The Mysterious Systems Engineering Landscape

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Challenging World

- Terrorism
- Global culture clashes
- Information overload
- Disease – Health Care
- Infrastructure
- Technical Complexity
- Business and Finance
Systems Engineering is increasingly the field expected to solve problems
Why is Systems Engineering a Mystery?
(We have multiple views of the Field)
Attributes View of a Complex System

- **Form**
  - Incorporates Many Capabilities
  - Comprised of Interacting, Diverse Elements
  - Definable Structure and Interconnections
  - Bounded; Has Inputs and Outputs

- **Function**
  - It Does Something Valuable
  - It is Dynamic—Not Inert
Partitioning View

Each system can be broken down into components which in turn can be broken down into smaller components, etc.

Air Defense System
  ├── System
  │    ├── Subsystem
  │    │    ├── Search Radar
  │    │    │    ├── Subsystem
  │    │    │    │    ├── Component
  │    │    │    │    │    ├── Subcomponent
  │    │    │    │    │    │    └── Part
  │    │    │    │    └── T/R Module
  │    │    │    └── Component
  │    │    └── Component
  │    └── Component
  └── Subsystem
     └── Subsystem
         └── Component
             └── Component
                 └── Component
                                 └── Part
                                         └── Part
                                                 └── Screw

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Problem Solving View

- Life Cycle – Cradle to Grave
  - Generic and Formal DoD
  - Concurrent Engineering

- No Rigid or Fixed Approach
  - Tailored to the problem
  - Sponsor/corporate/compliance guidelines and directives
  - Qualitative & quantitative (objective and subjective)
Organizational View

**NOT THIS WAY!!!**

Program Management

- Analysis
- Design
- Integration
- Test
- Systems Engineering

**OR THIS WAY!!!**

Program Management

- Analysis
- Design
- Integration
- Test
- Systems Engineering

**THIS WAY!!!**

Program Management

- Analysis
- Design
- Integration
- Test
- Systems Engineering

Systems Engineering Role and Program Culture Matters!
Systems Engineering Management View

**Systems Engineering**
- System Design & Engineering
- Interface Management
- Analysis & Evaluation
- Integration & Test

**Project Management**
- Risk Management
- Configuration Management
- Quality Control
- Contract Management
- Production Management
- Project Administration & Support
- Data Management
- Scope, Schedule, and Cost
Definitions View

- The function of systems engineering is to guide (lead, manage, or direct, usually based on the superior experience in pursuing a given course) the engineering (application of scientific principles to practical ends; as the design, construction and operation of efficient and economical structures, equipment, and systems) of complex (diverse and have intricate relationships) systems (a set of interrelated components working together toward some common objective). (Kossiakoff, Sweet, Seymour and Biemer)

- A system is a construct or 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 (Rechtin).
More Definitions

Systems engineering is an interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and total life cycle balanced set of system, people, and process solutions that satisfy customer needs. Systems engineering is the integrating mechanism across the technical efforts related to the development, manufacturing, verification, deployment, operations, support, disposal of, and user training for systems and their life cycle processes. Systems engineering develops technical information to support the program management decision-making process. DOD 2008

DoD Instruction 5000.02, directs the use of systems engineering across the acquisition life cycle:
Rigorous systems engineering discipline is necessary to ensure that the Department of Defense meets the challenge of developing and maintaining needed warfighting capability. Systems engineering provides the integrating technical processes to define and balance system performance, cost, schedule, and risk within a family-of-systems and systems-of-systems context. Systems engineering shall be embedded in program
More Definitions

- Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholders needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle (INCOSE).

- It is a robust approach to the design, creation, and operation of systems (NASA Systems Engineering Handbook).

- It is the design, production, and maintenance of trustworthy systems within cost and time constraints (Sage).

