Guide to the Systems Engineering Body of Knowledge (SEBoK) v1.4
-
Part 5: Enabling Systems Engineering

BKCASE

June 29, 2015

Contents

Cover

Letter from the Editor

A very warm welcome to all SEBoK users, both old and new. The BKCASE Editor in Chief (EIC) has overall responsibility for the continuing review and update of the SEBoK. Many thanks to the BKCASE Governors and the current members of the Editorial Board for supporting me.

I am delighted to be able to talk to you about SEBoK v. 1.4 which continues our commitment to regular review of the information referenced in our "Guide to the Systems Engineering Body of Knowledge".

This new version features changes to respond to publication of ISO/IEC/IEEE. 15288:2015 Systems and Software Engineering - System Life Cycle Processes and the INCOSE SE Handbook v4.0, 2015. Over the last 12 months the BKCASE Editorial Board has made significant efforts to become more involved in activities within our sponsoring organizations on key topics such as model based systems engineering (MBSE), systems of systems, systems engineering leadership, etc. You will begin to see the impact of this in v1.4 of the SEBoK, with further updates in v. 1.5, planned for Autumn 2015.

SEBoK v. 1.4

SEBoK v.1.4 feels like something of a turning point for the body of knowledge. On one hand we have “closed the loop” on the current cycle of updates to our core Systems Engineering reference sources, while on the other we have taken the first steps towards a richer relationship with other sources of knowledge and turned our focus onto some of the exciting transformations happening within Systems Engineering.

A brief summary of the changes in this version are given below, for details of content affected by these updates go to Acknowledgements and Release History.

A small but significant change has been made in SEBoK Part 2. This has been renamed from Systems to Foundations of Systems Engineering. This change reflects the focus of part 2 on the wider knowledge sources which underpin or enable good SE practice. While this has always been our aim for part 2, the old name was interpreted as an overview of all systems knowledge by some both inside and outside of BKCASE. This confusion led to a confusion in scope and purpose of some articles and miss understanding of our relationships with the systems science community. With this change we have begun to address this miss understanding and provide a firmer basis for this part of the SEBoK in future.

The most significant change to the SEBoK for v1.4 is in Part 3: SE and Management. A number of the technical and project process articles in SEBoK have been updated to reflect the revisions of ISO/IEC/IEEE 15288 (ISO 2015):

- A new “**Business or Mission Analysis Process**” has been added to the standard. This process defines SE activities to assist business or enterprise decision makers to define the problem space, identify the stakeholders, develop preliminary operational concepts, and distinguish environmental conditions and constraints that bound the solution space. This process follows the same approach as the Business or Mission Analysis article which was already in SEBoK. This article has been updated to better align with the standard.
- The “**Stakeholder Requirement Definition Process**” in the standard has been renamed “**Stakeholder Needs and Requirements Definition**”. The revised process builds on the change above to include more description of how to translate stakeholder needs and business strategy into requirements. The SEBoK article Stakeholder Needs and Requirements has been updated to better align with the standard; a new article Life Cycle Processes and Enterprise Need has been added to discuss how requirements can be related to business strategy and needs where appropriate.
- The “**Architectural Design Process**” in the standard has been replaced with an “**Architecture Definition Process**” which focuses more on the identification of stakeholder concerns and the higher level system architecture that will address the concerns. A new “**Design Definition Process**” describes how system architecture translates into realisable system design. Two new SEBoK articles System Architecture and System Design reflect

this revision of the standard and replace the previous article on architectural design. The Systems Requirements article has also changed to reflect these updates.

- The Logical Architecture Model Development and Physical Architecture Model Development SEBoK articles remain, describing the development of a couple commonly used architecture models in more detail as described in other standards, such as ISO/IEC/IEEE 42010, Systems and Software Architecture Description (ISO 2011).
- A new "**System Analysis Process**" has been added to the standard. This process defines SE activities to allow developers to objectively plan and carry out quantitative assessments of a system or aspects of a system, in order to select and/or update the most efficient system architecture and to generate derived engineering data. This process follows the same approach as the System Analysis article which was already in SEBoK. This article has been updated to better align with the standard.

Some of the changes to the standard build on the descriptions of SE which were developed for the SEBoK. This is not surprising, since many of the same authors were involved in both. The alignment of these views also includes the updated INCOSE SE Handbook v4.0 (INCOSE 2015), which now fully aligns with the standard. This completes a process which has overlapped the creation of the SEBoK. Going forward we plan to expand the scope of knowledge in the SEBoK to cover broader applications of SE within this generic framework of Life Cycle Processes. It is likely that this will shift the focus of activity from SEBoK Part 3 to SEBoK Part 4: Applications of SE and in particular the tailoring of SE to a range of application types and domains.

Some other small changes have been made in Parts 4, 5 and 7 as part of the ongoing review of SEBoK material to reflect new source material.

Future Direction for SEBoK

Once again, many thanks to the "core group of dedicated and knowledgeable contributing authors and reviewers" who make up the BKCASE community. It has been my privilege over the last 12 months to continue working with and grow this community and to expand our relationships with key organizations and groups both within systems engineering and outside of it.

The role of the Editorial Board is to work with this community of interest on an ongoing review of the current SEBoK content and structure and to develop plans for its maintenance and evolution. Our overall goals in evolving the SEBoK remain broadly the same as those outlined in the previous SEBoK updates. I have restated and slightly modified those goals below:

- Improve the ways in which Part 1 (SEBoK Introduction) provides a starting point for different SEBoK users to find and navigate knowledge relevant to them. This will include consideration of some of the SEBoK Use Cases which were not expanded in previous releases, and possible new case studies covering application domains such as Defense, Health Care or Transport.
- Review Part 2 (Foundations of Systems Engineering) with help from the International Society for the Systems Sciences (ISSS) to better understand the relationships between Systems Science (glossary) and Systems Thinking (glossary) as applied to engineered systems. We hope this will lead to an improved integration of systems principles, concepts, patterns and models into the other systems engineering focused knowledge areas across the SEBoK.
- Look for broader views on the key practices of Part 3 (Systems Engineering and Management) to feed back into the ongoing co evolution of key standards. In particular make more direct reference to the continuing evolution of Agile life cycle thinking and bring in more knowledge sources from the model based SE (MBSE) community.
- Expand our coverage of knowledge on systems engineering application and practices. In particular look for ways to bring in more knowledge on how systems engineering practices such as architecting, life cycle tailoring and model based systems engineering are applied in other domains.
- Identify the other groups, both within the systems engineering community and beyond, with interest in the topics of Part 5 (Enabling Systems Engineering) and Part 6 Related Disciplines and form stronger relationships with

them.

We continue to work towards ensuring that our coverage of existing systems engineering knowledge is complete and to push the boundaries of that knowledge into new approaches and domains. I also want to strengthen further our links to all members of the systems engineering community through things like the SEBoK Sandbox. If you are interested in any of the activity discussed above or if you have other topics which we should be considering please contact me or the appropriate member of the Editorial Board directly or use one of the available feedback mechanisms.

We have made a good start on gathering review comments and content suggestions from as wide a variety of individuals as possible to make the SEBoK a truly community-led product. Thank you to all those who have already joined this effort and I continue to look forward to working with many of you on future SEBoK releases.

Thank you,

BKCASE Governance and Editorial Board

BKCASE Governing Board

The three SEBoK steward organizations – the International Council on Systems Engineering (INCOSE), the Institute of Electrical and Electronics Engineers Computer Society (IEEE-CS), and the Systems Engineering Research Center (SERC) provide the funding and resources needed to sustain and evolve the SEBoK and make it available as a free and open resource to all. The stewards appoint the BKCASE Governing Board to be their primary agents to oversee and guide the SEBoK and its companion BKCASE product, GRCSE.

The BKCASE Governing Board includes:

- **INCOSE**
  - Paul Frenz, William Miller (Governing Board Chair)
- **IEEE Computer Society**
  - Richard Fairley, Massood Towhidnejad
- **SERC**
  - Art Pyster, Cihan Dagli

Past INCOSE governors Kevin Forsberg, David Newbern, David Walden, Courtney Wright, Dave Olwell, and Ken Nidiffer. The governors would also like to acknowledge John Keppler, IEEE Computer Society, who has been instrumental in helping the Governors to work within the IEEE CS structure.

The stewards appoint the BKCASE Editor in Chief to manage the SEBoK and GRCSE and oversee the Editorial Board.

Editorial Board

The SEBoK Editorial Board is chaired by an Editor in Chief, supported by a group of Associate Editors.

BKCASE Editor in Chief

Richard D. Adcock

Cranfield University (UK)

richard.adcock@incose.org [1]

Responsible for the appointment of SEBoK Editors and for the overall content and coherence of the SEBoK.

Each Editor has his/her area(s) of responsibility, or shared responsibility, highlighted in the table below.

SEBoK Part 1 SEBoK Introduction

Ariela Sofer

George Mason University (USA)

asofer@gmu.edu [2]

Responsible for Part 1

SEBoK Part 2: Systems

Cihan Dagli

Missouri University of Science & Technology (USA)

dagli@mst.edu [3]

Responsible for the Systems Approach Applied to Engineered Systems knowledge areas

Dov Dori

Massachusetts Institute of Technology (USA) and Technion Israel Institute of Technology (Israel)

dori@mit.edu [4]

Responsible for the Representing Systems with Models knowledge area

Duane Hybertson

MITRE (USA)

Jointly responsible for the Systems Fundamentals, Systems Science and Systems Thinking knowledge areas

Janet Singer (USA)

Jointly responsible for the Systems Fundamentals, Systems Science and Systems Thinking knowledge areas

Mike Yearworth

University of Bristol (UK)

Jointly responsible for the Systems Fundamentals, Systems Science and Systems Thinking knowledge areas

SEBoK Part 3: Systems Engineering and Management

Barry Boehm

University of Southern California (USA)

boehm@usc.edu [5]

Jointly responsible for the Systems Engineering Management and Life Cycle Models knowledge areas

Kevin Forsberg

OGR Systems

Jointly responsible for the Systems Engineering Management and Life Cycle Models knowledge areas

Gregory Parnell

University of Arkansas (USA)

gparnell@uark.edu [6]

Responsible for Systems Engineering Management knowledge area.

Garry Roedler

Lockheed Martin (USA)

garry.j.roedler@lmco.com [7]

Responsible for the Concept Definition and System Definition knowledge areas.

Ricardo Valerdi

University of Arizona (USA)

rvalerdi@email.arizona.edu [8]

Responsible for the System Realization knowledge area.

Ken Zemrowski

TASC

kenneth.zemrowski@incose.org [9]

Responsible for the Systems Engineering Standards knowledge area.

SEBoK Part 4: Applications of Systems Engineering

Judith Dahmann

MITRE Corporation (USA)

jdahmann@mitre.org [10]

Jointly responsible for Product Systems Engineering and Systems of Systems (SoS) knowledge areas

Rick Hefner

California Institute of Technology (USA)

Responsible for the Service Systems Engineering knowledge area.

Michael Henshaw

Loughborough University (UK)

M.J.d.Henshaw@lboro.ac.uk [11]

Jointly responsible for Product Systems Engineering and Systems of Systems (SoS) knowledge areas

James Martin *The Aerospace Corporation*

james.martin@incose.org [12]

Responsible for the Enterprise Systems Engineering knowledge area.

SEBoK Part 5: Enabling Systems Engineering

Heidi Davidz

Aerojet Rocketdyne (USA)

heidi.davidz@rocket.com [13]

Jointly responsible for the Enabling Individuals and Enabling Teams knowledge area

Emma Sparks

Cranfield University

Jointly responsible for the Enabling Individuals and Enabling Teams knowledge area

SEBoK Part 6 Related Disciplines

Alice Squires

Washington State University (USA)

alice.squires@wsu.edu [14]

Responsible for Part 6

SEBoK Part 7 Systems Engineering Implementation Examples

Brian Sauser
University of North Texas (USA)
brian.sauser@unt.edu [15]
Responsible for Part 7: Systems Engineering Implementation Examples, which includes Case Studies and Vignettes

Brian White
CAU>SE (USA)
bewhite71@gmail.com [16]
Responsible for Part 7: Systems Engineering Implementation Examples, which includes Case Studies and Vignettes

Graduate Reference Curriculum for Systems Engineering (GRCSE)

David H. Olwell
Naval Postgraduate School (USA)
Senior Editor for GRCSE.

Editorial Board Support

The Assistant Editor provide general editorial support across all topics and assist with both content improvement and production issues.

BKCASE Assistant Editor

Claus Ballegaard Nielsen
Cranfield University (UK)
c.nielsen@cranfield.ac.uk [17]

Interested in Editing?

The Editor in Chief is looking for additional editors to support the evolution of the SEBoK. Editors are responsible for maintaining and updating one to two knowledge areas, including recruiting and working with authors, ensuring the incorporation of community feedback, and maintaining the quality of SEBoK content. We are specifically interested in support for the following knowledge areas:

- System Deployment and Use
- Product and Service Life Management
- Enabling Businesses and Enterprises
- Systems Engineering and Software Engineering
- Systems Engineering and Procurement/Acquisition
- Systems Engineering and Specialty Engineering

If you are interested in being considered for participation on the Editorial Board, please visit the BKCASE website http://www.bkcase.org/join-us/or contact the BKCASE Staff directly at bkcase.incose.ieeecs@gmail.com [18].

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [19].

ENCODED_CONTENT
MTkwMDgPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

References

[1] mailto:richard.adcock@incose.org
[2] mailto:asofer@gmu.edu
[3] mailto:dagli@mst.edu
[4] mailto:dori@mit.edu
[5] mailto:boehm@usc.edu
[6] mailto:gparnell@uark.edu
[7] mailto:garry.j.roedler@lmco.com
[8] mailto:rvalerdi@email.arizona.edu
[9] mailto:kenneth.zemrowski@incose.org
[10] mailto:jdahmann@mitre.org
[11] mailto:M.J.d.Henshaw@lboro.ac.uk
[12] mailto:james.martin@incose.org
[13] mailto:heidi.davidz@rocket.com
[14] mailto:alice.squires@wsu.edu
[15] mailto:brian.sauser@unt.edu
[16] mailto:bewhite71@gmail.com
[17] mailto:c.nielsen@cranfield.ac.uk
[18] mailto:bkcase.incose.ieeecs@gmail.com
[19] http://www.sebokwiki.org/sandbox/

Acknowledgements and Release History

This article describes the contributors to the current version of the SEBoK. For information on contributors to past versions of the SEBoK, please follow the links under "SEBoK Release History" below. To learn more about the updates to the SEBoK for v. 1.4, please see the Letter from the Editor.

