Developing Defense Systems Engineering into Engineering Competency via Multi-Quarter Carry-Through Projects

NDIA Systems Engineering Conference
San Diego, CA

27 October 2011
NPS SE Masters Program Overview

**Resident (580)**

- Individual Thesis
  - **Domain/Track** - Cohesive combination of 7 engineering, operations research, acquisition, or management topic courses
    - Logistics Engineering (SE)
    - Human Systems Engineering (SE)
    - Systems Analysis (OR)
    - Engineering Risk (SE)
    - Test and Evaluation (SE)
  
**Distributed Learning (311)**

- Individual Thesis/Team Based Capstone Project
  - **Domain/Track** - Cohesive combination of 4 engineering, operations research, acquisition, or management topic courses

- **580X P-Code ESR Not Required**

**Nine Common SE Core Courses for All SE Masters Degrees**

- Systems Integration and Development
- Software Systems Engineering
- System Architecture and Design
- Capability Engineering
- Engineering Economics and Cost Estimation
- Fundamentals of Engineering Project Management
- Systems Assessment
- System Suitability
- Fundamentals of Systems Engineering

**Resident Program Requires Minimum of 6 Quarters (Full Time)**

**DL Program Requires Minimum of 8 Quarters (Part Time)**
Program Objectives

• Resident and non-resident programs share common nine course core curriculum

• Informed by INCOSE reference curricula and DOD SE Competencies

• Course objectives mapped to ESRs Navy sponsor (NAVSEA); consistent with SPRDE-SE/SE/PSE Competencies

• Burnt orange courses compose the SE certificate

• Degree requirements met by core, 4 course track, and 3 course project

<table>
<thead>
<tr>
<th>Course</th>
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<tbody>
<tr>
<td>Fundamentals of Systems Engineering</td>
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<tr>
<td>System Suitability</td>
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<tr>
<td>Systems Assessment</td>
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<tr>
<td>Fundamentals of Engineering Project Management</td>
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<tr>
<td>Engineering Economics and Cost Estimation</td>
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<tr>
<td>Capability Engineering</td>
</tr>
<tr>
<td>System Architecture and Design</td>
</tr>
<tr>
<td>Software Systems Engineering</td>
</tr>
<tr>
<td>Systems Integration and Development</td>
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</tbody>
</table>
the 35 universities listed, 203 graduate courses were analyzed.

Jain, Squires, Verma, Chandrasekaran – July 2007
Probability and Statistics for Systems Engineers

[Calculus Prerequisite]

Domain Track Courses (3)
Capstone Integrating Project (3)

System Suitability
System Assessment
Engineering Economics and Cost Estimation
Capability Engineering
System Architecting and Design
Software Systems Engineering
System Integration and Development

Specialization Courses
- Software Systems Engineering
- General Project Management
- Finance, Economics, and Cost Estimation
- Manufacturing, Production, and Operations
- Organizational Leadership
- Engineering Ethics and Legal Considerations
- Masters Project or Seminar

Fundamentals of Systems Engineering
- Systems Design/Architecture
- Systems Integration and Test
- Quality, Safety, and Systems Suitability
- Modeling, Simulation and Optimization
- Decisions, Risks and Uncertainty

Fundamentals of Engineering Project Management
- General Mathematics
- Probability & Statistics
NPS RT-19 War Room Objectives Affinity
NPS RT-19 War Room Sequencing Options

How could we complete SE core in 4 quarters?

