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Towards a 4-D Systems Engineering Cognitive Competency Model

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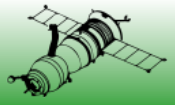



Introduction

- Much activity to develop systems engineering competency models has been done in recent years.
- This presentation focuses on SE cognitive competencies.
- First, twelve SE competency models are presented, chronology sorted according to the published year.
- Then, only the cognitive competencies are extracted from each model.
- Finally an integrated list of cognitive competencies is presented. The integrated list contains twenty cognitive competencies all related to systems thinking.

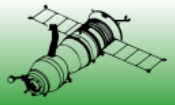
A SE competency framework: Why do we need it?

- Every enterprise strives to fill positions in the organization with employees who have the best chance to succeed.
- Employees are also interested in entering positions that fulfill their aspirations.
- The selection process for systems engineering positions should reliably predict those employees who can succeed and reject those who are likely to fail.
- Thus, there is a need to develop an objective competency framework to define the knowledge and skills needed by systems engineers in the workplace.
- The framework, once validated, may be used for systems engineering workforce selection and development, developing systems engineering curriculum and education and training programs and a standard tool for assessing systems engineers' competencies.

What is a 'Competency Framework'?

- A competency framework defines the knowledge, skills, and attributes needed for people within an organization. Each individual role has its own set of competencies needed to perform the job effectively (Mindtools, 2013).

- Review of already published systems engineering competency models reveals that most of them consist of areas (sometimes called dimensions, axes, clusters, etc.) such as knowledge, experience, proficiency level, skills, abilities, technical specialties, attributes, behavioral competencies (sometimes called personal behaviors, etc.) and systems thinking.


Why Focusing on Cognitive Competencies?

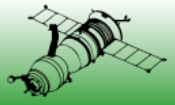
- Systems engineering **knowledge, skills and technical specialties** can be acquired through education, training and experience.
- **Professional development** through education, training and experience is not unique to the systems engineering discipline.
- **Behavioral competencies** (such as communication, management abilities, leadership, interpersonal skills, etc.) are required from managers in all fields and disciplines and vast amount of literature dealing with these topics has been published.
- This presentation focuses on **cognitive competencies** of successful systems engineers.

Cognitive Skills-Definition

- Cognitive functioning is a term referring to a human's ability to process thoughts.
- Cognition mainly refers to things like memory, the ability to learn new information, thinking, understanding, perception, attention skills, reasoning, processing audio/visual/spatial information.
- More terms related to cognition can be found in the literature: flexibility, anticipation, problem-solving, decision making, sequencing, etc.

What Next in This Presentation?

- First, twelve SE competency models are presented (chronology sorted according to the published year).
- Then, only the cognitive competencies are extracted from each model.
- Finally a unified list of cognitive competencies is presented.


Twelve SE Competency Models

(chronology sorted according to the published year).

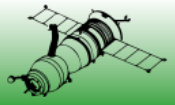
Model 1: Specifications or Traits for an "Ideal Systems Engineer" (Hall, 1962)

Hall's "ideal systems engineers" specifications or traits are grouped in several areas as follows (Hall, 1962):

- An ability to see the big picture.
- Objectivity.
- Creativity.
- Human Relations.
- Broker of Information.
- Education.
- Experience.

Model 2: Capacity for Engineering Systems Thinking (CEST) by Frank (2000; 2002; 2006)

- Frank (2000, 2002, 2006) has identified **eighty-three** competencies of successful systems engineers which he then has aggregated them to **thirty-four** competencies and classified them into:
  - 15 cognitive competencies
  - 9 skills/abilities
  - 7 behavioural competencies
  - 3 knowledge and experience related


Model 3: Systems Thinking Enablers
Davidz and Nightingale (2008)

- Experiential learning
  - Work experience
  - Education
  - Life experiences outside work
  - Training
- Certain individual characteristics
  - Thinking broadly
  - Curiosity
  - Questioning
  - Open-minded
  - Communication
  - Tolerance for uncertainty
  - Strong interpersonal skills
  - Thinking out of the box
- A supporting environment

Model 4: Whole-Brain Thinking
Di-Carlo and Khoshnevis (2006)

The competencies of successful system architects are:

1. Communication skills
2. High tolerance for ambiguity
3. The ability to make good associations of ideas
4. The ability to work consistently at an abstract level
5. Leadership; gets the most out of others
6. To seek multiple solutions; being multifaceted
7. The ability to build teams
8. Charisma
9. The ability to read people well
10. Self-discipline, self-confidence, a locus of control
11. A sense of faith or vision; having grand visions that extend beyond one's life
12. Curiosity, a generalist's perspective
13. Enthusiasm
14. Having reliable scientific knowledge and experience to attain practicality and optimality through quantitative, analysis based effort
15. Openness to new ideas
16. Technical expertise and enormous 'peripheral' knowledge to be exposed to vastly different modes of thinking.