- It is a holistic, product oriented engineering discipline whose responsibility is to create and execute an interdisciplinary process to ensure that customer and stakeholder needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's life cycle. (Bayhill)

- It is a discipline that concentrates on the design and application of the whole system, as distinct from the parts. It involves looking at the problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspects. (Ramo)
# Systems Perspectives View

<table>
<thead>
<tr>
<th>Systems Thinking</th>
<th>Systems Engineering</th>
<th>Engineering Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on Process</td>
<td>Focus On Whole Product</td>
<td>Focus on Both Process and Product</td>
</tr>
<tr>
<td>Consideration of Issues</td>
<td>Solve Complex Technical Problems</td>
<td>Solve Complex Interdisciplinary Technical, Social and Management Issues</td>
</tr>
<tr>
<td>Evaluation of Multiple Factors and Influences</td>
<td>Develop and Test Tangible System Solutions</td>
<td>Influence Policy, Processes and use Systems Engineering to Develop Systems Solutions</td>
</tr>
<tr>
<td>Inclusion of Patterns Relationships, and Common Understanding</td>
<td>Need to Meet Requirements, Measure Outcomes and Solve Problems</td>
<td>Integrate Human and Technical Domain Dynamics and Approaches</td>
</tr>
</tbody>
</table>
Systems Thinking and Systems Engineering

- Concept Development
  - Needs Analysis
  - Concept Exploration
  - Concept Definition

- System Development
  - Functional Designs
  - Trade Studies
  - Design and Build

- Product Evaluation
  - Integration and Testing
  - Field and Use the System
  - Support the Solution

Complex Problem

Definition

Parameters

Options

Observation

Systems Thinking

Process and Policy

Understanding

Products and Solutions

Systems Engineering
Systems Engineering Scope View

Scale

Players

Complexity

Device, Component, Subsystem, System, System of Systems, Enterprise Systems, Global Family of Systems
Systems Scope Relationships
Examples

Complexity vs. Scale

Device – Detector
Component - Sensor
Subsystem - IR Seeker
System – STD Missile
System of Systems - AEGIS BMD
Enterprise Systems – BMD Community
Global Family of Systems - Theater Defense
Systems Engineering Domain View

- Political
- Infrastructure
- Social
- Theoretical
- Medical
- Technical
- Acquisition
SE Fields or Branches View
A Systems Approach View

Operational Data Collection
Lessons Learned

Test & Evaluation
Product Development & Production

Prototype Development
Performance Demonstration
Critical Field Experiments

Technology Knowledge Transfer

Enabling Science & Technology
Hypothesis, Concept Development Trade-offs & Critical Experiments
Modeling and Simulations

Data Collection
Mission Performance Analysis

Capabilities Improvement
Needs Definition

Deployment

Operational Data Collection

Critical Needs

Solution Implementation

Prototype Development
Performance Demonstration
Critical Field Experiments

Solution Validation

Technology

Concept Exploration
Systems Engineering Approaches Views

Linear

- Concept Development
- Engineering Development
- Post Development

Spiral

- Need
- Concept Exploration
- Program/Project Definition
- Detailed Design
- Prototype
- Evaluation

Life cycle

- Requirements Analysis
- Functional Definition
- Physical Definition
- Design Validation
- Systems Engineering Method
- Objectives
- Systems Validation
- Operations and Maintenance
- Changes and Upgrades
- Retirement / Replacement

The “V”
# Products Views

<table>
<thead>
<tr>
<th>Critical Needs</th>
<th>Design (HW/SW) Products</th>
<th>Selected Reviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Requirements</td>
<td>Alternative Concepts</td>
<td></td>
</tr>
<tr>
<td>A-Specifications</td>
<td>Selected Concept / System Architecture</td>
<td>Technology Demos / Experimentation Articles / Simulations</td>
</tr>
<tr>
<td>Subsystem Specs / Component Specs</td>
<td>Preliminary Design</td>
<td>Virtual &amp; Physical Prototypes</td>
</tr>
<tr>
<td>“Design-to” Specs</td>
<td>Detailed Design</td>
<td>Components / Modules</td>
</tr>
<tr>
<td>“Built-to” Design</td>
<td>Integrated Subsystems / Tested System</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production System</td>
<td></td>
</tr>
</tbody>
</table>
Systems Engineering Components View