Governance

The SEBoK is shaped by the BKCASE Editorial Board and is overseen by the BKCASE Governing Board. A complete list of members for each of these bodies can be found on the BKCASE Governance and Editorial Board page.

Content and Feature Updates for 1.4

This is minor update, including changes related to ISO/IEC/IEEE 15288:2015 standard, updated articles in the areas of System Architecture, Life-Cycle processes, System of Systems, Competencies, Ethics and MBSE, as well as three new case studies.

For more information about this release please refer to Version 1.4.

SEBoK Release History

There have been 13 releases of the SEBoK to date, collected into 4 main releases.

- Version 1.0 – The first version intended for broad use.
- Version 1.1 - A minor update that made modest content improvements.
- Version 1.2 - A minor update, including two new articles and revision of several existing articles.
- Version 1.3 - A minor update, including three new case studies, a new use case, updates to several existing articles, and updates to references.

Click on the links above to read more information about each release.

Wiki Team

The wiki team is responsible for maintenance of the wiki infrastructure as well as technical review of all materials prior to publication.

- Claus Ballegaard Nielsen, Cranfield University.
- Kimberly Francia, IEEE

The wiki is currently supported by Daniel Robbins of WikiWorks.

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [19].

ENCODED_CONTENT
NDc5ODgPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

Part 5: Enabling Systems Engineering

Contents

Articles

References

Part 5: Enabling Systems Engineering

Enabling Systems Engineering

This part of the SEBoK is a guide to knowledge about how an enterprise prepares and positions itself to effectively perform the systems engineering (SE) activities described elsewhere in the SEBoK.

SE activities—how to develop requirements, select an appropriate life cycle model, and architect a system of systems, and so on—are covered elsewhere, especially in Part 3, Systems Engineering and Management. An organization that desires to do these things effectively must work through questions like whether to allow a project manager to select the systems engineers he or she employs, and, if so, what competencies the project manager might seek in those systems engineers. These are the kinds of questions that Part 5 explores.

The discussion defines three levels of organization: enterprise or business, team, and individual. To adapt an example to a more complex organizational structure, simply decompose enterprises into sub-enterprises and teams into sub-teams, as needed. For more about the different types of enterprises, see Types of Systems in Part 2.

Knowledge Areas in Part 5

Each part of the SEBoK is composed of knowledge areas (KA). Each KA groups topics around a theme related to the overall subject of the part.

The KAs in Part 5 explore how to enable an organization to perform SE:

- Enabling Businesses and Enterprises
- Enabling Teams
- Enabling Individuals

Common Practices

There are as many different ways to enable SE performance as there are organizations, and every organization's approach is detailed and unique. Nevertheless, common practices, methods, and considerations do exist. Part 5 uses them as a framework to structure the relevant knowledge.

SE activities that support business needs and deliver value are enabled by many factors, including

- Culture (see Culture),
- SE competencies (see Determining Needed Systems Engineering Capabilities in Businesses and Enterprises) and how the organization grows and deploys its workforce to acquire them, and
- SE tooling and infrastructure (see Systems Engineering and Management in Part 3).

Enterprises and Businesses

The fact that Part 5 uses two terms, “Enterprise” and “Business,” to name a single level of organization, indicates that the two are closely related. In many contexts it is not necessary to make any distinction between them: an enterprise may be a traditional business, and a business can be seen as a special type of enterprise. For the sake of brevity, the term “business” is used to mean “business or enterprise” throughout most of Part 5.

Traditional businesses usually have a legal structure and a relatively centralized control structure. Such a business may be a corporation, or a unit of a company or government agency, that creates a product line or offers services.

On the other hand, an enterprise can be structured in a way that excludes description as a business. This happens when the enterprise crosses traditional business boundaries, lacks a centralized legal authority, and has relatively loose governance. One example is the healthcare system in the US which encompasses hospitals, insurance companies, medical equipment manufacturers, pharmaceutical companies, and government regulators. Another is the set of companies that form the supply chain for a manufacturer, such as the thousands of companies whose parts and services Apple uses to create, distribute, and support the iPhone.

Significant actions that enable SE are often conducted by traditional businesses rather than by less tightly-structured enterprises. Even so, organizational context affects how the business approaches SE and therefore how it enables SE performance. A business that sells to the general commercial marketplace typically has far fewer constraints on its SE practices than one which performs contract work for a government agency. A business that creates systems with very demanding characteristics, such as aircraft, typically has a much more rigorous and planned approach to SE than one which creates less demanding systems, such as an app for a smartphone.

Traditional businesses are intended to be permanent, and typically offer a portfolio (glossary) of products and services, introduce new ones, retire old ones, and otherwise seek to grow the value of the business. Sometimes a single product or service has such value and longevity that it spawns a business or enterprise just for its creation, maintenance, and support. The Eurofighter Typhoon aircraft, for example, was developed by a consortium of three corporations that formed a holding company specifically to provide support and upgrade services throughout the in-service life of the aircraft.

For more on the distinction between businesses and enterprises and the value of systems engineering of enterprises to them, see Enterprise Systems Engineering in Part 4. Systems of Systems (SoS), also in Part 4, contrasts the tighter control over SE that is usual for businesses with the looser control that is usual for enterprises lacking a traditional business structure. Groupings of Systems in Part 2, discusses the Directed SoS, to which the traditional business may be equivalent.

Teams

Teams operate within the context of the businesses in which they reside. This context determines how the team is enabled to perform SE.

For example, a business may grant a team wide autonomy on key technical decisions, which are made either by systems engineers on the team or in consultation with team systems engineers. On the other hand, the same business could instead create a generic set of SE processes that all teams are to tailor and use, constraining the team to adhere to established business policies, practices, and culture. The business could even require that the team gain approval for its tailored SE process from a higher level technical authority.

Teams are usually formed for a limited duration to accomplish a specific purpose, such as creating a new system or upgrading an existing service or product. Once the purpose has been fulfilled, the team responsible for that effort is usually disbanded and the individuals associated with the effort are assigned to new tasks. Exceptions do happen, however. For example, a team of systems engineers tasked with assisting troubled programs throughout a corporation could persist indefinitely.

References

Works Cited

None.

Primary References

None.

Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
NTIyNjAPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

References

[1] http://www.sebokwiki.org/sandbox/

Enabling Businesses and Enterprises

Part 5 on Enabling Systems Engineering explores how systems engineering (SE) is enabled at three levels of an organization: the business or enterprise (hereafter usually just called "business" --- See Enabling Systems Engineering for more on this), the team, and individuals.

The **Enabling Businesses and Enterprises** Knowledge Area describes the knowledge needed to enable SE at the top level of the organization. Part 3, Systems Engineering and Management, describes how to perform SE once it has been enabled using the techniques described in Part 5. Moreover, a business is itself a system and can benefit from being viewed that way. (See Enterprise Systems Engineering in Part 4.)

Topics

Each part of the SEBoK is divided into knowledge areas (KAs), which are groupings of information with a related theme. The KAs in turn are divided into topics. This KA contains the following topics:

- Systems Engineering Organizational Strategy
- Determining Needed Systems Engineering Capabilities in Businesses and Enterprises
- Organizing Business and Enterprises to Perform Systems Engineering
- Assessing Systems Engineering Performance of Business and Enterprises
- Developing Systems Engineering Capabilities within Businesses and Enterprises
- Culture

Relationship Among Topics

- Systems Engineering Organizational Strategy describes how SE delivers value to the business, who makes decisions about SE in the business, how are those decisions made, how resources are allocated, and how the soundness and performance of those decisions are monitored.
- Determining Needed Systems Engineering Capabilities in Businesses and Enterprises describes how a business decides what specific SE capabilities are needed; e.g., a business that creates cutting edge products would likely require very strong architecting capabilities, including modeling tools. A business that has a global development team would likely need a very robust collaboration toolset.
- Organizing Business and Enterprises to Perform Systems Engineering describes various organizational models; e.g., which SE functions should be centralized, which should be distributed, how much SE every engineer should know.
- Assessing Systems Engineering Performance of Business and Enterprises describes how a business understands how well it is doing with respect to the SE actually being performed using the techniques described in Systems Engineering and Management.
- Developing Systems Engineering Capabilities within Businesses and Enterprises describes how SE talent that delivers the desired SE capabilities is grown and acquired
- Finally, Culture describes how the culture of a business affects SE; e.g., a risk-averse business will likely use plan-driven SE processes; an entrepreneurial fast-pace business will likely use agile SE processes (See Life Cycle Models).

To some extent, these topics have the character of a "plan-do-check-act" cycle, where the "do" part of the cycle is performing SE using the techniques described in Part 3, Systems Engineering and Management(Deming Part 3). For example, if assessing the business' SE performance shows shortfalls, then additional SE capabilities may need to be developed, the organization may need to be adjusted, processes may need to be improved, etc., all working within the existing cultural norms. If those norms prevent the business from successfully performing SE, then transformational efforts to change the culture may be needed as well.

References

Works Cited

Deming, W.E. 1994. *The New Economics*. Cambridge, MA, USA: Massachusetts Institute of Technology, Centre for Advanced Educational Services.

Primary References

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley and Sons.

Elliott, C. et al. 2007. *Creating Systems That Work – Principles of Engineering Systems for The 21st Century.* London, UK: Royal Academy of Engineering. Accessed September 2, 2011. Available at http://www.raeng.org.uk/education/vps/pdf/RAE_Systems_Report.pdf.

Hofstede, G. 1984. *Culture's Consequences: International Differences in Work-Related Values*. London, UK: Sage.

Lawson, H. 2010. *A Journey Through the Systems Landscape*. London, UK: College Publications, Kings College, UK.

Morgan, J. and J. Liker. 2006. *The Toyota Product Development System: Integrating People, Process and Technology*. New York, NY, USA: Productivity Press.

Rouse, W. 2006. *Enterprise Transformation: Understanding and Enabling Fundamental Change.* Hoboken, NJ, USA: John Wiley and Sons.

Senge, P. M. 2006. *The Fifth Discipline: The Art and Practice of the Learning Organization,* 2nd ed. New York, NY, USA: Currency Doubleday.

Shenhar, A.J. and D. Dvir. 2007. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Boston, MA, USA: Harvard Business School Publishing.

Additional References

INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities,* version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2.

ISO/IEC/IEEE. 2015. *Systems and Software Engineering -- System Life Cycle Processes*. Geneva, Switzerland: International Organisation for Standardisation / International Electrotechnical Commissions. ISO/IEC/IEEE 15288:2015.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MzExMDgPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Systems Engineering Organizational Strategy

Virtually every significant business (glossary) or enterprise (glossary) that creates products (glossary) or services (glossary) benefits from performing a wide variety of systems engineering (SE) activities to increase the value (glossary) that those products and services deliver to its owners, customers, employees, regulators, and other stakeholders. (See Stakeholder Needs and Requirements.)

A business is a specific type of enterprise, usually a legal entity with a management structure that allows for relatively tight control of its components...including how it enables SE. The term business is often used in this article in lieu of enterprise because specific actions to enable SE are typically done by businesses. This is discussed further in the parent article Enabling Systems Engineering. The strategy for organizing to conduct SE activities is important to their effectiveness. For example, every enterprise has a purpose, context, and scope determined by some of its stakeholders and modified over time to increase the value the enterprise offers to them.

Some enterprises are for-profit businesses. Others are not-for-profit businesses that work for the public good. Still others are non-traditional businesses, but more loosely structured entities without legal structure, such as a national healthcare system. Some enterprises are located at a single site, while some others are far-flung global "empires". Some work in highly regulated industries such as medical equipment, while others work with little government oversight and can follow a much wider range of business practices. All of these variations shape the strategy for performing SE.

Primary Considerations

SE organizational strategy is driven by the goals of the business and the resources and constraints available to achieve those goals. SE strategy in particular is influenced by several considerations:

- The purpose of the business
- The value the business offers its stakeholders; e.g., profits, public safety, entertainment, or convenience
- The characteristics of the system which the SE activities support; e.g., the size, complexity, primary design factors, major components, required products, critical specialties, or areas of life cycle
- The phases of the life cycle in which the SE activities are being performed; e.g., development, deployment, operations, or maintenance of a product or service
- The scale of the business, the systems and services of interest; e.g., is it a single site company or a global venture? Is the business creating a relatively modest product for internal use, such as a new Web application to track employee training, or a new hybrid automobile complete with concerns for engineering, manufacturing, servicing, and distribution?
- The culture of the business in which the SE activities are performed; e.g., is the business risk-averse? Do people normally collaborate or work in isolated organizations?
- The business structure and how well the current structure aligns with what is needed to create new products and services; e.g., does the structure of the business align with the architecture of its major products and services?
- The degree of change or transformation that the business is undertaking in its operation, products, and markets

Rouse (2006) offers a thorough look at enterprise strategy, especially as it relates to delivering value to the enterprise in various phases of the life cycle, beginning with research and development through operations. Rouse provides a number of techniques to determine and improve the value offered to enterprises using SE methods, especially useful when an enterprise is undergoing significant transformation rather than conducting "business as usual"; e.g., the enterprise could be trying to

- do current business better (drive down costs or improve quality of its current products and services);
- cope with a disruption in the market, a competitive threat, or changing customer expectations and ways of doing business;
- reposition itself in its value chain (move from being a part supplier to a subassembly supplier); or
- launch a new generation product or enter a new market.

Eisner (2008) provides a thorough look at different SE organizational approaches.

Systems Engineering Strategy Elements

Based on the primary considerations, the SE strategy generally addresses the following:

- How SE activities provide value to the business (See Economic Value of Systems Engineering)
- How SE activities are allocated among the various business entities (See Organizing Business and Enterprises to Perform Systems Engineering)
- What competencies are expected from the parts of the business in order to perform these SE activities (See Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises)
- How parts of the business gain and improve competencies (See Developing Systems Engineering Capabilities within Businesses and Enterprises)
- Who performs SE activities within each part of the business (See Team Capability)
- How people who perform SE activities interact with others in the business ((See Part 6: Related Disciplines)
- How SE activities enable the business to address transformation (See Enterprise Systems Engineering).