NOMINAL PROGRAM

1. Core - SE
2. Core - SE
3. Core - SE
4. Core - SE

OPTION A: Replace 4 with 1

These are where the SE learning is accomplished through synthesis of coursework into hands-on carry-through project:

- Put ESR materials into SE core, where applicable
- Put ESR L.O. into corresponding point in project systems synthesis
- Study ESR to determine if they are appropriate - move to Right of Bloom

There is a need for a pre-assessment (blue-tooth)
<table>
<thead>
<tr>
<th>Course and Objective</th>
<th>SE Competency</th>
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</thead>
<tbody>
<tr>
<td>SE3100: Fundamentals of Systems Engineering</td>
<td>28: Strategic Thinking</td>
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<td></td>
<td>25: System of Systems</td>
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<td></td>
<td>27: Problem Solving</td>
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<td>23: Acquisition, Element 34</td>
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<tr>
<td></td>
<td>15: Technical Planning</td>
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<tr>
<td>Elicit, elaborate and document system requirements based on user needs and</td>
<td>4: Stakeholder Requirements Definition</td>
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<tr>
<td>operational objectives; translate them to technical requirements</td>
<td>5: Requirements Analysis</td>
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<tr>
<td></td>
<td>9: Requirement Reviews</td>
</tr>
<tr>
<td>Create a system value hierarchy reflective of stakeholder goals</td>
<td>5: Requirements Analysis</td>
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<tr>
<td></td>
<td>14: Decision Analysis</td>
</tr>
<tr>
<td></td>
<td>16: Technical Assessment</td>
</tr>
<tr>
<td>Complete system functional analysis in support of requirements engineering</td>
<td>2: Modeling and Simulation</td>
</tr>
<tr>
<td>engineering using modeling tools such as IDEF0, FFBD, and other languages</td>
<td>6: Architecture Design, Elements 6 &amp; 8</td>
</tr>
<tr>
<td>Develop, evaluate and document alternative system architectures, using DoDADF</td>
<td>18: Requirements management</td>
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<tr>
<td>products where appropriate</td>
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</tr>
<tr>
<td>Plan for system validation, to ensure technical performance measures map to</td>
<td>9: Verification, Element 12</td>
</tr>
<tr>
<td>operational characteristics</td>
<td>10: Validation</td>
</tr>
<tr>
<td>SE4150: System Architecting and Design</td>
<td>24: SE Leadership</td>
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<tr>
<td></td>
<td>25: System of systems</td>
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<tr>
<td></td>
<td>27: Problem solving</td>
</tr>
<tr>
<td>Create system architectures consistent with stakeholder needs, systems thinking,</td>
<td>5: Requirements analysis</td>
</tr>
<tr>
<td>and systems engineering life cycle models using model-based systems engineering</td>
<td>6: Architecting Design, Elements 6, 7, 8</td>
</tr>
<tr>
<td>(MBSE) methods.</td>
<td>18: Requirements management</td>
</tr>
<tr>
<td>Construct alternative system architectures for balanced system solutions.</td>
<td>2: Modeling &amp; simulation</td>
</tr>
<tr>
<td>Demonstrate their feasibility through simulation (executable architectures).</td>
<td>6: Architecting Design, Elements 6, 8</td>
</tr>
<tr>
<td>Demonstrate coupling between system elements and value criteria (stakeholder</td>
<td>6: Architecting Design, Elements 6, 7, 8</td>
</tr>
<tr>
<td>requirements, performance, quality, investment) through requirements traceability</td>
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<tr>
<td>and management.</td>
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</tr>
<tr>
<td>Analyze and compare alternatives against system-level evaluation criteria.</td>
<td>6: Architecting Design, Elements 7, 8, 9</td>
</tr>
<tr>
<td>Explain trade-offs. Recommend &quot;best&quot; architectures</td>
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### Course Structure and Material

<table>
<thead>
<tr>
<th>Fall Qtr</th>
<th>Winter Qtr</th>
<th>Spring Qtr</th>
<th>Summer Qtr</th>
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<tbody>
<tr>
<td></td>
<td>SE3250: Capability Engineering</td>
<td>SE3302: System Suitability</td>
<td>SE4003: SW Systems Engineering</td>
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<tr>
<td></td>
<td>SE3011: Eng Econ &amp; Cost Estimation</td>
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**Individual Project**

