Systems Engineering: Fundamental Skills and Why They are Important

Presented at the Minnesota SWE Spring Seminar 13 March 2010

Sysnovation, LLC
13741 Johnson Memorial Drive
Shakopee, MN 55379
www.sysnovation.com

David D. Walden
Voice: 952-807-1388
Email: Dave@sysnovation.com

Citation:

Walden, D., "Systems Engineering: Fundamental Skills and Why They are Important," ***Seventeenth Annual Professional Development Seminar,*** **(St. Paul, MN, USA, March, 2010), The Society of Women Engineers Minnesota (SWE-MN), 2010.**

Current Author Contact Information:
David D. Walden, CSEP
Sysnovation, LLC
13741 Johnson Memorial Drive
Shakopee, MN 55379
Voice: 952-807-1388
Email: Dave@sysnovation.com
www.sysnovation.com

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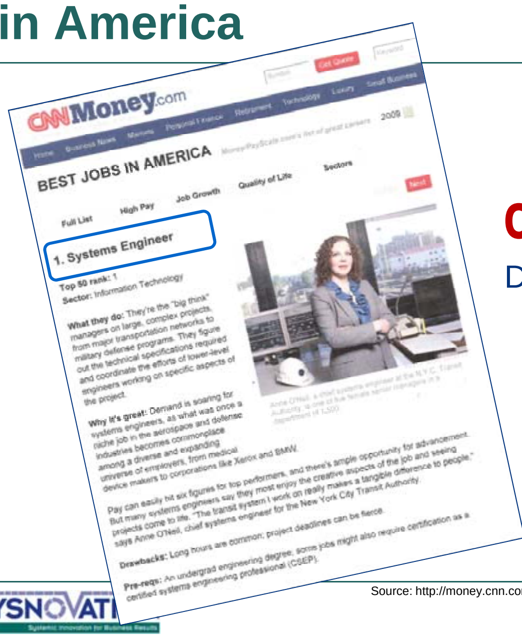
Systems Engineer Ranked as #1 job in America



CNNMoney.com

Date: Oct 2009

Source: http://money.cnn.com/magazines/moneymag/bestjobs/2009/snapshots/1.html

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Topics

- What is Systems Engineering?
- Fundamental Systems Engineering Maxims
- What are some key Systems Engineering Skills?
- Wrap Up and Conclusions

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Audience Participation: Key Definitions

- Before we become biased with others' definitions of the following terms, let's take some time to discuss your definitions of:
  - System
  - Systems Engineering
- Don't worry about a "formal" definition but rather focus on some key or unique ideas that define these terms.

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Formal Definitions of a System

- International Council on Systems Engineering (INCOSE):
  - An **integrated set** of **elements** that accomplish a **defined objective**. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements.
- ISO/IEC Standard 15288:2002
  - A **combination** of **interacting elements** organized to achieve one or more **stated purposes**
- Government Electronics & Information Technology Association (GEIA) Standard ANSI/EIA-632-1999
  - An **aggregation** of **end products** and **enabling products** to achieve a **given purpose**.
- Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE 1220-2005:
  - A **set or arrangement** of **elements** [people, products (hardware and software), and **processes** (facilities, equipment, material, and procedures)] that are **related**, and whose behavior **satisfies operational needs** and provides for the **life cycle sustainment** of the products.

Sources as indicated

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Formal Definitions of Systems Engineering

- International Council on Systems Engineering (INCOSE):
  - Systems engineering is an **interdisciplinary approach and means** to enable the **realization** of successful systems.
- Software Engineering Institute (SEI) Capability Maturity Model Integration (CMMI):
  - The **interdisciplinary approach** governing the total **technical** and **managerial** effort required to **transform** a set of customer needs, expectations, and constraints into a product solution and **support** that solution throughout the product's **life cycle**.
- Kossiakoff & Sweet:
  - The function of systems engineering is **guide the engineering** of complex systems.
- Blanchard & Fabrycky:
  - Basically, systems engineering is **good engineering** with special areas of emphasis (**top-down approach**, **life-cycle orientation**, **definition of system requirements**, and an **interdisciplinary or team approach**).