Depending on the business' approach to SE, there may not be a single coherent SE strategy common across the business. Different business units may have their own SE strategies, or development of a strategy may be delegated to individual projects. The SE strategy may not even be explicitly documented or may only be found in multiple documents across the business. Some businesses publish guidebooks and policies that describe their organizational strategy. These are usually proprietary unless the business is a government or quasi-government agency. Two public documents are NASA (2007) and MITRE (2012). The latter has a number of short articles on different topics including an article on Stakeholder Assessment and Management and another on Formulation of Organizational Transformation Strategies.

Product and Service Development Models

There are three basic product and service development models that most businesses employ:

1. Market-driven commercial
2. Product-line
3. Contract

The biggest differences between the three business models are where requirements risks lie and how user needs and usage are fed into the design and delivery process. SE support to the business varies in each case.

Market-driven commercial products and services are sold to many customers and are typically developed by organizations at their own risk. The requirements come from marketing based on understanding the market, relevant regulation and legislation, and good ideas from within the organization (Pugh 1991, Smith and Reinertsen 1997). Sillitto (1999) contends that market-driven commercial product development is a form of systems engineering with adapted techniques for requirements elicitation and validation.

Product-line products and services are variants of the same product and service, usually customized for each customer. Extra investment is required to create the underlying product platform. Architecting such a platform in a way that supports cost-effective customization is usually more complex both technically and organizationally than market-driven commercial products and services.

Systems engineers typically play a central role in establishing the platform architecture, understanding the implications of platform choices on manufacturing and service, etc. There are a number of examples of good practices in product line; e.g., automobile models from virtually all major manufacturers such as Toyota, General Motors, and Hyundai; Boeing and Airbus aircraft such as the B-737 family and the Airbus 320 family; and Nokia and Motorola cellphones. The Software Engineering Institute has done extensive research on product lines for software systems and has developed a framework for constructing and analyzing them (Northrop et.al. 2007). For a reference on product line principles and methods, see Simpson (et al. 2006).

Contract products and services often demand tailor-made system/service solutions which are typically specified by a single customer to whom the solution is provided. The supplier responds with proposed solutions. This style of development is common in defense, space, transport, energy, and civil infrastructure. Customers that acquire many systems often have a specific procurement organization with precise rules and controls on the acquisition process, and mandated technical and process standards. The supplier typically has much less flexibility in SE process, tools, and practices in this model than the other two.

Any single business or enterprise is likely to apply some combination of these three models with varying importance given to one or more of them.

Organizations That Use and Provide SE

There are five basic types of organizations that use SE or provide SE services:

1. A business with multiple project teams
2. A project that spans multiple businesses
3. An SE team within either of the above
4. A business with a single project team
5. An SE service supplier that offers a specific SE capability or service (tools, training, lifecycle process) to multiple clients, either as an external consultancy or as an internal SE function.

The kind of business determines the scope and diversity of SE across the organization. This is shown in abstract form in Figure 1, which illustrates the fundamental form of an extended enterprise. This also shows how organizational structure tends to match system structure.

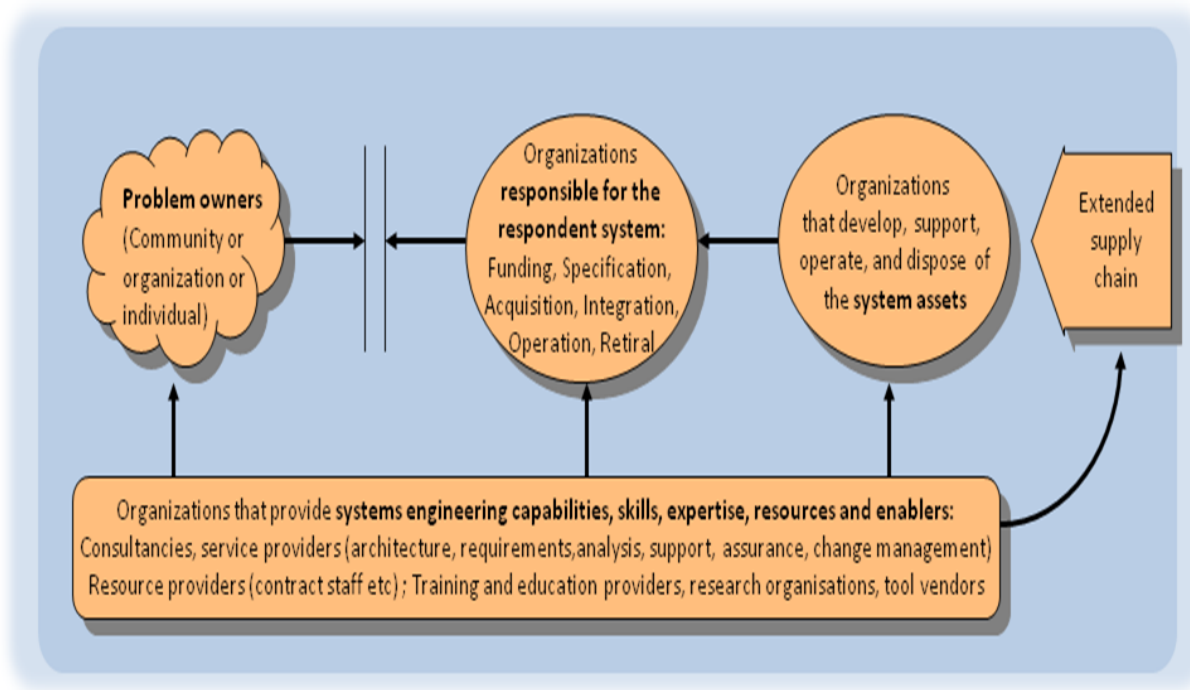

Figure 1. Organization Coupling Diagram. (SEBoK Original (Adapted from Lawson 2010))

The *problem owners* are the people, communities, or organizations involved in and affected by the *problem situation*. They may be seeking to defend a country, to improve transportation links in a community, or to deal with an environmental challenge. The *respondent system* might be a new fighter aircraft, a new or improved transportation infrastructure, or a new low-emission electricity generation systems (respectively). The organizations responsible for the respondent systems would be the Air Force, transport operator or regulator, or electricity supply company. The prime role of these organizations would be to operate the systems of interest to deliver value to the problem owners. They might reasonably be expected to manage the entire system lifecycle.

This same concept is expanded in Figure 2.

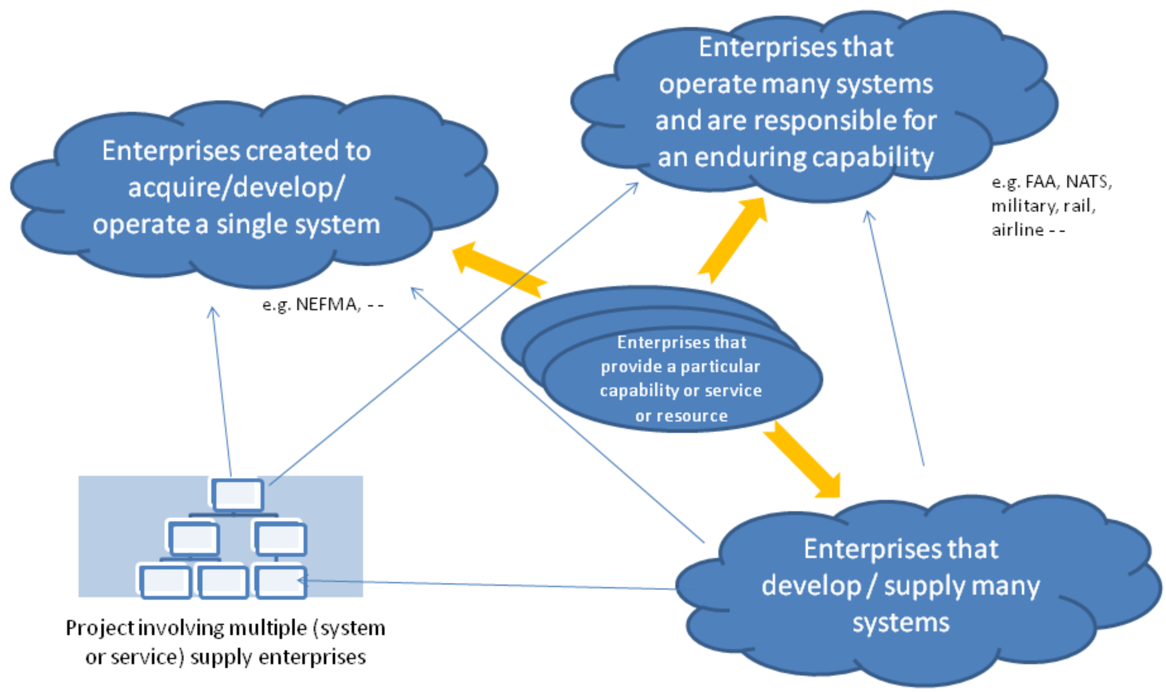

Figure 2. Systems Enterprises and Organizations. (SEBoK Original)

Goals, Measures, and Alignment in a Business

The alignment of goals and measures within the business strongly affects the effectiveness of SE and the benefit delivered by SE to the business, and needs to be carefully understood:

- Blockley and Godfrey (2000) describe techniques used successfully to deliver a major infrastructure contract on time and within budget, in an industry normally plagued by adversarial behavior.
- Lean thinking provides a powerful technique for aligning purpose to customer value – provided the enterprise boundary is chosen correctly and considers the whole value stream (Womack and Jones 2003; Oppenheim et al. 2010).
- Fasser and Brettner (2002, 18-19) see an organization as a system, and advocate three principles for organizational design: (1) increasing value for the ultimate customer, (2) strict discipline, and (3) simplicity.
- EIA 632 (ANSI/EIA 2003) advocates managing all the aspects required for the life cycle success of each element of the system as an integrated "building block". Similarly, Blockley (2010) suggests that taking a holistic view of *"a system as a process"* allows a more coherent and more successful approach to organization and system design, considering each element both as part of a bigger system-of-interest and as a "whole system" (a "holon") in its own right.
- Elliott et al. (2007) advocate six guiding principles for making systems that work: (1) debate, define, revise and pursue the purpose, (2) think holistic, (3) follow a systematic procedure, (4) be creative, (5) take account of the people, and (6) manage the project and the relationships.
- For organizations new to SE, the INCOSE UK Chapter has published a range of one-page guides on the subject, including Farncombe and Woodcock (2009a; 2009b).

Governance

SE governance is the process and practice through which a business puts in place the decision rights that enable SE to deliver as much business value as possible. Those rights may be codified in policy, implemented through the business structure, enforced through tools, and understood through measures of compliance and effectiveness.

SE governance in large businesses is often explicit and codified in policy. In small businesses, it is often tacit and simply understood in how the business works. One of the key implementation steps when a business defines its SE strategy is to establish its SE governance model, which should be tailored to the particular context in which the business operates and delivers value. Of course, in practice, this is often incremental and uneven, and subject to wide swings based on the current state of the business and the people occupying key management positions.

The term governance for development organizations was first popularized in reference to how Information Technology (IT) is overseen in businesses and enterprises (Weill and Ross 2006; Cantor and Sanders 2007). The recognition in the 1990s and the last decade that IT is a fundamental driver of performance and value for most corporations and government agencies led to the transformation of the Chief Information Officer (CIO) into a key senior manager.

Explicit governance of IT became important to enabling an enterprise to respond to new technology opportunities, emerging markets, new threats, and rapid delivery of new products and services. The term "governance" is now widely used to describe how SE is woven into an enterprise. Governance becomes especially challenging for complex projects in which there are high levels of uncertainty (Cantor 2006) or for system of systems projects in which responsibility for major decisions may be distributed over multiple organizations within an enterprise in which there is no single individual who is "in control" (see Systems of Systems (SoS)). Morgan and Liker (2006) describe the governance model for Toyota, which is one of the largest companies in the world.

SE governance establishes the framework and responsibility for managing issues such as design authority, funding and approvals, project initiation and termination, as well as the legal and regulatory framework in which the system will be developed and will operate. Governance includes the rationale and rules for why and how the enterprise policies, processes, methods and tools are tailored to the context. SE governance may also specify product and process measures, documentation standards, and technical reviews and audits.

The ways in which a team organizes to conduct SE activities either conform to policies established at the level above or are captured in that team's own governance policies, processes, and practices. These policies cover the organizational context and goals, the responsibilities for governance, process, practices and product at the level of interest, and the freedom delegated to and governance and reporting obligations imposed on lower organizational levels. It is good practice to capture the assignment of people and their roles and responsibilities in the form of the Responsible, Accountable, Consult, Inform (RACI) matrix (PMI 2013) or something similar. Responsibility in large organizations can easily become diffused. Sommerville et. al. (2009, 515-529) discuss the relationship between information and responsibility, and describe methods to analyze and model responsibility in complex organizations.

Small organizations tend to have relatively informal governance documentation and processes, while larger organizations tend towards more structure and rigor in their governance approach. Government organizations responsible for developing or acquiring large complex systems, such as the US Department of Defense or the US Federal Aviation Administration, usually develop policies that describe governance of their SE activities and SE organizations. See DoD (2012) for the Department of Defense SE policies.

Government contracting typically brings additional regulation and oversight, driving a group to greater rigor, documentation, and specific practices in their SE governance. Development of systems or operating services that affect public safety or security is subject to constraints similar to those seen in government contracting. Think of the creation of medical devices or the operation of emergency response systems, air traffic management, or the nuclear industry. (See Jackson (2010) for example).

Governance models vary widely. For example, Linux, the greatest success of the open source community, has a governance model that is dramatically different than those of traditional businesses. Smith (2009) offers a cogent explanation of how decisions are made on what goes into the Linux kernel. All of the decision rights are completely transparent, posted on the Linux website, and have proven remarkably effective as they have evolved. The classic paper *The Cathedral and The Bazaar* by Eric Raymond (2000) provides great insight into the evolution of Linux governance and how Linus Torvalds responded to changing context and circumstances to keep Linux so successful in the marketplace with a governance model that was radically novel for its time.

The project management literature also contributes to the understanding of SE governance (see Systems Engineering and Project Management). For example, Shenhar and Dvir (2007) offer the "diamond model" for project management, which identifies four dimensions that should guide how development projects are managed: novelty, technology, complexity, and pace. Application of this model to SE governance would influence the available life cycle models for development projects and how those models are applied.