**Carry-Through Project**
## Student Assessment

<table>
<thead>
<tr>
<th>Competency</th>
<th>Measures of Competency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge</strong></td>
<td><strong>Skill</strong></td>
</tr>
<tr>
<td><strong>Stakeholder Requirements</strong></td>
<td>Instructor introduces and student learns relation between stakeholders, their needs, problems, and requirements</td>
</tr>
<tr>
<td><strong>Requirements Analysis</strong></td>
<td>Instructor introduces and student learns how to conduct and monitor the analysis of stakeholder requirements to ensure functional and performance feasibility and effectiveness</td>
</tr>
<tr>
<td><strong>Requirements Reviews</strong></td>
<td>Instructor introduces <strong>walkthrough of requirements with stakeholders</strong> and student learns the essence of elicitation, questioning, and prioritizing requirements</td>
</tr>
<tr>
<td><strong>Manage Design Requirements</strong></td>
<td>Instructor introduces the methods of managing design requirements and student learns the processes and tools</td>
</tr>
</tbody>
</table>
### RT-19 2011 Number of Students

<table>
<thead>
<tr>
<th>Student Source</th>
<th>MSSE (580)</th>
<th>MSSEA (308)</th>
<th>Other</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>US Navy</td>
<td>20</td>
<td>18</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>US Army</td>
<td>1</td>
<td>3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>DoD Civilians</td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Int'l Civilians</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td><strong>19</strong></td>
<td><strong>7</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>
Key Objectives

• The pilot project involves the following competencies, along with the entire SE Competency list provided by OSD(AT&L):
  a. Technical Basis for Cost
  b. Stakeholder Requirements Definition
  c. Requirements Analysis
  d. Architecture Design (some elements)
  e. Alternative Generation, Scoring, and Selection
  f. Modeling & Simulation; Safety Assurance (where applicable & feasible)

• Learning objectives for current curriculum derived from:
  a. Navy sponsor-provided Educational Skill Requirements (ESR)
  b. INCOSE SE Handbook
  c. CSEP related learning objectives

• The project revisits these learning objectives, expanding the context to include:
  a. Systems engineering competencies identified by OSD(AT&L)
    a. SPRDE SE/PSE
  b. ABET EAC harmonized (a) - (k) criteria
  c. CDIO reference curriculum
Student Project Context

• **Project Carries Through Curriculum**
• **Implemented Through ‘Hands-on’ Lab Sections**
  – Primarily SI3400, SE3302, SE4150, SE4151
  – Other courses relate to project (SE3100, SE3011)
  – Instructors for all courses involved as project advisors for full curriculum scope

• **Learn by Doing**
  – Apply theories & concepts from courses

• **Formative and Summative Assessments**
  – Direct (exams, assignments, observation, …)
  – Indirect (surveys)
  – Based on competency development

*Don’t just act like a systems engineer, be a systems engineer!*
Student Products

• Fall 2010
  – Problem Definition
  – Preliminary Organization
  – Stakeholder Analysis
  – Initial CONOPS

• Spring 2011
  – System Architecture
  – Concept Design
  – System Modeling
    • Vitech CORE

• Winter 2011
  – SEMP
  – Requirements Elicitation
  – Requirements Definition
  – Function Flow

• Summer 2011
  – System Integration
  – Prototype Development
  – Project Demo
“An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use.”

- Majority of Humanitarian Assistance/Disaster Relief casualties (HA/DR) occur in first three days
- US military capabilities:
  - Worldwide initial deployment: 22 hours
  - Worldwide large scale aid: seven days
    - Includes response management infrastructure
- Long term aid not a factor
  - After seven days, aid is available
- 1-3 day period - capability gap
DATA TO DECISIONS AS IT HAPPENS

S.P.E.A.R.S.
Situational Awareness Providing Enhanced Analysis & Response System
SPEARS Architecture

External Connectivity (Raw Data) → Input

Keyword Database (User Control) → GINA

GINA → I.E.

I.E. → S.A.