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Sources as indicated

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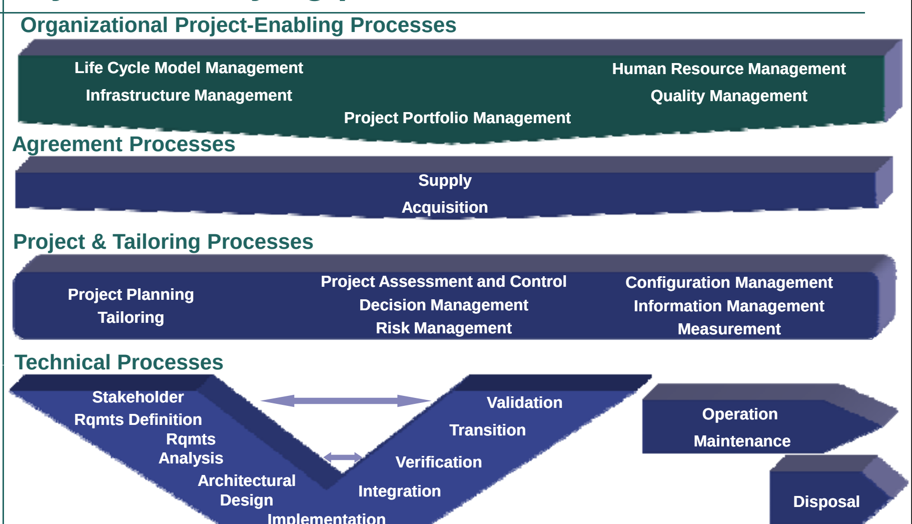
Another way to define Systems Engineering is by its underlying processes.



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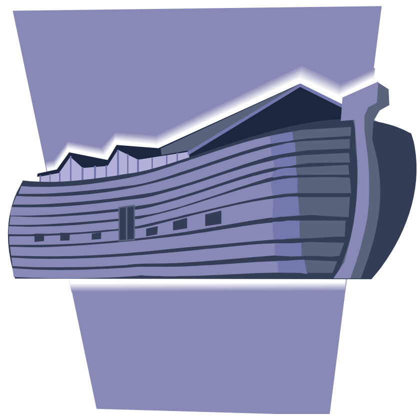
Adapted from ISO/IEC 15288:2008

Systems Engineering has Been Around for Awhile: An Early System Specification

- Genesis 6:13-16

  So God said to Noah, "... make yourself an ark of cypress wood; make rooms in it and coat it with pitch inside and out. This is how you are to build it: The ark is to be 450 feet long, 75 feet wide and 45 feet high. Make a roof for it and finish the ark to within 18 inches of the top. Put a door in the side of the ark and make lower, middle and upper decks…"



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Maxim

- n. 1 : a general truth, fundamental principle, or rule of conduct 2 : a saying of proverbial nature

Source: Webster's Collegiate Dictionary

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Fundamental Systems Engineering Maxims

1. Systems engineering **focuses on the whole**
2. Every system has a **life cycle**
3. Systems have **boundaries, interfaces, and hierarchies**
4. System **form** follows **function** follows **purpose**
5. A balanced system solution requires **trade-offs**
6. All systems have **risks** that must be managed
7. Following a **Systems Engineering process** increases your probability of success

These seven fundamental maxims permeate all aspects of the disciple of Systems Engineering.

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Fundamental Systems Engineering Maxims

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Systems Engineering Focuses on the System as a Whole

- Systems Engineering has its roots in Cybernetics and General Systems Theory
- Fundamental concepts leveraged include:
  - Holistic view
  - Understanding relationships
  - Emergent properties

A goal of Systems Engineering is to maximize positive emergent properties while minimizing negative emergent properties.

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Every system has a life cycle

- Many life cycle models exist:
  - Firms used to be concerned only with development and production, in that order
  - Then came "cradle to grave" life cycles
  - Now we have "lust to dust" life cycles

Systems Engineering leverages the concept of life cycles to ensure all aspects of the system, from concept through disposal, are considered.