There are numerous examples of projects that went well or badly based in large part on the governance practiced by both the acquirer and the supplier organizations. Part 7 of the SEBoK has several examples, notably the Singapore Water Management Vignette (went well) and FAA Advanced Automation System (AAS) Vignette (went not so well).

References

Works Cited

ANSI/EIA. 2003. *Processes for Engineering a System*. Philadelphia, PA, USA: American National Standards Institute (ANSI)/Electronic Industries Association (EIA). ANSI/EIA 632-1998.

Blockley, D. 2010. "The Importance of Being Process." *Journal of Civil Engineering and Environmental Systems*. 27(3).

Blockley, D. and Godfrey, P. 2000. *Doing It Differently – Systems for Rethinking Construction*. London, UK: Thomas Telford, Ltd.

Cantor, M. 2006. "Estimation Variance and Governance." In IBM developerWorks. Abstract [1] accessed on April 24, 2013.

Cantor, M. and J.D. Sanders. 2007. "Operational IT Governance." In IBM developerWorks. Accessed on September 15, 2011. Available at http://www.ibm.com/developerworks/rational/library/may07/cantor_sanders/.

DoD. 2012. "Systems Engineering Policy". Accessed on August 4, 2012. Available at http://www.acq.osd.mil/se/pg/index.html.

Eisner, H. 2008. "Essentials of Project and Systems Engineering Management", 3rd ed. Hoboken, NJ, USA: John Wiley & Sons.

Elliott, C. et al. 2007. *Creating Systems That Work – Principles of Engineering Systems for The 21st Century.* London, UK: Royal Academy of Engineering. Accessed September 2, 2011. Available at http://www.raeng.org.uk/education/vps/pdf/RAE_Systems_Report.pdf.

Fasser, Y. and D. Brettner. 2002. *Management for Quality in High-Technology Enterprises*. Hoboken, NJ, USA: John Wiley & Sons-Interscience.

Farncombe, A. and H. Woodcock. 2009a. "Enabling Systems Engineering". *Z-2 Guide,* Issue 2.0. Somerset, UK: INCOSE UK Chapter. March, 2009. Accessed September 2, 2011. Available at http://www.incoseonline.org.uk/Documents/zGuides/Z2_Enabling_SE.pdf.

Farncombe, A. and H. Woodcock. 2009b. "Why Invest in Systems Engineering". *Z-3 Guide,* Issue 3.0. Somerset, UK: INCOSE UK Chapter. March 2009. Accessed September 2, 2011. Available at http://www.incoseonline.org.

uk/Documents/zGuides/Z3_Why_invest_in_SE.pdf.

Jackson, S. 2010. *Architecting Resilient Systems: Accident Avoidance and Survival and Recovery from Disruptions.* Hoboken, NJ, USA: John Wiley & Sons.

Lawson, H. 2010. "A Journey Through the Systems Landscape". London, UK: College Publications, Kings College, UK.

MITRE. 2012. "Systems Engineering Guidebook". Accessed on August 4, 2012. Available at http://www.mitre.org/work/systems_engineering/guide/index.html.

Morgan, J. and J. Liker. 2006. *The Toyota Product Development System: Integrating People, Process and Technology.* New York, NY, USA: Productivity Press.

NASA. 2007. "NASA Systems Engineering Handbook". Accessed on April 24, 2013. Available at http://www.acq.osd.mil/se/docs/NASA-SP-2007-6105-Rev-1-Final-31Dec2007.pdf.Washington, DC, USA: NASA.

Northrop, L., P. Clements, et. al. 2007. *A Framework for Software Product Line Practice*, Version 5.0. With F. Bachmann, J. Bergey, G. Chastek, S. Cohen, P. Donohoe, L. Jones, R. Krut, R. Little, J. McGregor, and L. O'Brien. Pittsburgh, PA, USA: Software Engineering Institute.

Oppenheim, B., E.M. Murman, D.A. Secor. 2010. Lean Enablers for Systems Engineering. *Systems Engineering*. 14(1): 29-55.

PMI. 2013. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 5th ed. Newtown Square, PA, USA: Project Management Institute (PMI).

Raymond, E.S. 2000. *The Cathedral and The Bazaar,* version 3.0. Accessed on April 24, 2013. Available at http://www.catb.org/esr/writings/homesteading/cathedral-bazaar/cathedral-bazaar.ps.

Rouse, W. 2006. "Enterprise Transformation: Understanding and Enabling Fundamental Change." Hoboken, NJ, USA: John Wiley & Sons.

Shenhar, A.J. and D. Dvir. 2007. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Boston, MA, USA: Harvard Business School Publishing.

Sillitto, H. 1999. "Simple Simon Met A System". Proceedings of the 9th Annual International Council on Systems Engineering (INCOSE) International Symposium, 6-10 June, 1999, Brighton, UK.

Simpson, T.W., Z. Siddique, R.J. Jiao (eds.). 2006. *Product Platform and Product Family Design: Methods and Applications*. New York, NY, USA: Springer Science & Business Media, Inc.

Smith, J.T. 2009. "2.4 Kernel: How are Decisions Made on What Goes into The Kernel?" Available at http://www.linux.com/feature/8090.

Smith, P.G. and D.G. Reinertsen. 1997. *Developing Products in Half the Time*. New York, NY, USA: Wiley and Sons.

Sommerville, I., R. Lock, T. Storer, and J.E. Dobson. 2009. "Deriving Information Requirements from Responsibility Models." Paper presented at 21st International Conference on Advanced Information Systems Engineering, Amsterdam, Netherlands.

Weill, P. and J.W. Ross. 2004. *IT Governance: How Top Performers Manage IT Decision Rights for Superior Results*. Boston, MA, USA: Harvard Business School Publishing.Pugh, S. 1991. *Total Design: Integrated Methods for Successful Product Engineering.* New York, NY, USA: Addison-Wesley.

Womack, J. and D. Jones. 2003. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Revised Edition. New York, NY, USA: Simon & Schuster.

Primary References

Blockley, D. and Godfrey, P. 2000. *Doing It Differently – Systems for Rethinking Construction*. London, UK: Thomas Telford, Ltd.

Cantor, M. and J.D. Sanders. 2007. "Operational IT Governance." In IBM developerWorks. Accessed on September 15, 2011. Available at http://www.ibm.com/developerworks/rational/library/may07/cantor_sanders/.

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons.

Elliott, C., et al. 2007. *Creating Systems That Work – Principles of Engineering Systems for The 21st Century.* London, UK: Royal Academy of Engineering. Accessed September 2, 2011. Available at http://www.raeng.org.uk/education/vps/pdf/RAE_Systems_Report.pdf.

Lawson, H. 2010. *A Journey Through the Systems Landscape*. London, UK: College Publications, Kings College, UK.

Morgan, J. and J. Liker. 2006. *The Toyota Product Development System: Integrating People, Process and Technology*. New York, NY, USA: Productivity Press.

Northrop, L., P. Clements, et al. 2007. *A Framework for Software Product Line Practice,* version 5.0. With F. Bachmann, J. Bergey, G. Chastek, S. Cohen, P. Donohoe, L. Jones, R. Krut, R. Little, J. McGregor, and L. O'Brien. Pittsburgh, PA, USA: Software Engineering Institute. Accessed on April 25, 2013. Available at http://www.sei.cmu.edu/productlines/frame_report/index.html.

Rouse, W. 2006. *Enterprise Transformation: Understanding and Enabling Fundamental Change.* Hoboken, NJ, USA: John Wiley & Sons.

Shenhar, A.J. and D. Dvir. 2007. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Boston, MA, USA: Harvard Business School Publishing.

Additional References

Chastek, D., P. Donohoe, and J.D. Mcgregor. 2009. *Formulation of a Production Strategy for a Software Product Line*. Pittsburgh, PA, USA: Software Engineering Institute, CMU/SEI-2009-TN-025. Accessed on September 14, 2011. Available at http://www.sei.cmu.edu/reports/09tn025.pdf.

Sillitto, Mazzella, and Fromenteau. 2001. "The development of Product Lines in THALES: methods, examples, lessons learnt," Paper presented at the INCOSE UK Spring Conference.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MjA2MDIPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

References

[1] http://www.ibm.com/developerworks/library/?sort_by=&show_abstract=true&show_all=&search_flag=&contentarea_by=All+Zones&search_by=Estimation+Variance+and+Governance&product_by=-1&topic_by=-1&industry_by=-1&type_by=All+Types&ibm-search=Search

Determining Needed Systems Engineering Capabilities in Businesses and Enterprises

Enabling a business or enterprise to perform systems engineering (SE) well requires deciding which specific SE capabilities the business or enterprise needs in order to be successful. (In the rest of this article business or enterprise is usually abbreviated to just "business", because a business is a specific type of enterprise that has sufficiently strong central authority and motivation to take steps to enable SE). SE capabilities should support the Systems Engineering Organizational Strategy and reflect the nature of the business, its products and services, various stakeholders, business leadership focus, etc.

This topic, which is part of the Enabling Businesses and Enterprises knowledge area (KA) of Part 5, summarizes the factors used to decide which SE capabilities a business needs; e.g., the interactions between SE and other functional areas in the business, and consideration of social dynamics and leadership at the team and business levels. Needed capabilities may be decided and developed centrally by a business, or within teams and individuals, or through some combination of the two. Determination of team SE capability is discussed in the article Team Capability, and individual SE competencies are discussed in the article Roles and Competencies.

Relationship of this Topic to Enterprise Systems Engineering

Enterprise Systems Engineering and Capability Engineering techniques can be used to establish needed SE capabilities. At a high level of abstraction, the following are basic steps that could be used to decide the desired SE capabilities within the business:

1. understand the context;
2. determine the required SE roles;
3. determine the competencies and capabilities needed for each of the SE roles;
4. assess the ability and availability of the needed SE organizations, teams, and individuals;
5. make adjustments to the required SE roles based on the actual ability and availability; and
6. organize the SE function to facilitate communication, coordination, and performance.

See the article Organizing Business and Enterprises to Perform Systems Engineering for additional information. More information on context and required SE roles is provided below.

Contextual Drivers

The following discussion illustrates some of the contextual factors that influence the definition of the SE capability needed by a business.

Where the SE Activities are Performed in the Value Chain

The SE approach adopted by the business should depend on what role the organization plays. Ring (2002) defines a value cycle, and where the business sits in that cycle is a key influence of SE capability need.

- **Problem owner:** focus on identifying and scoping the system problem (defining system-of-interest (SoI)(glossary))and understanding the nature of the appropriate respondent system using Enterprise Systems Engineering and Capability Engineering approaches.
- **System operator:** focus on establishing all the necessary components of capability (glossary) to deliver the required services, as well as on integrating new system assets into the system operation as they become available (see Service Systems Engineering). The definition of the components of capability varies by organization - e.g.,
  - The US Department of Defense defines the components of capability as DOTMLPF: doctrine, organization, training, materiel, logistics, people, and facilities.
  - The UK Ministry of Defense defines the components of capability as TEPIDOIL; i.e., training, equipment, people, information, doctrine, organization, infrastructure, and logistics.
  - Other domains and organizations define the components of capability with similar, equivalent breakdowns which are either explicit or implicit.
- **Prime contractor or primary commercial developer:** focus on understanding customer needs and trading alternative solution approaches, then establishing a system team and supply chain to develop, deliver, support, and in some cases, operate the system solution. This may require enterprise SE (see Enterprise Systems Engineering) as well as "traditional" product SE (see Product Systems Engineering).
- **Subsystem/component developer:** focus on understanding the critical customer and system integrator issues for the subsystem or component of interest, define the component or subsystem boundary, and integrate critical technologies. This may exploit re-usable elements and can be sold in identical or modified forms to several customers. (In Part 4 of the SEBoK, see Systems of Systems, Enterprise Systems Engineering, and Product Systems Engineering for more information and references to the literature.)
- **Specialist service provider:** focus on specific process capabilities and competences which are typically sold on a time and materials or work package basis to other businesses.

Where the Enterprise Operates in the Lifecycle

The SE capabilities required by the business will depend on the system life cycle (glossary) phase(s) in which it operates (see Life Cycle Models in Part 3).

- **Concept definition phase:** requires the SE capability to identify a “problem situation,” define the context and potential concept of operations for a solution system, assess the feasibility of a range of possible solutions in broad terms, and refine the definition to allow the development of system requirements for the solution (see Concept Definition in Part 3).
- **System Definition phase:** requires the SE capability to influence concept studies (ensure feasible and understood by the development team), establish the trade space that remains at the end of the concept study, perform the system definition activities, including architecture design, and create a detailed definition of the system elements.
- **System realization phase:** requires the SE capability to configure the manufacturing and logistics systems for the system assets, and manufacture system assets (see System Realization in Part 3).
- **System deployment and use:** requires the SE capability to maintain business continuity during the transition to operation, bring the system into service, support system, monitor system performance, and respond to emerging needs (see System Deployment and Use. Elliott et al. (2008) describe the different emphases that should be placed

in SE during the "in-service" phase. This phase particularly requires the business to be able to perform SE at an appropriate operational tempo.

- **Retirement phase:** requires the SE capability for ensuring the safe retirement of systems and keeping them in a state ready for re-activation (“mothballed”), safe disposal of the system assets.

Nature of Responsibility to End Users and Society

Depending on the business model and the contracting environment, the business may find that its responsibility to end users is

- **explicit**, or spelled out by clear requirements and prescriptive legislation; or
- **implicit**; i.e., a legal or ethical obligation to ensure “fitness for purpose” which may be enforced by commercial frameworks, national or international standards, and specific product liability legislation.

Typically, businesses whose business model is contract driven focus on satisfying explicit requirements, whereas market-driven businesses have to be more aware of implicit responsibilities.

Nature of Responsibility to Customers

The business may contract with its customers to deliver any of the following:

- **an outcome**: The intended benefits the system is expected to provide, requires enterprise systems engineering;
- **an output**: Deliver or operate the system or part of it against agreed acceptance criteria; requires product systems engineering;
- **an activity**: Perform a specified set of tasks, requires service systems engineering; and
- **a resource**: Provide a specified resource; requires focus on individual competencies - see Enabling Individuals.