Model 5: Advancing the Practice of Systems Engineering at JPL

Jansma & Jones (2006)

A systems engineering competency model along three axes:

- The ***processes*** axis encompasses nine systems engineering functions:
- The identified ***personal behaviors*** fall into five clusters.
- The ***technical knowledge*** axis encompasses twenty-one engineering disciplines and fields

Model 6: INCOSE UK SE Competencies Framework (2006)

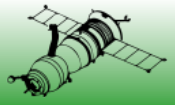
- **systems engineering ability comprises four key elements:**
  - competencies
  - supporting techniques
  - domain knowledge
  - basic skills and behaviors
- **The framework identifies 21 competencies categorized into three categories:**
  - systems thinking
  - holistic lifecycle view
  - systems engineering management
- **The full document presents the following information for each competency: a description, why it matters and effective indicators of knowledge and experience in four levels:**
  - Awareness
  - supervised practitioner
  - Practitioner
  - expert

Model 7: MITRE Systems Engineering Competency Model

- The model consists of 36 competencies organized into five sections (Metzger and Bender, 2007):
  - Enterprise Perspectives
  - Systems Engineering Life Cycle
  - Systems Engineering Planning and Management
  - Systems Engineering Technical Specialties
  - Collaboration and Individual Characteristics
- Successful MITRE systems engineers:
  - Define the sponsor's and customer's problem or opportunity
  - Apply systems thinking to create strategies, anticipate problems, and provide short- and long-term solutions
  - Adapt to change and uncertainty in the project and program environment
  - Propose a comprehensive, integrated solution or approach
  - Cultivate partnerships with sponsors and customers to work in the public interest
  - Bring their own and others' expertise to provide evidence and advice

Model 8: Characteristics of the Ideal Systems Engineer

- According to Burk (2008), the characteristics of the ideal systems engineer are:
  - Systems outlook
  - Customer/User/Consumer orientation
  - Inquisitiveness
  - Intuition
  - Discipline
  - Communication
  - Cooperation (but not capitulation)


Model 9: NASA Systems Engineering Competencies

- The SE competencies of NASA (2010) are structured according to competency areas, *competencies, competency elements and proficiency level description.*

There are 35 SE competencies organized in 10 areas as follows:

- Competency area 1.0 - concepts and architecture
- Competency area 2.0 - system design
- Competency area 3.0 - production, product transition, operations
- Competency area 4.0 - technical management
- Competency area 5.0 - project management and control
- Competency area 6.0 - internal and external environments
- Competency area 7.0 - human capital management
- Competency area 8.0 - security, safety and mission assurance
- Competency area 9.0 - professional and leadership development
- Competency area 10.0 - knowledge management

Model 10: The Maturity Model Framework

- The Maturity model (Kasser, Hitchins and Huynh, 2009), is a 2-D model in which:
  - The vertical axis or dimension defines the knowledge
  - The horizontal axis or dimension defines five increasing levels of ability needed to perform work successfully
- The vertical dimension covers the three areas: Knowledge, cognitive characteristics and individual traits.
- The five maturity levels are:
  - **Type I**. This type is an "apprentice who can be told "how" to implement the solution and can then implement it.
  - **Type II**. This type is the most common type of systems engineer. Type II's have the ability to follow a systems engineering process to implement a physical solution once told what to do.
  - **Type III**. Once given a statement of the problem, this type has the necessary know-how to conceptualize the solution and to plan the implementation of the solution, namely create the process to realize the solution.
  - **Type IV.** This type has the ability to examine the situation and define the problem.
  - **Type V.** This type is rare and combines the abilities of the Types III and IV, namely has the ability to examine the situation, define the problem, conceptualize the solution and plan the implementation of the physical solution.

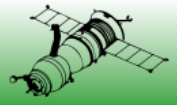
Model 11: A Systems Engineering Competency Taxonomy

- Squires et al. (2011) have built a systems engineering competency taxonomy from a selected set of existing competency models combined with systems thinking research.
- The final competency taxonomy covers 87 unique competencies and includes a proficiency table based on the learner's level of self-assessed and demonstrated ability.
- The eighty-seven competencies are organized in five sections:
  - Technical leadership
  - Technical management
  - Technical/Analytical skills
  - Project management competencies
  - Broad professional competencies

Model 12: Generic Competency Model (GCM)

- Armstrong et al. (2011) have presented the competencies required for successful acquisition of large, highly complex systems of systems.