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Example Life Cycle Stages

Stage	Purpose
Concept	Capture the stakeholders' requirements Define alternative concepts
Development	Refine system requirements Architect the system solution Build the system Verify and validate system
Production	Produce systems Inspect and test
Utilization	Operate system to satisfy users' needs
Support	Provide sustained system capability
Retirement	Store, archive, or dispose of the system

Adapted from ISO/IEC 15288:2002

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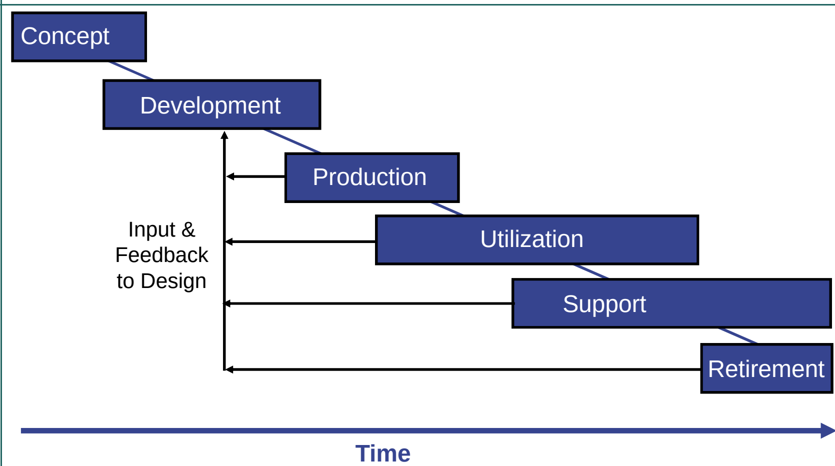
Life Cycle Thinking Creates Better Systems



"Think about the end before the beginning."

Adapted from ISO/IEC 15288:2002
Quote form ΩA, the Systems Engineering Honor Society 17

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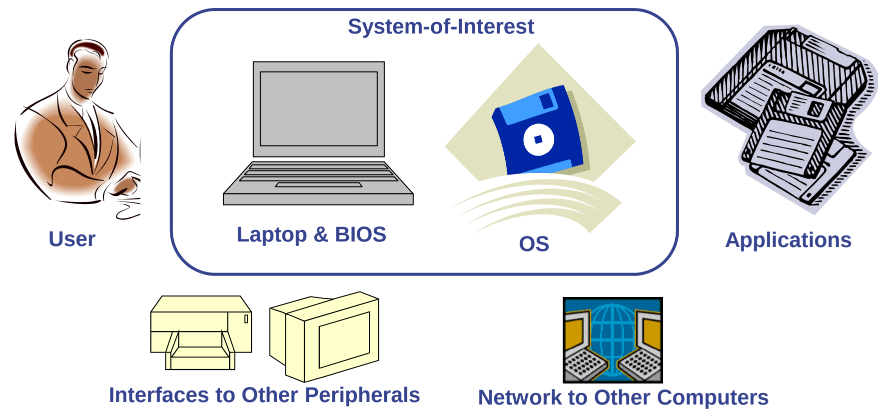
Systems Have Boundaries



System boundary definition is one of the key tasks of Systems Engineering -- what is in/not in of the system-of-interest.

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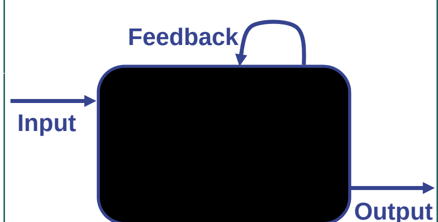
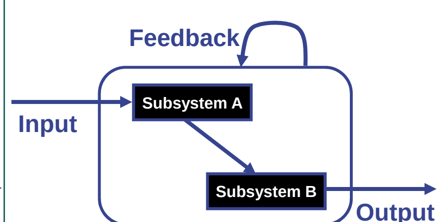
Systems Have Interfaces

- External Interfaces
  - Go across the system boundary
  - Treat the system as a "Black Box"



- Internal Interfaces
  - Within the system boundary
  - Treat the system as a "White Box"



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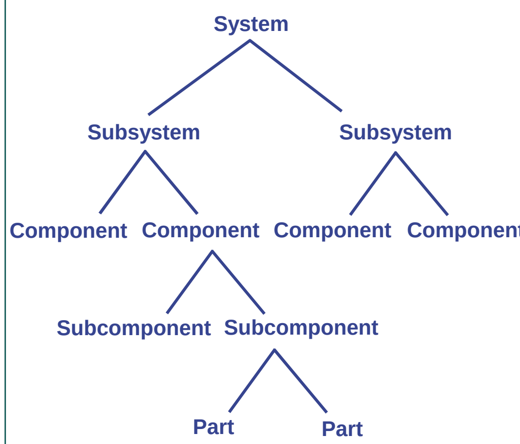
Systems Have Hierarchies