Scale of Systems

The business or enterprise may need very different SE approaches depending on the scale of the system at which the business operates. The following categories are based on Hitchins’ five layered system model (Hitchins 2005):

- **Level 1: Subsystem and technical artifacts –** focus on product systems engineering and on technology integration.
- **Level 2: Project systems –** focus on product systems engineering with cross-discipline and human integration.
- **Level 3: Business systems –** focus on enterprise systems engineering , service systems engineering to implement them, and on service management (Chang 2010) and continuous improvement (SEI 2010b); see also Quality Management) for the day to day running of the business.
- **Level 4: Industry systems –** If there is a conscious effort to treat an entire industry as a system, the focus will be on Enterprise Systems Engineering, and on the long-term economic and environmental sustainability of the overall industry.
- **Level 5: Societal systems –** Enterprise systems engineering is used to analyze and attempt to optimize societal systems (see Singapore Water Management Vignette in Part 7).

Sillitto (2011) has proposed extending this model to cover sustainability issues by adding two additional layers, the “ecosystem” and the “geosystem”.

Complexity of Systems Integration Tasks and Stupples' levels

Creating Systems That Work – Principles of Engineering Systems for The 21st century identifies three "kinds" of SE, originally proposed by Stupples (2006), that have to do with the level of cross-disciplinary integration involved (Elliot et al. 2007)

1. Within a discipline (e.g., software, hardware, optics, *or* mechanics), the SE focus is on taking a systems view of the architecture and implementation to manage complexity and scale within a single engineering discipline.
2. In multiple disciplines (e.g., software, hardware, optics, *and* mechanics), the SE focus is on holistic integration of multiple technologies and skills to achieve a balanced system solution.
3. In socio-technical systems integration, the SE focus is on getting people and the non-human parts of the system working synergistically.

Sillitto (2011) proposed extending this model properly to cover sustainability issues by adding one additional level, "Environmental Integration". He describes this level and show how the Stupples' levels relate to other dimensions used to categorize systems and professional engineering skills.

Criticality of System and Certification Requirements

The level of rigor in the SE approach adopted by the business will depend on the criticality of various classes of requirement. (See Systems Engineering and Specialty Engineering.)

- Safety and security requirements often demand specific auditable processes and proof of staff competence.
- Ethical and environmental requirements may require an audit of the whole supply and value chain.
- Extremely demanding combinations of performance requirements will require more design iteration and more critical control of component characteristics; e.g., see Quality Management and *Management for Quality in High-Technology Enterprises* (Fasser and Brettner 2010).

The Nature of a Contract or Agreement

The nature of the contractual relationship between a business and its customers and end users will influence the style of SE.

- Fixed price, cost plus, or other contracting models influence the mix of focus on performance and cost control and how the business is incentivized to handle risk and opportunity.
- In mandated work share arrangements, the architecture of the product system may be compromised or constrained by the architecture of a viable business system; this is often the case in multi-national projects and high profile government procurements (Maier and Rechtin 2009, 361-373).
- In self-funded approaches, the priorities will be requirements elicitation approaches designed to discover the latent needs of consumers and business customers, as well as development approaches designed to achieve rapid time to market with a competitive offering, or to have a competitive offering of sufficient maturity available at the most critical time during a customer's selection process.
- In single phase or whole-life approaches, the business may be able to optimize trade-offs across the development, implementation, and in-service budgets, and between the different components of capability (glossary).

The Nature and Predictability of Problem Domain(s)

Well-defined and slowly-changing technologies, products, and services permit the use of traditional SE life cycle models based on the waterfall model because the requirements risk and change is expected to be low (see Life Cycle Models).

Poorly defined and rapidly changing problem domains, with operators subject to unpredictable and evolving threats, demand more flexible solutions and agile processes. SE should focus on modular architectures that allow rapid reconfiguration of systems and systems-of-systems, as well as rapid deployment of new technologies at a subsystem level to meet new demands and threats.

Fundamental Risks and Design Drivers in the Solution Domain

When the solution domain is stable, with a low rate of technology evolution, and systems use mature technology, the focus is on optimum packaging and configuration of known and usually well-proven building blocks within known reference architectures, and on low-risk incremental improvement over time.

When there is rapid technology evolution, with pressure to bring new technologies rapidly to market and/or into operational use, the SE approach has to focus on technology maturation, proof of technology and integration readiness, and handling the technology risk in the transition from the lab to the proof of concept to the operational system.

There is usually a trade-off between lead time expectations and the level of integrity/certification. In the development of new systems, short lead times are seldom compatible with high levels of system integrity and rigorous certification.

Competitive Situation and Business Goals

The business drivers for SE deployment may be one or more of the following:

- To perform existing business better;
- To recover from a competitive shock or a shift in clients' expectations;
- To develop a new generation product or service;
- To enter a new market; and/or
- To reposition the business or enterprise in the value chain.

In the first case, SE can be deployed incrementally in parts of the business process where early tangible benefits can be realized. This could be the early steps of a business-wide strategic plan for SE. (See Systems Engineering Organizational Strategy for more on setting SE strategy and Developing Systems Engineering Capabilities within Businesses and Enterprises for improving SE capabilities.)

In the other cases, the business is going through disruptive change and the early priority may be to use systems thinking (see Systems Thinking) and enterprise SE approaches to scope the transformation in the context of a major change initiative.

Type of System or Service

There are three distinct flavors of products or service types (see Systems Engineering Organizational Strategy):

1. In a product or productized service, the focus will be on predicting how the market might change during the development period, eliciting, anticipating, and balancing requirements from a variety of potential customers, and optimizing features and product attractiveness against cost and reliability.
2. In a custom solution (product or service) the focus will be on feasible and low-risk (usually) approaches to meet the stated requirement within budget, using system elements and technologies that are known or expected to be available within the desired development timescale.
3. Tailored solutions based on standard product and/or service elements require a much more sophisticated SE process that is able to use a “product line approach” to blend standard modules with planned adaptation to meet clients’ specific needs more quickly and cheaply than would be possible with a single contract solution. The business needs to manage the life cycle and configuration of the standard modules separately from, but coherently with, the life cycle and configuration of each tailored solution.

Needed Systems Engineering Roles

After understanding the context for the business, the next step is to determine the SE capabilities required in the role in the business. The SEI Capability Maturity Models for acquisition, development, and services (SEI 2007; SEI 2010a; SEI 2010b) provide a framework for selecting SE capabilities relevant to different types of business. Existing SE competency models can be used to assist in determining the needed capabilities. An example is the INCOSE SE Competencies Framework (INCOSE 2010). (See Roles and Competencies for more information on competency models.).

There can be a wide spectrum of the spread of SE focus, from SE being focused in a specialist role, an interface or glue role (Sheard 1996), or the idea that “SE is good engineering with special areas of emphasis… including interfaces between disciplines” (Blanchard and Fabrycky 2005) and so it is shared by all. In any organization where activities and skills are shared, there is always a danger of silos or duplication.

As part of the role definition, the business must define where an individual doing SE fits into career progression (what roles before SE, what after?). Developing Individuals describes how individuals improve SE; the organization must define the means by which that development can be enacted. Businesses need to customize from a range of development strategies; see, for example, Davidz and Martin (2011).

As shown in Figure 1 below, management action on workforce development will be required if there are systemic mismatches between the competencies required to perform SE roles and the actual competencies of individuals. The organizational culture may have a positive or negative effect on team performance and the overall value added by the business (see Culture).

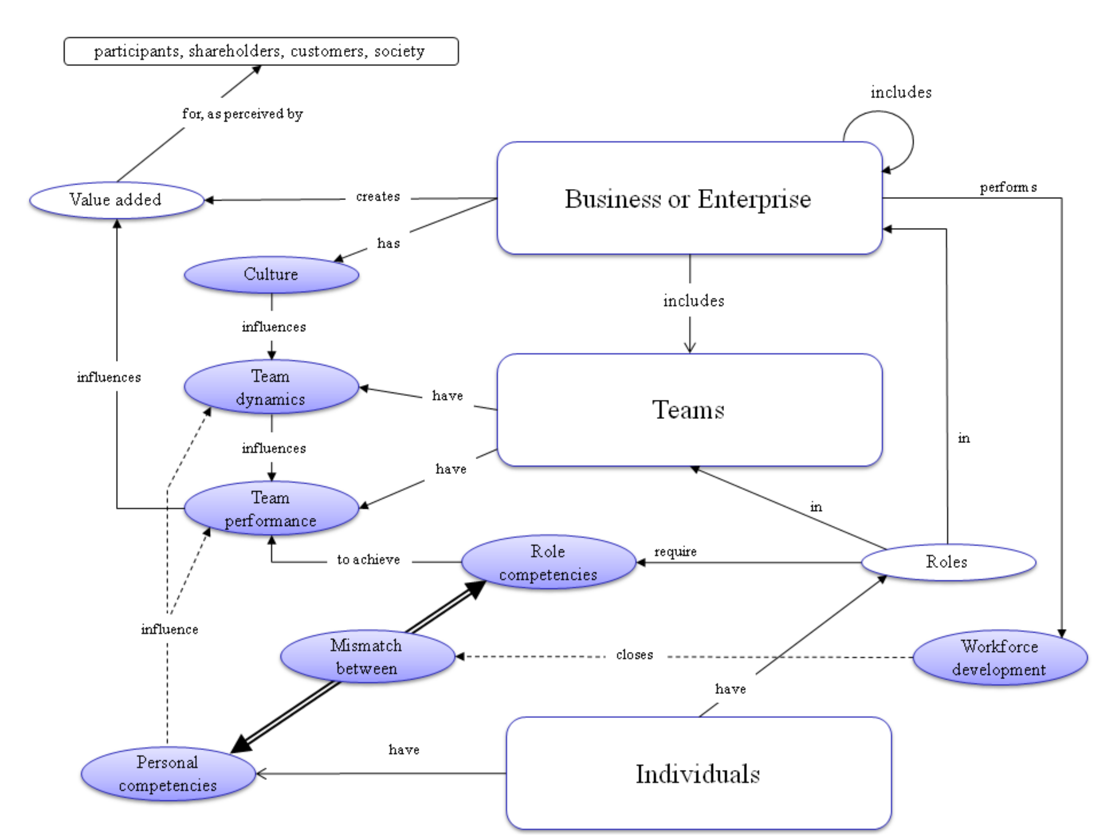

Figure 1. Culture, Competence, Team Performance and Individual Competence. (SEBoK Original)

Required SE Processes and Methods

The decisions on how to implement SE capability must be embedded in the businesses processes and its availability methodologies and toolsets. Embedding SE principles, processes, and methods in the organization's quality management system means that senior management and the quality system will help embed SE in the organizational business process and make sure it is applied (INCOSE 2012; ISO/IEC 2008; see Quality Management).

When defining the processes and tools, a balance between the need for a systematic and standardized approach to SE processes, such as that seen in INCOSE (2012), with the flexibility inherent in systemic thinking is critical. Systems thinking helps the organization understand problem situations, remove organizational barriers, and make the most of the organization's technical capabilities (see Beasley (2011)).

Need for Clarity in the SE Approach and the Dangers of Implementing SE

Clarity on how the organization does SE is important. Typically, implementing SE may be part of an organization's improvement, so Kotter's principles on creating a vision, communicating the vision, and empowering others to act on the vision are extremely relevant (Kotter 1995). The way an organization chooses to do SE should be part of the vision of the organization and must be understood and accepted by all.

Many of the major obstacles in SE deployment are cultural (see Culture).

One of the lean enablers for SE is to "pursue perfection" (Oppenheim et al. 2010). The means of improvement at a business or enterprise level are discussed in detail elsewhere, but the starting point has to be deciding what SE capabilities the organization wants. It needs to be recognized that the needed capabilities change over time (learning, improving, or losing capability). Thus, balancing SE with everything else that it involves is an ever changing process.

References

Works Cited

Beasley, R. 2011. "The Three T's of Systems Engineering." Paper presented at the 21st Annual International Council on Systems Engineering (INCOSE) International Symposium. June 2011. Denver, CO, USA.

Blanchard, B. and W. Fabrycky. 2005. *Systems Engineering and Analysis,* 4th edition. Upper Saddle River, NJ, USA: Prentice Hall.

Chang, C.M. 2010. Service Systems Management and Engineering: Creating Strategic Differentiation and Operational Excellence. Hoboken, NJ, USA: John Wiley and Sons.

Davidz, H. L. and J. Martin. 2011. "Defining a Strategy for Development of Systems Capability in the Workforce." Systems Engineering. 14(2) (Summer, 2011): 141-143

Elliott, B. et al. 2008. *INCOSE UK Chapter Working Group on Applying Systems Engineering to In-Service Systems,* Final Report. Somerset, UK: INCOSE UK Chapter Working Group. Accessed September 6, 2011. Available at http://www.incoseonline.org.uk/Documents/Groups/InServiceSystems/is_tr_001_final_report_final_1_0.pdf.

Fasser, Y. and D. Brettner. 2001. *Management for Quality in High-Technology Enterprises*. New York, NY, USA: Wiley.

Hitchins, D. 2005. *Systems Engineering 5 Layer Model.* Accessed on April 24,2013. Available at http://www.hitchins.net/systems/world-class-systems-enginee.html.

INCOSE. 2010. *SE Competencies Framework*, Issue 3. Somerset, UK: International Council on Systems Engineering (INCOSE), INCOSE Technical Product 2010-0205.

INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities,* version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2.

ISO/IEC/IEEE. 2015. *Systems and Software Engineering -- System Life Cycle Processes*. Geneva, Switzerland: International Organisation for Standardisation / International Electrotechnical Commissions. ISO/IEC/IEEE 15288:2008.

Kotter, J. 1995. *Leading Change: Why Transformation Efforts Fail*. Boston, MA, USA: Harvard Business Review (March–April 1995).

Maier, M. and E. Rechtin. 2009. *The Art of System Architecting, Third Edition*. Boca Raton, FL, USA: CRC Press.

Oppenheim et al. 2010. *Lean Enablers for Systems Engineering*. New York, NY, USA: Wiley and Sons, Inc.

Ring J. 2002. *Toward an Ontology of Systems Engineering.* INSIGHT, 5(1): 19-22

SEI. 2007. *CMMI for Acquisition*. Version 1.2. Technical Report CMU/SEI-2007-TR-017. Pittsburgh, PA, USA: Software Engineering Institute, Carnegie Mellon University.