- Their list of competencies is divided to 3 areas:
  - Foundations
  - Technical
  - Management and life cycle


Extracting the Cognitive Competencies from The 12 SE Competency Models

- Review of the twelve models reveals that all of them include cognitive competencies.
- However, most models do not particularly stress the cognitive competencies and some models present only few cognitive competencies.
- The integration (or the union) of the models' cognitive competencies produces twenty cognitive competencies of successful systems engineers.
- All the twenty cognitive competencies related to:

systems thinking

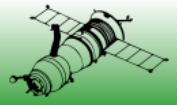
The Twenty Cognitive Competencies

Successful systems engineers:

- understand the whole system and see the big picture; think broadly; have grand visions; have a generalist's perspective; have holistic view; think strategically;
- able to work consistently at an abstract level;
- understand interconnections; closed-loop thinking; recognize patterns;
- understand system synergy (emergent properties);
- understand the system from multiple perspectives;
- think creatively; think out of the box; able to make good associations of ideas; able to seek multiple solutions; think laterally; think divergently;
- understand systems without getting stuck on details;
- tolerance for ambiguity and uncertainty; adapt to change;
- understand the implications of proposed change;
- understand a new system/concept immediately upon presentation;
- understand analogies and parallelism between systems;
- understand limits to growth;
- ask good (the right) questions; know when to ask; maintain healthy skepticism
- are innovators, originators, promoters, initiators, curious;
- are able to define boundaries;
- are open minded; open to new ideas
- are able to take into consideration non-engineering factors;
- "see" the technical/engineering future (vision); have a sense of faith or vision; anticipate problems; see future trends;
- think objectively
- think critically

Towards a 4-D Systems Engineering Cognitive Competency Model

- It is unlikely that a successful systems professional would possess all of these 20 cognitive competencies.
- Systems engineers may be considered as “successful systems engineers” even if they do not demonstrate all of the competencies listed in the unified list.
- It is more likely that a certain systems engineer possesses part of the listed competencies and is employed in a position that requires these specific competencies.
- Thus in order to complete the cognitive competency framework it is not enough to present list of cognitive competencies but also:
  - Role
  - Proficiency level
  - Competency level


The 2nd Dimension: Role

- Each individual role has its own set of competencies needed to perform the job effectively.
- For defining SE roles, a model such as Sheard's (1996)* model may be used.

* Sheard, S. "Twelve Systems Engineering Roles". *Proceedings of the INCOSE Sixth Annual International Symposium,* Boston, MA, 1996. Available online at: http://incose.org/educationcareers/PDF/12-roles.pdf

The 3rd Dimension: Proficiency Level

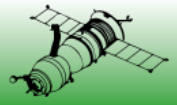
Model that may be used:

- INCOSE UK "Systems Engineering Competencies Framework" (2006) refers to four proficiency levels:
  - awareness
  - supervised practitioner
  - Practitioner
  - expert
- NASA (2010) model which also refers to four proficiency levels:
  - technical engineer/project team member,
  - subsystem lead,
  - project systems engineer
  - program systems engineer
- MITRE (2007) model refers to three proficiency levels:
  - Foundational
  - Intermediate,
  - Expert

The 4th Dimension: Competency Level

- Level of each cognitive competency of candidates for systems engineering jobs may be assessed by a tool such as the Interest Inventory proposed by Frank (2010) *

* Frank, M. "Assessing the interest for systems engineering positions and other engineering positions' required capacity for engineering systems thinking (CEST)". *The INCOSE Journal of Systems Engineering,* Vol. 13 (2010) no. 2, 161-174.


Conclusion

- A competency framework defines the knowledge, skills, and attributes needed for people within an organization.
- Each individual role has its own set of competencies needed to perform the job effectively.
- This paper focuses on cognitive competencies of successful systems engineers.
- First, twelve SE competency models are presented. Then, the cognitive competencies are extracted from each model. The integrated list contains twenty cognitive competencies all related to **systems thinking**.

Conclusion

- The 4 dimensions of the 4-D Systems Engineering Cognitive Competency Model are:
  - Cognitive competency (20 values?)
  - Role (12 values?)
  - Proficiency Level (3-4 values?)
  - Systems Thinking level (0-100 scale?)

- The model, once validated, may be used for systems engineering workforce selection and development, developing systems engineering curriculum and education programs and developing a tool for assessing systems engineering cognitive competencies.