S.A. → PROg

Output

GINA:
- Filter Settings
- Data Packs

I.E.:
- User Controls
- Correlations
- Analyzed Equations
- Missing Tokens ID

PROg/SA Info

User Settings

Predictions and Projections

Models
SPEARS Prototype Scenario

• Twitter trends
  – Shaking
  – Earthquake
  – Broken windows

• News sources
  – Power outages
  – Fires

• USGS RSS Feed
• Early development
• Physical hardware
  – Desktop computer
  – 2 x video monitors
  – 2 TB hard drive
• Software
  – Windows 7 Pro
  – GINA
  – FalconView 4.2.1
  – Cursor On Target / Excel2FV
RT-19 Outcomes

• Student Related
  – SPEARS offers way forward to close current capability gap
  – 1-3 day HA/DR response
  – Architecture viable for other Data to Decisions applications
  – Academic impact on 48 students
    • Exponential propagation throughout the Fleet

• Faculty Related
  – Developed learner-centered pedagogical approach
  – Assessment focusing on SE competency
# Future Curriculum Pilot

![Diagram](image_url)

## Focus on SE Competency Development

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<tbody>
<tr>
<td>Math</td>
<td>OS3180</td>
<td>SE3011</td>
<td>SE4150</td>
<td>SE4151</td>
<td>Track</td>
<td>Military JPME</td>
<td>Thesis</td>
</tr>
<tr>
<td>Physics</td>
<td>Pre-req</td>
<td>SE3250</td>
<td>Track</td>
<td>SE4003</td>
<td>Adv SE</td>
<td>Adv SE</td>
<td>Track</td>
</tr>
<tr>
<td>Physics</td>
<td>Track</td>
<td>Conceive Lab</td>
<td>Design Lab</td>
<td>Implement &amp; Operate Lab</td>
<td>Track</td>
<td>Track</td>
<td>Track</td>
</tr>
</tbody>
</table>

**CDIO Inspired Project-Based Learning Labs**
RT-19 Faculty

Cliff Whitcomb
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Diana Angelis
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• Providing a technical basis for comprehensive schedule realism (beyond #1, element 1)
• Modeling or simulation in support of operational realism, referenced to gap analysis (beyond #2, element 1)
• Systems thinking when analyzing stakeholder requirements (beyond #5, element 5; and beyond #6, element 6)
• Human interactions anticipated due to the delivered system engineered product (beyond #6, element 6)
• Trade analyses that include cost and schedule constraints (beyond #6, element 6)
• Consideration of boundary conditions beyond physical domains to include functional and process contexts (beyond #6, element 7)
• Additional consideration to reflect the consequences on architecture and its trade spaces for refinements made after requirements and specifications have been promulgated (beyond #8, element 11)
• Extending the view of validation to encompass determining the operational limitations of the requirements, functional and physical architectures, and the “as-built” implementation (beyond #10, element 14)
• Considerations of RAM using discrete Markov processes (developed as event-based structures), rather than simple formulations that average various contributions to RAM (beyond #13, element 17 and element 18)
• Discussion and understanding of the systems engineering management plan (SEMP) (beyond #15, element 20)
• Clear delineation between measures, metrics, and figures of merit in cardinal and ordinal scaling (beyond #16, element 21)
• Incorporating architectural perspective (i.e., resources, constraints, limitations, spatial and temporal interactions, and data context(s) (including scalability model(s) when considering, and “ensuring” interface definitions and compliances (beyond #21, element 27 and element 28).
Requirements Elicitation

- Direct Elicitation
  - Student team
  - PACOM
  - AFRICOM
- VTC
- Follow-on Interactions
- Iteration

Notes from 2/11/2011 VTC with PACOM

PACOM attendees: Jim Ellert, NPS PAC
Dave Brown, J2
Biff Baker, Socio-cultural engagement officer

