for me; I was able to achieve something I eluded me for a long time.

[Link to Master’s Project Report]

4 Reflection on the SE Program and Future Study Plans
In an attempt to identify gaps in my SE training, I have created a table that maps the 12 SE roles to SE responsibilities and SE courses. As the table below shows, the courses I have taken throughout the program will fill my knowledge gaps as it relates to the 12 SE roles. However, there are other topics that I would like to explore. I listed these extra topics/courses in the 'Courses/Skills for Future' column of the table.
Table Keys:
PE – Project Engineer
PM – Project/Program Manager
SE – Systems Engineer
Type – Types of SEs

<table>
<thead>
<tr>
<th>Roles(1)</th>
<th>Type(1)</th>
<th>CM(1)</th>
<th>Experience</th>
<th>Completed SE Classes</th>
<th>Courses/Skills for Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Owner (RO)</td>
<td>Discovery; Program SE; Approach</td>
<td>Life Cycle</td>
<td>SE; PE</td>
<td>SYSE573</td>
<td></td>
</tr>
<tr>
<td>System Designer (SD)</td>
<td>Program SE; Approach</td>
<td>Life Cycle</td>
<td>SE</td>
<td>SYSE591; SYSE595; EAS561; SYSE575</td>
<td></td>
</tr>
<tr>
<td>System Analyst (SA)</td>
<td>Discovery</td>
<td>Life Cycle</td>
<td>SE</td>
<td>SYSE591; SYSE595; SYSC514; SYSC527; EMGT540; EAS561; SYSE575</td>
<td>Could use general knowledge in stress, thermal and EMI analysis (SYSE 505)</td>
</tr>
<tr>
<td>Validation and Verification Engineer (VV)</td>
<td>Program SE; Approach</td>
<td>Life Cycle</td>
<td>SE; PE</td>
<td>SYSE591</td>
<td></td>
</tr>
<tr>
<td>Glue among subsystems (G)</td>
<td>Program SE; Design Reviews</td>
<td>PM; Manage Risk</td>
<td>SE; PE</td>
<td>SYSE573; SYSE591; SYSE595</td>
<td></td>
</tr>
<tr>
<td>Customer Interface (CI)</td>
<td>Program SE; Design Reviews</td>
<td>PM; Manage Risk</td>
<td>PE; PM</td>
<td>SYSE573; SYSE591; SYSE510MP</td>
<td></td>
</tr>
<tr>
<td>Technical Manager (TM)</td>
<td>Discovery; Program SE; Design Reviews</td>
<td>PM; Manage Risk</td>
<td>PE; PM</td>
<td>EMGT540; SYSE510MP; SYSE575</td>
<td>SYSC529</td>
</tr>
<tr>
<td>Information</td>
<td>Discovery</td>
<td>PM</td>
<td>PE; SE</td>
<td>EMGT540; SYSC529</td>
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<tr>
<td>Role</td>
<td>Responsibilities</td>
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<tr>
<td>Requirements Owner (RO)</td>
<td>Systems engineers are responsible for generating the Engineering Functional Specification (EFS) which is the technical requirements response to the product requirements document that Marketing provides for product development.</td>
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<tr>
<td>System Design (SD)</td>
<td>Systems engineers help define the high-level system architecture but not necessarily design or select major components.</td>
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<tr>
<td>Systems Analyst (SA)</td>
<td>Systems engineers are responsible for modeling and simulating overall system and in some cases model sub-systems.</td>
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</tr>
<tr>
<td>Validation and Verification (VV)</td>
<td>Systems engineers are responsible for Feasibility model, Alpha, Beta, and Pilot test plans.</td>
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<tr>
<td>Glue (G) Role</td>
<td>Systems engineers are responsible for maintaining cross-functional communication and information exchange.</td>
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<tr>
<td>Process Engineer (PE)</td>
<td>Systems engineers are responsible for improving and maintaining product development processes.</td>
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<tr>
<td>Coordinator (CO)</td>
<td>Systems engineers are responsible for resolving issues, seeking consensus, or making recommendations.</td>
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</table>

In addition to the courses offered in the SE Program, I would like to see a course designed to address some of the product qualification challenges new product developers face. I have in mind a course that can equip systems engineers to avoid pitfalls during Environmental and EMC qualification tests. Unless an SE has a mechanical degree, I feel it would be difficult for him or her to judge the work done by thermal stress and vibration stress experts, for example. The same can be said about the work of EMC experts. Of course, this is assuming that one has access to these experts, which is not always the case.

Obviously there is no way I could do justice to the excellent courses I have taken by summarizing here some of the concepts taught in these courses. The SE Program is designed well and offers lots of hands-on experiences. In addition to the weekly reading and problem solving requirements, most if not all classes required participation in discussions, journal writing, and class projects. These additional requirements enhanced considerably the on-line learning experience. I have attempted throughout the program to share and apply my industry experiences as well as give back to my employers by working on company related class projects. However, I found that it is not always easy to work on company related problems because of the red tape involved in getting approvals.
5 Acknowledgment

I want to thank Dr. Migliore and all my other professors for their support throughout the Master's Program and for their dedication to the noblest profession of teaching. I also want to thank PSC Scanning (now part of Datalogic) and Honeywell, the two companies that provided complete financial support, and all my current and former colleagues at both companies for their understanding, encouragement and technical support. Last but not least I would like to thank my wife and our two daughters for their patience and for all the evenings and weekends that they sacrificed. I love you and appreciate you.