- Systems can be organized in a hierarchical manner
- A system hierarchy is a tree structure used to describe the system as consisting of its elements
- A system is designed from
  - system
  - to subsystems
  - to components
  - to subcomponents
  - to parts
- A system is integrated in the reverse order



Adapted from Kossiakoff & Sweet, 2003

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Form Follows Function Follows Purpose (Not Vice Versa)

- Purpose
  - Why the system is being realized
  - Defined by a Concept of Operations (CONOPS) and a set of Stakeholder Requirements
- Function
  - What the system must do
  - Defined by a Logical (or Functional) Architecture and a set of System Requirements
- Form
  - How the system does it
  - Defined by a Physical Architecture and a set of Component Requirements

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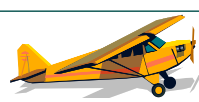
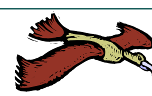
Function vs. Form





Function	Airplane Physical Component	Bird Physical Component
Take off & land	Wheels, skis, or pontoons	Legs
Sense position & velocity	Navigation, air data, radar	Eyes
Navigate	Computer	Brain
Produce horizontal thrust	Engine	Wings
Produce vertical lift	Wings	Wings

Adapted from University of Minnesota CCE On-Line SE Principles Course

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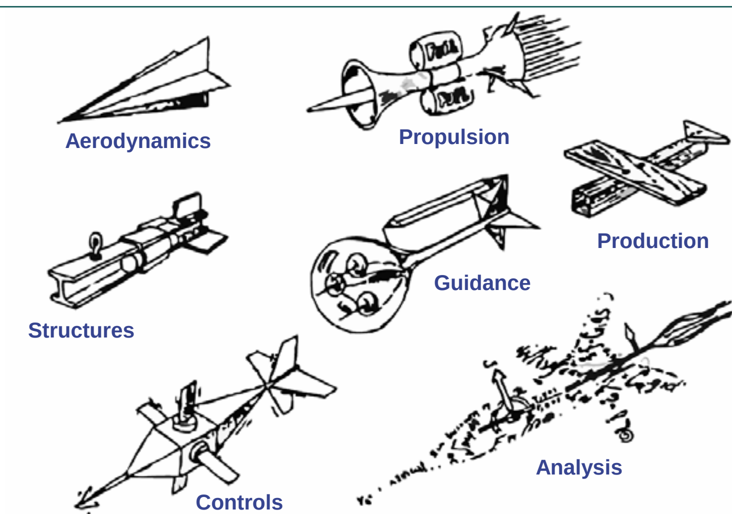
Systems Engineering has to Trade-off all of the Competing Interests and Perspectives so the best Balanced Solution can be Realized



Adapted from Kossiakoff & Sweet, 2003

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Systems Engineering is About Making Tough Decisions (and Sticking to Them)

- It is typically the Systems Engineers upon whom the difficult decisions fall
  - A system can only be optimized by addressing it as a whole
  - If any component of the system is optimized, then the overall system will not be optimized
- Systems Engineers use trade-off analyses to help with the decision making process

Good rule of thumb – if all the specialists aren't at least a little bit annoyed, it is likely the Systems Engineers did not do their job.

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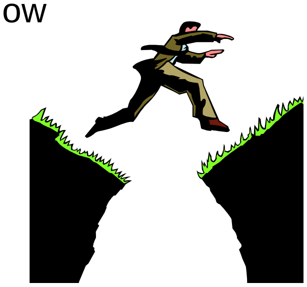
All Systems have Risks that Must be Managed

Unless you have...

- Technical goals that are very low
- An infinite schedule
- Unlimited budgets
- No enemies

… then you have risks!



All projects of significance have risk. Systems Engineering recognizes this and provides the methods and tools to manage risk.

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Fundamental Systems Engineering Maxims