SEI. 2010a. *Capability Maturity Model Integrated (CMMI) for Development*. Version 1.3. Pittsburgh, PA, USA: Software Engineering Institute, Carnegie Mellon University.

SEI. 2010b. *CMMI for Services*. Version 1.3. Technical Report CMU/SEI-2010-TR-034. Pittsburgh, PA, USA: Software Engineering Institute, Carnegie Mellon University.

Sheard, S. 1996. "12 Systems Engineering Roles." Paper presented at the 6th Annual International Council on Systems Engineering (INCOSE) International Symposium. Boston, MA, USA. Accessed September 14, 2011.

Sillitto, H. 2011. "Unravelling Systems Engineers from Systems Engineering - Frameworks for Understanding the Extent, Variety and Ambiguity of Systems Engineering and Systems Engineers." Paper presented at the 21st Annual

International Council on Systems Engineering (INCOSE) International Symposium. 20-23 June 2011. Denver, CO, USA.

Stupples, D. 2006. "Systems Engineering – a road from perdition." Published on Royal Academy of Engineering website - available at http://www.raeng.org.uk/education/vps/systemdesign/pdf/David_Stupples.pdf

Primary References

Hitchins, D. 2007. *Systems Engineering: A 21st Century Systems Methodology*. Chichester, UK: Wiley and Sons, Inc.

Oppenheim, B. 2011. *Lean for Systems Engineering - with Lean Enablers for Systems Engineering*. Hoboken, NJ, USA: Wiley and Sons, Inc.

Sheard, S. 1996. *Twelve Systems Engineering Roles.* Paper presented at the 6th Annual International Council on Systems Engineering (INCOSE) International Symposium. Boston, MA, USA. Accessed September 14, 2011.

Additional References

Rhodes, D., and G. Roedler (eds.). 2007. *Systems Engineering Leading Indicators Guide*, version 1.0. San Diego, CA, USA: International Council on Systems Engineering (INCOSE). INCOSE-TP-2005-001-02.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTA1ODQPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Ny
END_ENCODED_CONTENT

Organizing Business and Enterprises to Perform Systems Engineering

In order for a business or enterprise to perform systems engineering (SE) well, the team must decide which specific SE capabilities the business or enterprise needs in order to be successful and then organizing to deliver those capabilities. (In the rest of this article, business or enterprise is usually abbreviated to just "business", because a business is a specific type of enterprise that has sufficiently strong central authority and motivation to take steps to enable SE).

SE capabilities and organizational approach should support the Systems Engineering Organizational Strategy and reflect the nature of the business, its products and services, various stakeholders, business leadership focus, etc. This topic, which is part of Part 5, Enabling Businesses and Enterprises, summarizes the factors used to organize a business to perform SE.

Components of Business and Enterprise SE Capability

Organization Issues - Culture, Knowledge, Information, and Infrastructure

The way SE is managed is described in Systems Engineering Organizational Strategy, which both impacts and responds to the SE culture and approach.

Knowledge and Information

Knowledge and Information are key assets in a business, and their management is critical. Fasser and Brettner (2002) discuss knowledge management extensively. They assert that *"We may think that knowledge transfer is just an information technology issue, but in actuality, it is also a psychological, cultural, and managerial issue – in short a human issue" and "Only information in action can create knowledge".*

Organizations need to manage SE know-how, integration of SE with other organizational processes and activities, and knowledge of their business domain. The INCOSE Intelligent Enterprise Working Group's work on knowledge management in an SE context led to the publication of a *"Concept of Operations for a Systems Engineering Educational Community"* (Ring et al. 2004).

Information has to be both shared and protected in complex organizations. Sharing is key to effective collaboration and is constrained by the need to protect intellectual property, as well as commercially and nationally sensitive material. Different cultures and personal styles use information in different ways and in different orders. (Levels of abstraction, big picture first or detail, principles first or practical examples, etc.) Sillitto (2011b) describes the knowledge management challenges for large, multi-national organizations.

Projects need to manage project information and establish configuration control over formal contractual information, as well as the information that defines the product/service being developed, supplied, or operated. A key role of systems engineers is to "language the project" (Ring et al. 2004). Good data management and tool support will allow people to document once, use many times, and ensures consistency of information over time and between different teams.

System information needs to be maintained throughout the life of the system and made available to relevant stakeholders – including those designing new systems that have to interface to the system-of-interest - to allow system management, maintenance, reconfiguration, upgrade and disposal, and forensics after accidents and near-misses. Elliott et al. (2008) suggest that information management is the dominant problem in SE in service systems, and that the cost and difficulty of establishing current state and legacy constraints before starting to implement a change is often underestimated.

"Infostructure" (information infrastructure) to support the system lifecycle will include the following:

- Information assets such as process libraries, document templates, preferred parts lists, component re-use libraries, as-specified and as-tested information about legacy systems, capitalized metrics for organizational performance on previous similar projects, all with appropriate configuration control
- Modeling and simulation tools, data sets and run-time environments
- Shared working environments – workspaces for co-located teams, areas for people to interact with each other to develop ideas and explore concepts, work areas suitable for analysis tasks, meeting rooms, access control provision, etc.
- IT facilities - computer file structures, software licenses, IT equipment, computer and wall displays to support collaborative working, printers, all with appropriate security provision and back-up facilities, procedures for efficient use, and acceptable performance and usability
- Security provisions to protect own, customer, supplier and third party IPR and enforce necessary protective working practices while allowing efficient access to information for those with a need to know

SE is a knowledge activity. Systems engineers need appropriate facilities for accessing, sharing and capturing knowledge, as well as for interacting effectively with the whole set of stakeholders. Warfield (2006) describes collaborative workspaces, environments and processes for developing a shared understanding of a problem situation.

Enabling Infrastructure

The ISO/IEC 15288 (ISO 2008) Infrastructure Management Process provides the enabling infrastructure and services to support organization and project objectives throughout the life cycle. Infrastructure to support the system life cycle will often include the following:

- Integration and test environment – bench and lab facilities, facilities for development testing as well as acceptance testing at various levels of integration, calibration and configuration management of test environments
- Trials and validation environment – access to test ranges, test tracks, calibrated targets, support and storage for trials-equipment, harbor, airfield and road facilities, safe storage for fuel, ordinance, etc.
- Training and support infrastructure – training simulators, embedded training, tools and test equipment for operational support and maintenance, etc.

People

The roles people fill are typically defined by the business/enterprise (see Determining Needed Systems Engineering Capabilities in Businesses and Enterprises), although those decisions may be pushed down to teams. Enabling Teams explains how people are used in teams; Enabling Individuals describes the development of an individual's SE competence.

The implementation of these roles needs further consideration. Sheard (1996) lists twelve system engineering roles. Sheard (2000) draws an important distinction between roles involved in the discovery phase, characterized by a high level of uncertainty, the program phase, which is more deterministic and defined, and the overall systems engineering approach. Kasser et al. (2009) identify five types of systems engineer distinguished by the need to work at increasing levels of abstraction, ambiguity, scope and innovation. Sillitto (2011a) discusses a number of SE roles and the characteristics required of them, in the context of the wider engineering and business professional landscape.

Systems engineering exists within an enterprise "ecosystem." Two key aspects to consider:

- How much should the business/enterprise nurture and value the systems engineer?
- How much should the business/enterprise pull value from systems engineers, rather than wait for systems engineers to "push" value on the business/enterprise?

Process

Many SE organizations maintain a set of organizational standard processes which are integrated in their quality and business management system, adapted to their business, and with tailoring guidelines used to help projects apply the standard processes to their unique circumstances. Guidance on organizational process management is provided by such frameworks as the Capability Maturity Model Integration (CMMI) (SEI 2010), which has two process areas on organizational process: Organizational Process Development (OPD) is concerned with organizational definition and tailoring of the SE lifecycle processes (discussed in detail elsewhere in this document) and Organizational Process Focus (OPF), which is concerned with establishing a process culture in an organization.

To document, assess, and improve SE processes, businesses often establish a systems engineering process group. Members of such groups often create standard process assets, may mentor teams and business units on how to adopt those standard processes and assess how effective those processes are working. There is a large body of literature on SE process improvement based on various process improvement models. Two of the most popular are ISO/IEC 9000 (2000) and CMMI (SEI 2010). The Software Engineering Institute, which created the CMMI, offers many free technical reports and other documents on CMMI at http://www.sei.cmu.edu/cmmi.

Assessment and measuring process performance is covered in Assessing Systems Engineering Performance of Business and Enterprises.

Tools and Methods

SE organizations often invest in SE tools and models, develop their own, and/or integrate off-the-shelf tools into their particular business/enterprise processes. Tools require great attention to culture and training; to developing a consistent “style” of use so that people can understand each others’ work; and proper configuration and management of the information so that people are working on common and correct information.

It is important that methods are used as well as tools, particularly to support Systems Thinking.

It is common practice in large SE organizations to have a tool support infrastructure which ensures that tools support the organizational standard processes and are fully integrated with training, and that projects and teams can use the tools to do their job and are not distracted by tool management issues that are more efficiently handled centrally. Smaller SE organizations often operate more informally.

Fitting It All Together

The concept map in Figure 1 below shows the relationships between the various aspects of organization, resource, responsibility, and governance.

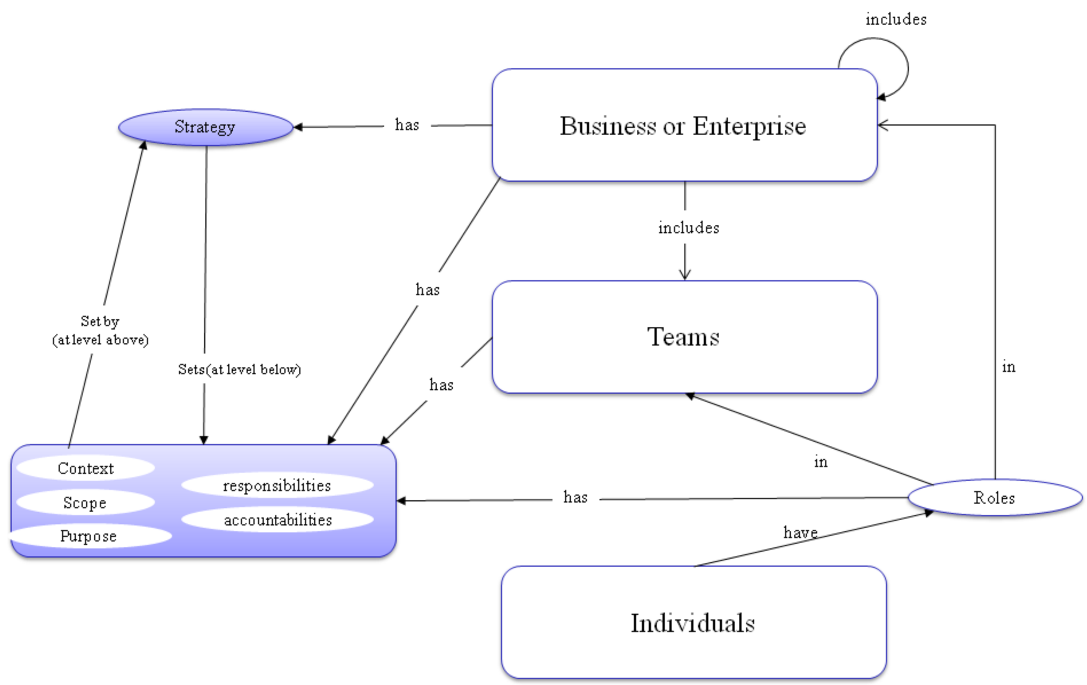

Figure 1. Businesses, Teams, and Individuals in SE. (SEBoK Original)

Enterprise Structures and Their Effects on SE

Enterprises manage SE resources in many different ways. A key driver is the extent to which they seek to optimize use of resources (people, knowledge, and assets) across teams and across the enterprise as a whole. Five common ways of organizing resources to support multiple projects are: project; matrix; functional; integrated; and product centered (CM Guide 2009, Handy 1985, PMI 2013, section 2.1.3). A large enterprise would likely apply some combination of these five ways across its constituent sub-enterprises and teams. Browning (2009) offers a way to optimize project organizational structure. Eisner (2008) offers a good overview of different organizational models.

Project Organization

A project organization is one extreme in which projects are responsible for hiring, training, and terminating staff, as well as managing all assets required for delivery. In this model, systems engineers on a project report to the project manager and resources are optimized for the delivery of the project. This model has the advantage of strongly aligning the authority and responsibility of the project with the project manager. However, it operates at the expense of sub-optimizing how the staff is deployed across the larger enterprise, how technology choices are made across projects, etc. *Systems Engineering Fundamentals* (DAU 2001) offers a DoD view of good practice project organizations.

Functional Organization

A functional organization demonstrates the opposite extreme. In a functional organization projects delegate almost all their work to functional groups, such as the software group, the radar group or the communications group. This is appropriate when the functional skill is fast-evolving and dependent on complex infrastructure. This method is often used for manufacturing, test engineering, software development, financial, purchasing, commercial, and legal functions.

Matrix Organization

A matrix organization is used to give systems engineers a “home” between project assignments. Typically, a SE functional lead is responsible for career development of the systems engineers in the organization, a factor that influences the diversity and length of individual project assignments.

Integrated Organization

In an integrated organization, people do assigned jobs without specific functional allegiance. Those that perform SE tasks are primarily identified as another type of engineer, such as a civil or electrical engineer. They know systems engineering and use it in their daily activities as required.

Product Centered Organization

In accordance with the heuristic (glossary) that “the product and the process must match” (Rechtin 1991, 132), a common method for creating an organizational structure is to make it match the system breakdown structure (SBS) (glossary). According to Browning (2009), at each element of the SBS there is an assigned integrated product team (IPT)(glossary). Each IPT consists of members of the technical disciplines needed to design the product system. The purpose of the IPT is to assure that the interactions among all the technical disciplines are accounted for in the design and that undesirable interactions are avoided.

Interface to Other Organizations

Outside official engineering and SE organizations within an enterprise, there are other organizations whose charter is not technical. Nevertheless, these organizations have an important SE role.