Scales

- Enterprise Systems Engineering
- System of Systems Engineering
- System Engineering

Groupings

- Enterprise Sub-enterprise
- Tens of System of Systems (Mission Strings)
- Hundreds of Independent Systems

Patterns

- Net-centric Capabilities-based Evolutionary Development
- Mission Capabilities-based Composition of Systems
- Functional Capabilities

Descriptions

- Broad Descriptions
- Mission Descriptions
- Functional Descriptions

Constraints

- Capabilities
- Functionalities
- Constraints

Examples

- Functional Descriptions
- Detailed Specifications
- Detailed Requirements
Enterprise System Engineering View

Demand for action → Context → Vision → Communication

Consistent, Meaningful

Strategy, Policy, Governance
Resource Mgmt, Architecture

Enterprise Alignment

Strategic Agenda for the Enterprise

Business
- Strategy
- Tactics
- Execution

Technical
- Strategy
- Tactics
- Execution

Acquisition
- Strategy
- Tactics
- Execution

Functional
- Strategy
- Tactics
- Execution

Unrelenting Change

Enterprise Assessment

Outcomes
Enterprise Systems Engineering

- Typical program domain
  - Traditional systems engineering
  - Chief Engineer inside the program; reports to program manager

- Transitional domain
  - Systems engineering across boundaries
  - Work across system/program boundaries
  - Influence vs authority

- Messy frontier
  - Political engineering (power, control…)
  - High risk, potentially high reward
  - Foster cooperative behavior

Source: Renee Stevens
Systems Engineering Standards View

DOD MIL Std 499B
DAU Systems Engineering Fundamentals 2002, 222 pages
USAF SMC SE Primer and Handbook 2005
INCOSE Guidebook 2006
EIA/IS 632
ISO 15288

• Continues to be a plethora of SE Processes
• US DoD continues to use DOD-STD-499B or IEEE-1220
• Non-DOD US Industry tends to use EIA-632 (and variants)
• International Industry tends to use ISO 15288
# Systems Engineering Tools View

**INCOSE Tools Database Working Group**

## The TDWG Charter is to:
Partner with appropriate INCOSE Functional Working Groups to host the SE Tools Database, a resource for systems engineers to obtain information on tools based on their specific needs.

## Published Products
Three Survey Response Databases:
1. Requirements Management
2. Systems Architecture
3. Measurements

General Tools Database
>1600 entries

## TDWG Chairs:
Randy Bullard, Dona Lee
Tdwg-info@incose.org

**INCOSE Web page:**
http://www.incose.org/practice/techactivities/wg/tools/

## Planned Work
1. Review and update current SE Tools Database (in-work)
2. Initiated design of Next Generation Tools Database System including stakeholder identification, functional analysis, and dialogue with current Architecture and Requirements Working Group partners (in-work)
3. Develop proposal requesting INCOSE funds to build the Next Generation Tools Database system
With all these Views what is the Mystery or Confusion Anyway!

How the customer explained it

How the Project Leader understood it

How the Analyst designed it

How the Programmer wrote it

How the Business Consultant described it

How the project was documented

What operations installed

How the customer was billed

How it was supported

What the customer really needed
UTADS Context Diagram

Urban Threat Assessment & Detection System (UTADS)

- COTS Providers
  - login, location, SW/HW planning need, commands
- Threat Device
  - location, physical signature, behaviors, biometrics
- Threat Individual
- Planning/Operational Environment
  - crowd info., architecture, weather...
- C2 User
  - power
- UTADS Installer/Maintainer
- Urban Operations Center/Backup Operations Center
- ATD/PTD Operator
  - login, ATD/PTD commands requests, ATD/PTD status
- HTD User/VTD User
  - HTD/VTD command
- Utility/Backup Power