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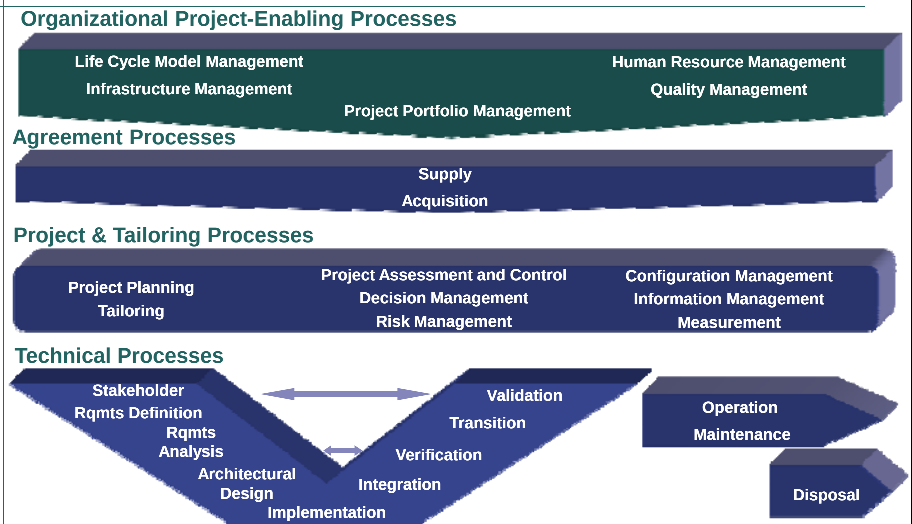
Here is one way to define the Systems Engineering Process



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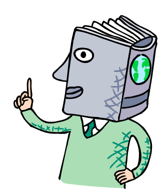
Adapted from ISO/IEC 15288:2008

Following a Systems Engineering Process Increases Your Probability of Success

- A standard process
  - Captures organizational knowledge
  - Allows for continual improvement
  - Helps avoid repeating mistakes
  - Lets you leverage industry best practices, such as external standards



- However, your standard processes must be tailored to the unique aspects of each project and system

"Not every process will apply universally."
"Reliance on process over progress will not deliver a system."
INCOSE Systems Engineering Handbook

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These seven fundamental maxims permeate all aspects of the disciple of Systems Engineering.

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Why is Systems Engineering Important?

- The new business reality – ever increasing…
  - System complexity & scope
  - Rate of change & delivery/time-to-market pressures
  - Use of multi-organizational & geographically distributed teams
  - Business performance expectations
- Systems Engineering's response:
  - Systems viewpoint focusing on the whole
  - Focus on providing a balanced systems solution
  - Focus on managing risks
  - Leadership in a distributed & integrated development environment
  - Discipline to deal with complexity

Systems Engineering is, and will continue to be, a critical discriminator in the development of modern systems.

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What is a Systems Engineer and why are they needed?

- An engineer in any field can (and should) apply the “Systems Engineering process” to his or her “system”
  - But this does not necessarily qualify them as a “System Engineer”
- There is a marked distinction between:
  - One who simply understands and can apply the Systems Engineering process to their discipline and
  - A trained, experienced Systems Engineer

- Four key aspects of a successful Systems Engineer
  - Knowledge of the discipline of Systems Engineering
  - Domain knowledge
  - Organizational knowledge
  - Appropriate soft skills (General Cognitive Characteristics, Abilities, Behavioral Competencies)

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General Cognitive Characteristics of Successful Systems Engineers

- Understanding the whole system and seeing the big picture
- Understanding interconnections; closed-loop thinking
- Understanding systems synergy
- Understanding the system from multiple perspectives
- Thinking creatively
- Understanding the systems without getting stuck on the details; tolerance for ambiguity and uncertainty
- Understanding the implications of proposed change
- Understanding a new system/concept immediately upon presentation
- Understanding analogies and parallelism between systems
- Understanding limits to growth

Source: Frank, Moti. "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST)." *Systems Engineering: The Journal of the International Council on Systems Engineering* 9, no. 2 (2006).

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Abilities of Successful Systems Engineers

- The ability to…
  - Analyze the need
  - Analyze/develop the concept of operations
  - Analyze requirements
  - Conceptualize the solution
  - Generate the logical solution (functional analysis)
  - Generate the physical solution (architectural synthesis)
  - "See" the future
  - Use simulations and systems engineering tools
  - Perform optimizations
  - Use system design considerations
  - Conduct trade studies

Source: Frank, Moti. "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST)." *Systems Engineering: The Journal of the International Council on Systems Engineering* 9, no. 2 (2006).

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Behavioral Competencies of Successful Systems Engineers

- Management skills
  - Team leader
  - Building and controlling the work plan
  - Defining boundaries
  - Taking into consideration non-engineering factors
- Good human relations; good team player; good communication skills; good interpersonal skills
- Autonomous and independent learner; strong learning skills
- Willing to deal with systems
- Curious, innovator, initiator, promoter, originator
- Asks good questions

Source: Frank, Moti. "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST)." *Systems Engineering: The Journal of the International Council on Systems Engineering* 9, no. 2 (2006).