Problems facing PACOM

Issues and challenges in regards to HA/DR and Knowledge Management:
As an Intel/Plans Officer he is interested in ISR/Enterprise architectures, UNCLAS architecture enhancements, and socio-cultural dynamics/human terrain. He spoke about 4 particular problem areas that RT-19 could explore:

a. SMARTphone technology. Using COTS technology to deploy downrange and use operationally for area assessments and HA/DR functions.
   i. The phones would be used to push/pull data and information.
   ii. A recent thesis topic at NPS was FIST (Field Information Support Tool), an Android-based SMARTphone that uses all functionality of the phone (GPS, DTG, etc.)
   iii. The interest would be to aggregate and fuse data that all could use, including international organizations
   iv. This should be a portal to push information from the field to COCOM users.
   v. Requires policies, procedures, and technical solutions.

b. Development of an UNCLAS geo/non-geospatial data repository.
   i. The server and data must be structured for use by many different entities.
   ii. There are already several PORs (programs of record) that store and sort data in many different formats. There should be a method to pull information from these sources as well.
   iii. The database should be structured, yet flexible.

c. Business rules for what data is:
   i. Stored
   ii. Migrated
   iii. Replicated
   iv. Structured

d. Making improvements to the operating environment
   i. Envision a GUI with tools available:
      1. Geo-spatial analysis/RGS
      2. Google Earth
      3. Interface between 1&2
      4. Modeling/simulation
      5. Making the tools accessible via the internet
   2. They envision each country with its own network, with a larger global network that sits on top. Each country should have its own local architecture and there should be a method to push local data to the global system.
   3. Each person on the ground is a sensor – how do we take advantage of it?
   4. We also want information from ‘folks on the street.’ How do we get that?
   5. Supply chain tracking
Research Topic 19 Systems Engineering Management Plan

Version 1.0 draft 1
Prepared by RT-19 Project Team
NPS Systems Engineering Students

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1. Technical Control and Planning
   1.1. List of Acronyms
   1.2. Staff Structure
   1.3. Configuration Control
   1.4. Master Schedule
   1.5. Risk Management Strategy

2. Systems Engineering Processes
   2.1. Identification and Implementation of Waterfall Processes
   2.2. Functional Decomposition
   2.3. Physical Decomposition
   2.4. Process Decomposition
   2.5. Stakeholder Analysis
   2.6. Capability Gap
   2.7. CONOPS
   2.8. Scenario Development

3. Appendices
   3.1. RT-19 Systems Engineering Plan Guide
   3.2. Definitions
   3.3. Work Assignment Log
   3.4. Master Schedule
   3.5. Risk Management Plan Database
   3.6. Waterfall Process Model
   3.7. Stakeholder Analysis Model
   3.8. Functional Decomposition Model
   3.9. Physical Decomposition Model

N-squared Chart Perspective of Developing Requirements

<table>
<thead>
<tr>
<th>Capture Sources</th>
<th>Requirements</th>
<th>Required Capability</th>
<th>Mission Parameters</th>
<th>External Workflows, Compliance Documents</th>
<th>Mission Requirements</th>
</tr>
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High Level System Boundaries
Basic system interactions

- Affected Population
- World Aid Organizations
- Local Leaders/Government
- Military and Law enforcement
- Contractors
- Process of Aiding affected Population
- Stabilized and Recovering Population
- Call for help, guidance
- Process support
- Encompasses all disaster scenarios
- Scalable, flexible
- Domestic turnover
- Contractors

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System Modeling - FFBD

Low Intensity Conflict Functional Flow Block Diagram

- Establish Facilities
  - Establish and Maintain C2
  - Establish Communication
- Determine Support Required
- Communicate Situation
- Organize Agencies
- Acquire Resources
- Deliver Resources
- Provide Security

Functions addressed by the Low Intensity Conflict Thread covered by sub-functions in the Functional Flow Block Diagram:

- Assess Situation
- Provide Support
- Sustain Human Life
- Provide Goods
- Provide Services
- Maintain Order
- Establish Procedures
- Establish Logistics