- **Customer Interface Organizations:** These are organizations with titles such as Marketing and Customer Engineering. These are the organizations with the most direct interface with current or potential clientele. Their role is to determine customer needs and communicate these needs to the SE organization for conversion to product requirements and other system requirements. Kossiakoff and Sweet (2003, 173) discuss the importance of understanding customer needs.
- **Contracts Organizations:** These organizations interface with both customer and supplier organizations. Their role is to develop clearly stated contracts for the developer or the supplier. These contracts convey tasks and responsibilities for all SE roles of all parties. Technical specifications are attached to the contracts. Responsibilities for verification and validation are specified.
- **Supplier Management Organizations:** These organizations are responsible for selecting and managing suppliers and assuring that both contractual and technical products are in place. These organizations balance cost and risk to assure that supplier products are delivered, verified, and validated for quality product. Blanchard and Fabrycky (2005, 696-698) discuss the importance of supplier selection and agreement.

References

Works Cited

Blanchard, B. and W. Fabrycky. 2005. *Systems Engineering and Analysis,* 4th ed. Upper Saddle River, NJ, USA: Prentice Hall.

Browning, T.R. 2009. "Using the Design Structure Matrix to Design Program Organizations." In A.P. Sage and W.B. Rouse (eds.), *Handbook of Systems Engineering and Management,* 2nd ed. Hoboken, NJ, USA: John Wiley & Sons.

Construction Management (CM) Guide. 2009. *Project Organization Types*. Accessed on September 14, 2011. Available at http://cmguide.org/archives/319.

DAU. 2001. *Systems Engineering Fundamentals*. Ft. Belvoir, VA, USA: Defense Acquisition University (DAU), U.S. Department of Defense (DoD). Accessed on September 14, 2011. Available at http://www.dau.mil/pubscats/PubsCats/SEFGuide%2001-01.pdf.

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons.

Elliott et al. 2008. *INCOSE UK Chapter Working Group on Applying Systems Engineering to In-Service Systems*. Final Report. Somerset, UK: INCOSE UK Chapter Working Group. Accessed September 6, 2011. Available at http://www.incoseonline.org.uk/Documents/Groups/InServiceSystems/is_tr_001_final_report_final_1_0.pdf.

Fasser, Y. and D. Brettner. 2002. *Management for Quality in High-Technology Enterprises*. Hoboken, NJ, USA: John Wiley & Sons.

ISO/IEC. 2000. *International standards for quality management.* Genève, Switzerland: International Organization for Standardization. ISO 9000:2000.

ISO/IEC. 2008. *Systems and Software Engineering -- System Life Cycle Processes*. Geneva, Switzerland: International Organisation for Standardisation / International Electrotechnical Commissions. ISO/IEC/IEEE 15288:2008.

Kasser, J., D. Hitchins, and T. Huynh. 2009. "Re-engineering Systems Engineering." Proceedings of the 3rd Annual Asia-Pacific Conference on Systems Engineering (APCOSE). 20-23 July 2009. Singapore.

Kossiakoff, A., and W.N. Sweet. 2003. *Systems Engineering: Principles and Practice*. Edited by A. Sage, Wiley Series in Systems Engineering and Management. Hoboken, NJ: John Wiley & Sons.

PMI. 2013. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 5th ed. Newtown Square, PA, USA: Project Management Institute (PMI).

Rechtin, E. 1991. *Systems Architecting: Creating and Building Complex Systems.* Englewood Cliffs, NJ, USA: CRC Press.

Ring, J. and A.W. Wymore (eds.). 2004. *Concept of Operations (conops) of A Systems Engineering Education Community (SEEC)*. Seattle, WA, USA: INCOSE Education Measurement Working Group (EMWG), INCOSE-TP-2003-015-01.

SEI. 2010. *Capability Maturity Model Integrated (CMMI) for Development,* version 1.3. Pittsburgh, PA, USA: Software Engineering Institute (SEI)/Carnegie Mellon University (CMU).

Sheard, S. 1996. "12 Systems Engineering Roles." Paper presented at the Sixth Annual International Council on Systems Engineering (INCOSE) International Symposium. 7-11 July 1996. Boston, MA, USA.

Sheard, S. 2000. "The 12 Systems Engineering Roles Revisited." Paper presented at the INCOSE Mid-Atlantic Regional Conference. April 2000. Reston, VA, USA. p 5.2-1 - 5.2-9.

Sillitto, H. 2011a. "Unravelling Systems Engineers from Systems Engineering - Frameworks for Understanding the Extent, Variety and Ambiguity of Systems Engineering and Systems Engineers." Paper presented at the 21st Annual International Council on Systems Engineering (INCOSE) International Symposium. 20-23 June 2011. Denver, CO, USA.

Sillitto, H. 2011b. *Sharing Systems Engineering Knowledge through INCOSE: INCOSE as An Ultra-Large-Scale System?* INCOSE *Insight.* 14(1) (April): 20.

Warfield, J. 2006. *An Introduction to Systems Science*. Washington, DC, USA: The National Academies Press, World Scientific.

Primary References

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley and Sons.

Kotter, J. 1995. "Leading Change: Why Transformation Efforts Fail." Harvard Business Review. *73(2): 59–67.*

Sheard, S. 2000. "Systems Engineering Roles Revisited." Paper presented at the INCOSE Mid-Atlantic Regional Conference. April 5-8 2000. Reston, VA, USA. p 5.2-1 - 5.2-9.

Additional References

Blanchard, B. and W. Fabrycky. 2005. *Systems Engineering and Analysis,* 4th edition. Upper Saddle River, NJ, USA: Prentice Hall.

Construction Management (CM) Guide. 2009. *Project Organization Types.* Accessed on September 6, 2011. Available at http://cmguide.org/archives/319.

Defense Acquisition University (DAU). 2001. *Systems Engineering Fundamentals.* Fort Belvoir, VA, USA: Defense Acquisition University Press. Accessed on September 6, 2011. Available at http:/ / www. dau. mil/ pubscats/ PubsCats/SEFGuide%2001-01.pdf.

Handy, C.B. 1985. *Understanding Organizations.* London, UK: Penguin Business.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTUzOTkPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Assessing Systems Engineering Performance of Business and Enterprises

At the project level, systems engineering (SE) measurement focuses on indicators of project and system success that are relevant to the project and its stakeholders. At the enterprise level there are additional concerns. SE governance should ensure that the performance of systems engineering within the enterprise adds value to the organization, is aligned to the organization's purpose, and implements the relevant parts of the organization's strategy.

For enterprises that are traditional businesses this is easier, because such organizations typically have more control levers than more loosely structured enterprises. The governance levers that can be used to improve performance include people (selection, training, culture, incentives), process, tools and infrastructure, and organization; therefore, the assessment of systems engineering performance in an enterprise should cover these dimensions.

Being able to aggregate high quality data about the performance of teams with respect to SE activities is certainly of benefit when trying to guide team activities. Having access to comparable data, however, is often difficult, especially in organizations that are relatively autonomous, use different technologies and tools, build products in different domains, have different types of customers, etc. Even if there is limited ability to reliably collect and aggregate data across teams, having a policy that consciously decides how the enterprise will address data collection and analysis is valuable.

Performance Assessment Measures

Typical measures for assessing SE performance of an enterprise include the following:

- Effectiveness of SE process
- Ability to mobilize the right resources at the right time for a new project or new project phase
- Quality of SE process outputs
- Timeliness of SE process outputs
- SE added value to project
- System added value to end users
- SE added value to organization
- Organization's SE capability development
- Individuals' SE competence development
- Resource utilization, current and forecast
- Productivity of systems engineers
- Deployment and consistent usage of tools and methods

How Measures Fit in the Governance Process and Improvement Cycle

Since collecting data and analyzing it takes effort that is often significant, measurement is best done when its purpose is clear and is part of an overall strategy. The "goal, question, metric" paradigm (Basili 1992) should be applied, in which measurement data is collected to answer specific questions, the answer to which helps achieve a goal, such as decreasing the cost of creating a system architecture or increasing the value of a system to a particular stakeholder. Figure 1 shows one way in which appropriate measures inform enterprise level governance and drive an improvement cycle such as the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) model.

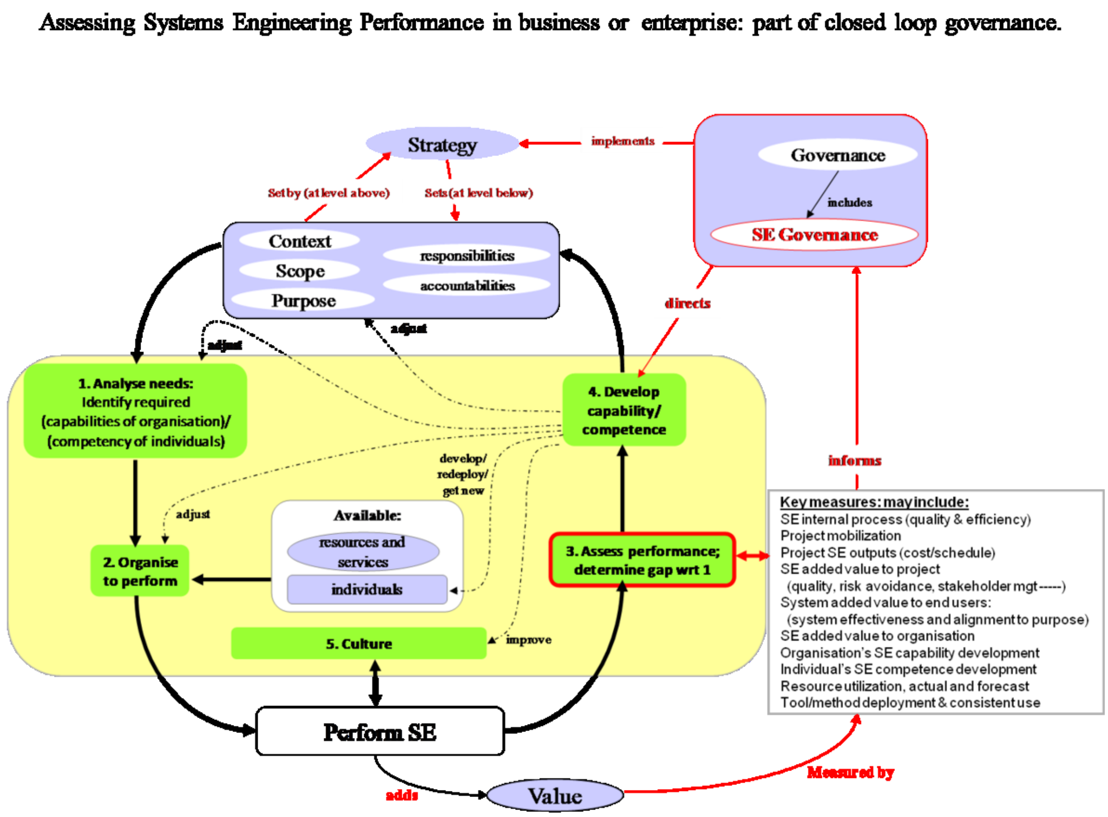

Figure 1. Assessing Systems Engineering Performance in Business or Enterprise: Part of Closed Loop Governance. (SEBoK Original)

Discussion of Performance Assessment Measures

Assessing SE Internal Process (Quality and Efficiency)

A Process (glossary) is a *"set of interrelated or interacting activities which transforms inputs into outputs."* The SEI CMMI Capability Maturity Model (SEI 2010) provides a structured way for businesses and enterprises to assess their SE processes. In the CMMI, a process area is a cluster of related practices in an area that, when implemented collectively, satisfies a set of goals considered important for making improvement in that area. There are CMMI models for acquisition, for development, and for services (SEI 2010, 11). CMMI defines how to assess individual process areas against Capability Levels on a scale from 0 to 3, and overall organizational maturity on a scale from 1 to 5.

Assessing Ability to Mobilize for a New Project or New Project Phase

Successful and timely project initiation and execution depends on having the right people available at the right time. If key resources are deployed elsewhere, they cannot be applied to new projects at the early stages when these resources make the most difference. Queuing theory shows that if a resource pool is running at or close to capacity, delays and queues are inevitable.

The ability to manage teams through their lifecycle is an organizational capability that has substantial leverage on project and organizational efficiency and effectiveness. This includes being able to

- mobilize teams rapidly;
- establish and tailor an appropriate set of processes, metrics and systems engineering plans;
- support them to maintain a high level of performance;
- capitalize acquired knowledge; and
- redeploy team members expeditiously as the team winds down.

Specialists and experts are used to a review process, critiquing solutions, creating novel solutions, and solving critical problems. Specialists and experts are usually a scarce resource. Few businesses have the luxury of having enough experts with all the necessary skills and behaviors on tap to allocate to all teams just when needed. If the skills are core to the business' competitive position or governance approach, then it makes sense to manage them through a governance process that ensures their skills are applied to greatest effect across the business.

Businesses typically find themselves balancing between having enough headroom to keep projects on schedule when things do not go as planned and utilizing resources efficiently.

Project SE Outputs (Cost, Schedule, Quality)

Many SE outputs in a project are produced early in the life cycle to enable downstream activities. Hidden defects in the early phase SE work products may not become fully apparent until the project hits problems in integration, verification and validation, or transition to operations. Intensive peer review and rigorous modeling are the normal ways of detecting and correcting defects in and lack of coherence between SE work products.

Leading indicators could be monitored at the organizational level to help direct support to projects or teams heading for trouble. For example, the INCOSE Leading Indicators report (Roedler et al. 2010) offers a set of indicators that is useful at the project level. Lean Sigma provides a tool for assessing benefit delivery throughout an enterprise value stream. Lean Enablers for Systems Engineering are now being developed (Oppenheim et al. 2010). An emerging good practice is to use Lean Value Stream Mapping (glossary) to aid the optimization of project plans and process application.

In a mature organization, one good measure of SE quality is the number of defects that have to be corrected "out of phase"; i.e., at a later phase in the life cycle when the defect was introduced. This gives a good measure of process performance and the quality of SE outputs. Within a single project, the Work Product Approval, Review Action Closure, and Defect Error trends contain information that allows residual defect densities to be estimated (Roedler et al. 2010; Davies and Hunter 2001)

Because of the leverage of front-end SE on overall project performance, it is important to focus on quality and timeliness of SE deliverables (Woodcock 2009).