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Top Individual Characteristics and Traits for the Development of Systems Thinking

- Thinking Broadly
- Curiosity
- Questioning
- Open-Minded
- Communication
- Tolerance for Uncertainty
- Strong Interpersonal Skills
- Thinking Out-of-the-Box

Source: Davidz, Heidi & Deborah Nightingale. "Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers." *Systems Engineering: The Journal of the International Council on Systems Engineering* 11, no. 1 (2008).

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Career Opportunities in Systems Engineering

- Junior SE Opportunities
  - Requirements Engineer
  - System Designer
  - Systems Analyst
  - System Modeler
  - Specialty Engineer
  - Verification/Validation Engineer
  - Logistics Engineer
  - Information/Data Manager
  - Configuration Manager
  - Process Engineer
  - Subsystem Lead
- Senior SE Opportunities
  - IPT Lead
  - Lead Systems Engineer
  - Principal Investigator
  - Deputy Technical Program Manager
  - SE Manager
  - SE Educator
  - Chief Architect
  - Chief Engineer
  - VP of Engineering
  - CTO
  - Consultant (?)

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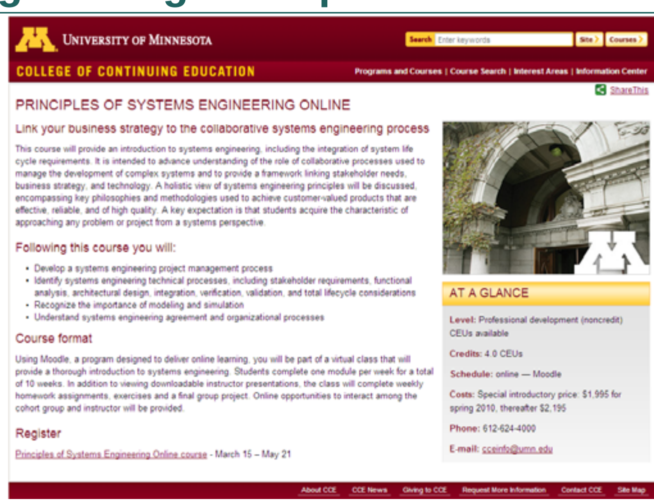
Shameless Plug for INCOSE Certification

ESEP	Expert Systems Engineering Professional
CSEP	Certified Systems Engineering Professional
ASEP	Associate Systems Engineering Professional
-Acq	US DoD Acquisition Extension

www.incose.org (click the "CSEP" logo)

Shameless Plug for On-Line Systems Engineering Principles Course



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PRINCIPLES OF SYSTEMS ENGINEERING ONLINE

Link your business strategy to the collaborative systems engineering process

This course will provide an introduction to systems engineering, including the integration of system life cycle requirements. It is intended to advance understanding of the role of collaborative processes used to manage the development of complex systems and to provide a framework linking stakeholder needs, business strategy, and technology. A holistic view of systems engineering principles will be discussed, encompassing key philosophies and methodologies used to achieve customer-valued products that are effective, reliable, and of high quality. A key expectation is that students acquire the characteristic of approaching any problem or project from a systems perspective.

Following this course you will:

- Develop a systems engineering project management process
- Identify systems engineering technical processes, including stakeholder requirements, functional analysis, architectural design, integration, verification, validation, and total lifecycle considerations
- Recognize the importance of modeling and simulation
- Understand systems engineering agreement and organizational processes

Course format

Using Moodle, a program designed to deliver online learning, you will be part of a virtual class that will provide a thorough introduction to systems engineering. Students complete one module per week for a total of 10 weeks. In addition to viewing downloadable instructor presentations, the class will complete weekly homework assignments, exercises and a final group project. Online opportunities to interact among the cohort group and instructor will be provided.

Register

Principles of Systems Engineering Online course - March 15 – May 21

AT A GLANCE

Level: Professional development (noncredit) CEUs available

Credits: 4.0 CEUs

Schedule: online — Moodle

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Wrap Up and Conclusions

- Presented a brief overview of the discipline of Systems Engineering
  - What is Systems Engineering?
  - Fundamental Systems Engineering Maxims
  - Systems Engineering Skills?
- Significantly more material is available to dig deeper into this topic
- Thank you for your time and participation!

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COMMENTS? QUESTIONS?