Internal to UTADS:
- Schedule, issues, feedback request, UOC status
- Login, location, planning need, needs
- ATD/PTD login, ATD/PTD commands requests, ATD/PTD status
The Urban Threat Detection CONOPS - “OV-1”
Views: UTADS

City Planners

Politicians

Communication Systems

Public

Environmentalists

The Urban Threat Detection CONOPS - “OV-1”

Urban Operations Center

Command & Control

Industry

Financial Support

Architects

Construction

Information Systems

Engineers

Scientists

Protection, Enforcement & Rescue Workers

Public Health & Hospitals

Politicians

Urban Operations Center

Command & Control

Information Systems

Engineers

 Scientists

Industry

Financial Support

Architects

Construction

Information Systems

Engineers

 Scientists

Protection, Enforcement & Rescue Workers

Public Health & Hospitals

View: UTADS

City Planners

Politicians

Communication Systems

Public

Environmentalists

The Urban Threat Detection CONOPS - “OV-1”

Urban Operations Center

Command & Control

Industry

Financial Support

Architects

Construction

Information Systems

Engineers

 Scientists

Protection, Enforcement & Rescue Workers

Public Health & Hospitals

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CONOPs & Architectures
Bringing in New Capabilities into Existing Enterprises

Current Functioning Enterprise (No UTADS)

The Urban Threat Detection CONOPS - "OV-1"

What Needs to be Done?

Not in Current Functioning Enterprise

Existing
**Functional Diagram**

*Detect Threat*

The Urban Threat Assessment and Detection System (UTADS)

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**FUNC.1.1**

Detect Threat

ATD Behavior

**FUNC.1.2**

Maneuver to Specified Location/Angle

ATD Behavior

**FUNC.1.3**

ATD GPS Comp...

**FUNC.1.4**

Determine Threat Location

ATD GPS Comp...

**FUNC.1.5**

Determine Threat Location

ATD GPS Comp...

---

**Ref.**

**OR**

**AND**

**Refs.**

**FUNC.1.1**

Maneuver to Specified Location/Angle

ATD Behavior

**FUNC.1.2**

Monitor/Scan for Threat

ATD Behavior

**FUNC.1.3**

ATD GPS Comp...

**FUNC.1.4**

Determine Threat Location

ATD GPS Comp...

**FUNC.1.5**

Determine Threat Location

ATD GPS Comp...

---

**Accepted Commands**

**TDS Ready Status**

**TDS Status**

**Threat Location**

**Cells Phone Signal**

**INS Data**

**TDS Location Data**

**GPS Signal**

**Transmitted Operator Command**

**Raw Threat Data**

**TDS Location**

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**Project:** Urban Threat Assessment and Detection System

**Organization:** MITRE COHORT - TEAM 2

**Date:** December 11, 2010

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Physical Diagram
Threat Detection Subsystem

The Urban Threat Assessment and Detection System (UTADS)
Physical Diagram
Command and Control Subsystem

The Urban Threat Assessment and Detection System (UTADS)

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Allocated Diagram
Command and Control Subsystem

The Urban Threat Assessment
and Detection System (UTADS)
The Urban Threat Assessment and Detection System – System Project

Module
1. Introduction
2. Technical Management
3. Critical needs
4. Capability Assessment
5. Concept Exploration
6. Solution Validation
7. Detailed Design and Fab
8. Integration, T&E
9. Deployment
10. Future of SE

In Class Team Assignment
1. Introduction/Q&A/Objectives
2. Key Risks
3. CONOPS
4. System Level AOA
5. Functional Diagram
6. Technical Trade Study
7. Key Design Drivers
8. Verification Matrix and facilities
9. Deployment and Op Assessment
10. System Feasibility/Assessment
Okay, this probe is ready to orbit Saturn, extract rock samples from Jupiter, and examine the atmosphere of Neptune...

Now... if we can only get it to stop flashing "12:00."

We plan to add another deck...
Locking down requirements later in the life cycle

Defining customer requirements, “But I thought he said stonehinge?”
Systems Engineering
Academic Challenges

*Full MS SE program available at the HEAT Center*

*Flash News: MS SE Offering on base APG in Fall 2012*
Integrated Curriculum of SE courses

Prepares students to apply sound systems engineering principles in all aspects of analysis, design, development, integration, production & operation of modern high technology hardware & software systems for the full acquisition cycle

- Balanced DOD and commercial focus
  Operational/military examples used frequently
  Faculty from JHU APL or DoD background
  Seasoned SE professionals – Best Practices

- Emphasizes learning by doing
  Courses use case studies and emphasize team projects
  Apply SE principles to specific systems
  Highly interactive class sessions

- Provides multiple viewpoints
  APL and local co-instructors for each course
  All practicing senior systems engineers or managers
  Expert guest lecturers

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Degree Program Objectives

- Acquire the knowledge and problem-solving skills required to
  - Guide the development of modern complex systems.
  - Integrate systems and make tradeoffs between performance, cost, and schedule.
  - Employ the principles of systems engineering.

- Apply knowledge and skills to solve practical systems engineering problems
  - Exercise skills in analysis, synthesis and coordination of the various disciplines required to develop, engineer and produce a complex system to meet a customer's need.
  - Think through the entire complex process of system development, from analyzing requirements to deploying systems in the field.
JHU Systems Engineering Program

Over 1900 students enrolled per year – 960 Active students
Over 600 applicants 2010-2011
60% students are government employees or government contractors

Government Focused Offerings at:
- Pax River, MD (NAVAIR),
- Crystal City (NAVSEA)

Partnerships
- BAE Systems, NH
- Northrop Grumman Corporation
- LMCO, ELDP
- MITRE Corporation
- Raytheon Corporation

Public Offerings at:
- JHU Applied Physics Laboratory
- Dorsey Center near BWI
- Montgomery County, Rockville
- HEAT Center, Hartford County

Post Masters Graduate Certificate Program
First offerings in 2004

Doctorate in Engineering Systems
Under development – Expected Start Fall 2014
JHU Systems Engineering MS Student Enrollments

*1600 students 2009-2010
Concentrations in the Systems Engineering Program

- Systems Engineering (with two technical electives)
- Technical Management
- Human Systems Engineering (NEW)
- Software Systems Engineering
- Information Assurance Systems Engineering
- Biomedical Systems Engineering (not online)
- Modeling and Simulation Systems Engineering
Systems Engineering Basic Curriculum

Core Courses
- Introduction to Systems Engineering
- Management of Systems Projects
- Software Engineering Management
- System Conceptual Design
- System Design and Integration
- System Test and Evaluation

Select One of these four advanced Courses:
- Systems of Systems Engineering
- Enterprise Systems Engineering
- Systems Architecting, or
- Management of Complex Systems

Option A – Complete a one-semester Master’s Project and two relevant elective courses, or

Option B – (Recommended for students who plan to pursue doctoral studies) Complete a two-semester Master’s Thesis and one relevant elective course.
Academic Research Areas and Challenges

Systems Engineering Research Hot Topics

Architectures, systems security, organic adaptability, advanced M/S, humans systems integration, dynamic requirements, model based SE

Systems Engineering Challenges

SE centric vs domain systems focus
Quality vs growth
SE titles with experience or training
Increasing rigor in training and applications
Online vs classical education methods
STEM as SteM -- Opportunity

Current Systems need to be thought of as Systems of Systems with interfaces to infrastructure, people, energy and information systems.
One must keep fresh in the technical field to avoid obsolescence.

Leading multi-disciplinary teams and developing diverse products.

Focus on whole systems product.

Increasing Technical and Program Responsibility.

Interfacing with the customer and managing WBS, budgets and schedules.

Developing fiscal skills and tools through horizontal and lateral transitions.

Chief or Lead Systems Engineer
Attributes of a Applied Systems Engineer

- Problem Solver
- Communicator
- Thick-skinned
- Systems Perspective
- Determined
- Organized
- Leader
- Creative
- Interdisciplinary