SE Added Value to Project

SE that is properly managed and performed should add value to the project in terms of quality, risk avoidance, improved coherence, better management of issues and dependencies, right-first-time integration and formal verification, stakeholder management, and effective scope management. Because quality and quantity of SE are not the only factors that influence these outcomes, and because the effect is a delayed one (good SE early in the project pays off in later phases) there has been a significant amount of research to establish evidence to underpin the asserted benefits of SE in projects.

A summary of the main results is provided in the Economic Value of Systems Engineering article.

System Added Value to End Users

System added value to end users depends on system effectiveness and on alignment of the requirements and design to the end users' purpose and mission. System end users are often only involved indirectly in the procurement process.

Research on the value proposition of SE shows that good project outcomes do not necessarily correlate with good end user experience. Sometimes systems developers are discouraged from talking to end users because the acquirer is afraid of requirements creep. There is experience to the contrary, that end user involvement can result in more successful and simpler system solutions.

Two possible measures indicative of end user satisfaction are

1. The use of user-validated mission scenarios (both nominal and "rainy day" situations) to validate requirements, drive trade-offs and organize testing and acceptance;
2. The use of Technical Performance Measure (TPM) (glossary) to track critical performance and non-functional system attributes directly relevant to operational utility. The INCOSE SE Leading Indicators Guide (Roedler et al. 2010, 10 and 68) defines "technical measurement trends" as *"Progress towards meeting the Measure of Effectiveness (MoE) (glossary) / Measure of Performance (MoP) (glossary) / Key Performance Parameters (KPPs) and Technical Performance Measure (TPM) (glossary)"*. A typical TPM progress plot is shown in Figure 2.

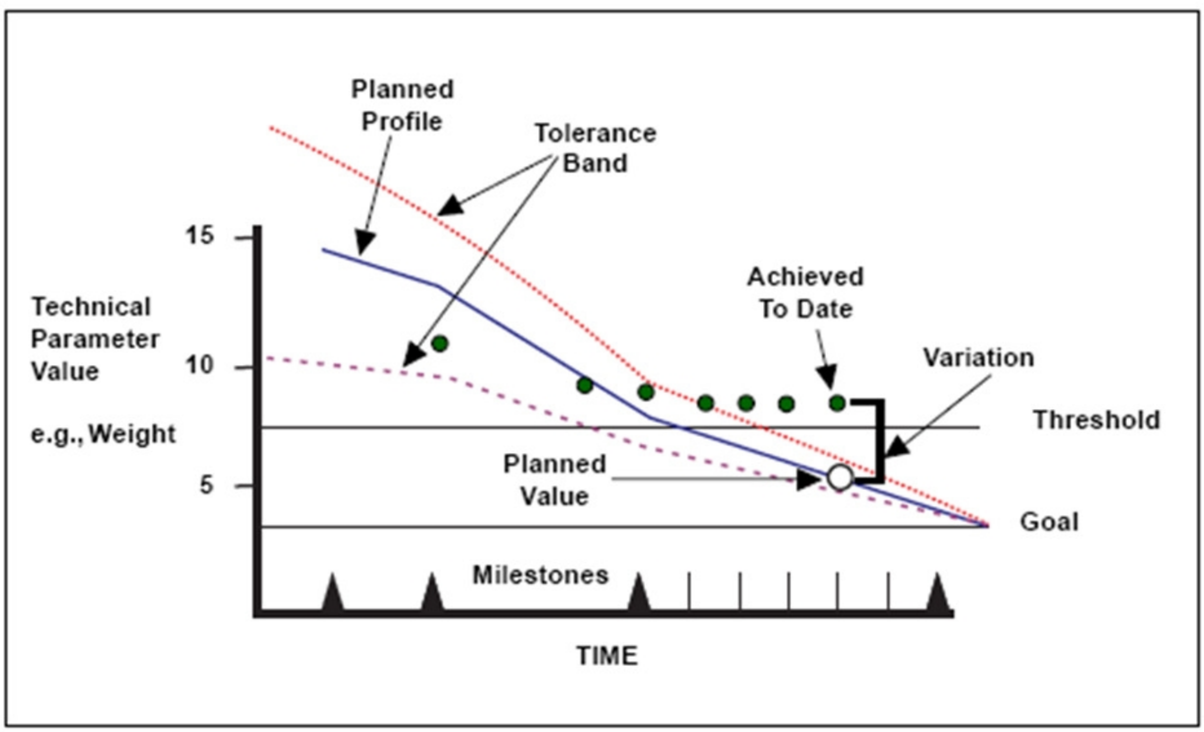

Figure 2. Technical Performance Measure (TPM) Tracking (Roedler et al. 2010). This material is reprinted with permission from the International Council on Systems Engineering (INCOSE). All other rights are reserved by the copyright owner.

SE Added Value to Organization

SE at the business/enterprise level aims to develop, deploy and enable effective SE to add value to the organization's business. The SE function in the business/enterprise should understand the part it has to play in the bigger picture and identify appropriate performance measures - derived from the business or enterprise goals, and coherent with those of other parts of the organization - so that it can optimize its contribution.

Organization's SE Capability Development

The CMMI (SEI 2010) provides a means of assessing the process capability and maturity of businesses and enterprises. The higher CMMI levels are concerned with systemic integration of capabilities across the business or enterprise.

CMMI measures one important dimension of capability development, but CMMI maturity level is not a direct measure of business effectiveness unless the SE measures are properly integrated with business performance measures. These may include bid success rate, market share, position in value chain, development cycle time and cost, level of innovation and re-use, and the effectiveness with which SE capabilities are applied to the specific problem and solution space of interest to the business.

Individuals' SE Competence Development

Assessment of Individuals' SE competence development is described in Assessing Individuals.

Resource Utilization, Current and Forecast

Roedler et al. (2010, 58) offer various metrics for staff ramp-up and use on a project. Across the business or enterprise, key indicators include the overall manpower trend across the projects, the stability of the forward load, levels of overtime, the resource headroom (if any), staff turnover, level of training, and the period of time for which key resources are committed.

Deployment and Consistent Usage of Tools and Methods

It is common practice to use a range of software tools in an effort to manage the complexity of system development and in-service management. These range from simple office suites to complex logical, virtual reality and physics-based modeling environments.

Deployment of SE tools requires careful consideration of purpose, business objectives, business effectiveness, training, aptitude, method, style, business effectiveness, infrastructure, support, integration of the tool with the existing or revised SE process, and approaches to ensure consistency, longevity and appropriate configuration management of information. Systems may be in service for upwards of 50 years, but storage media and file formats that are 10-15 years old are unreadable on most modern computers. It is desirable for many users to be able to work with a single common model; it can be that two engineers sitting next to each other using the same tool use sufficiently different modeling styles that they cannot work on or re-use each others' models.

License usage over time and across sites and projects is a key indicator of extent and efficiency of tool deployment. More difficult to assess is the consistency of usage. Roedler et al. (2010, 73) recommend metrics on "facilities and equipment availability".

Practical Considerations

Assessment of SE performance at the business/enterprise level is complex and needs to consider soft issues as well as hard issues. Stakeholder concerns and satisfaction criteria may not be obvious or explicit. Clear and explicit reciprocal expectations and alignment of purpose, values, goals and incentives help to achieve synergy across the organization and avoid misunderstanding.

"What gets measured gets done." Because metrics drive behavior, it is important to ensure that metrics used to manage the organization reflect its purpose and values, and that they do not drive perverse behaviors (Roedler et al. 2010).

Process and measurement cost money and time, so it is important to get the right amount of process definition and the right balance of investment between process, measurement, people and skills. Any process flexible enough to allow innovation will also be flexible enough to allow mistakes. If process is seen as excessively restrictive or prescriptive, in an effort to prevent mistakes it may inhibit innovation and demotivate the innovators, leading to excessive risk avoidance.

It is possible for a process improvement effort to become an end in itself rather than a means to improve business performance (Sheard 2003). To guard against this, it is advisable to remain clearly focused on purpose (Blockley and Godfrey 2000) and on added value (Oppenheim et al. 2010) as well as to ensure clear and sustained top management commitment to driving the process improvement approach to achieve the required business benefits. Good process improvement is as much about establishing a performance culture as about process.

> *The Systems Engineering process is an essential complement to, and is not a substitute for, individual skill, creativity, intuition, judgment etc. Innovative people need to understand the process and how to make it work for them, and neither ignore it nor be slaves to it. Systems Engineering measurement shows where invention and creativity need to be applied. SE process creates a framework to leverage creativity and innovation to deliver results that surpass the capability of the creative individuals – results that are the emergent properties of process, organisation, and leadership.* (Sillitto 2011)

References

Works Cited

Basili, V. 1992. "Software Modeling and Measurement: The Goal/Question/Metric Paradigm" Technical Report CS-TR-2956. University of Maryland: College Park, MD, USA. Accessed on August 28, 2012. Available at http://www.cs.umd.edu/~basili/publications/technical/T78.pdf.

Blockley, D. and P. Godfrey. 2000. *Doing It Differently – Systems For Rethinking Construction*. London, UK: Thomas Telford Ltd.

Davies, P. and N. Hunter. 2001. "System Test Metrics on a Development-Intensive Project." Paper presented at the 11th Annual International Council on System Engineering (INCOSE) International Symposium. 1-5 July 2001. Melbourne, Australia.

Oppenheim, B., E. Murman, and D. Sekor. 2010. *Lean Enablers for Systems Engineering*. Systems Engineering. 14(1). New York, NY, USA: Wiley and Sons, Inc.

Roedler, G. D. Rhodes, H. Schimmoller, and C. Jones (eds.). 2010. *Systems Engineering Leading Indicators Guide,* version 2.0. January 29, 2010, Published jointly by LAI, SEARI, INCOSE, and PSM. INCOSE-TP-2005-001-03. Accessed on September 14, 2011. Available at http://seari.mit.edu/documents/SELI-Guide-Rev2.pdf.

SEI. 2010. *CMMI for Development,* version 1.3. Pittsburgh, PA, USA: Software Engineering Institute/Carnegie Mellon University. CMU/SEI-2010-TR-033. Accessed on September 14, 2011. Available at http://www.sei.cmu.edu/reports/10tr033.pdf.

Sheard, S, 2003. "The Lifecycle of a Silver Bullet." *Crosstalk: The Journal of Defense Software Engineering.* (July 2003). Accessed on September 14, 2011. Available at http://www.crosstalkonline.org/storage/issue-archives/2003/200307/200307-Sheard.pdf.

Sillitto, H. 2011. Panel on "People or Process, Which is More Important". Presented at the 21st Annual International Council on Systems Engineering (INCOSE) International Symposium. 20-23 June 2011. Denver, CO, USA.

Woodcock, H. 2009. "Why Invest in Systems Engineering." INCOSE UK Chapter. Z-3 Guide, Issue 3.0. March 2009. Accessed on September 14, 2011. Available at http://www.incoseonline.org.uk/Documents/zGuides/Z3_Why_invest_in_SE.pdf.

Primary References

Basili, V. 1992. "Software Modeling and Measurement: The Goal/Question/Metric Paradigm". College Park, MD, USA: University of Maryland. Technical Report CS-TR-2956. Accessed on August 28, 2012. Available at http://www.cs.umd.edu/~basili/publications/technical/T78.pdf.

Frenz, P., et al. 2010. *Systems Engineering Measurement Primer: A Basic Introduction to Measurement Concepts and Use for Systems Engineering,* version 2.0. San Diego, CA, USA: International Council on System Engineering (INCOSE). INCOSE-TP-2010-005-02.

Oppenheim, B., E. Murman, and D. Sekor. 2010. *Lean Enablers for Systems Engineering*. Systems Engineering. 14(1). New York, NY, USA: Wiley and Sons, Inc.

Roedler, G., D. Rhodes, H. Schimmoller, and C. Jones (eds.). 2010. *Systems Engineering Leading Indicators Guide,* version 2.0. January 29, 2010, Published jointly by LAI, SEARI, INCOSE, PSM. INCOSE-TP-2005-001-03. Accessed on September 14, 2011. Available at http://seari.mit.edu/documents/SELI-Guide-Rev2.pdf.

Additional References

Jelinski, Z. and P.B. Moranda. 1972. "Software Reliability Research". In W. Freiberger. (ed.), *Statistical Computer Performance Evaluation.* New York, NY, USA: Academic Press. p. 465-484.

Alhazmi O.H. and Y.K. Malaiya. 2005. *Modeling the Vulnerability Discovery Process*. 16th IEEE International Symposium on Software Reliability Engineering (ISSRE'05). 8-11 November 2005. Chicago, IL, USA.

Alhazmi, O.H. and Y.K. Malaiya. 2006. "Prediction Capabilities of Vulnerability Discovery Models." Paper presented at Annual Reliability and Maintainability Symposium (RAMS). 23-26 January 2006. p 86-91. Newport Beach, CA, USA. Accessed on September 14, 2011. Available at http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1677355&isnumber=34933.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTc0NjgPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

Developing Systems Engineering Capabilities within Businesses and Enterprises

The pursuit of continuous improvement is a constant for many organizations. The description of Toyota (Morgan and Liker 2006), the Lean principle of “pursue perfection” (Oppenheim et al. 2010), and the principle of “don’t let up” (Kotter 1995), all drive a need for continuous improvement.

The ability to manage teams through their lifecycle - mobilize teams rapidly, establish and tailor an appropriate set of processes, metrics and systems engineering plans, support them to maintain a high level of performance, capitalize acquired knowledge and redeploy team members expeditiously as the team winds down - is a key organizational competence that has substantial leverage on project and organizational efficiency and effectiveness.

The enterprise provides teams with the necessary resources, background information, facilities, cash, support services, tooling, etc. It also provides a physical, cultural and governance environment in which the teams can be effective. The key functions of the enterprise include generating and maintaining relevant resources, allocating them to teams, providing support and governance functions, maintaining expertise and knowledge (on process, application domain and solution technologies), securing the work that teams perform, organizing finance, and maintaining the viability of the enterprise.

For improvements to persist, they must reside in the enterprise rather than just the individuals, so the improvements can endure as personnel leave. This is reflected in the Capability Maturity Model Integrated (CMMI) (SEI 2010) progression from a "hero culture" to a "quantitatively managed and optimizing process".

This topic outlines the issues to be considered in capability development and organizational learning.

Overview

Figure 1 shows an "analyze - organize - perform - assess - develop" cycle, which is essentially a reformulation of the Deming (1994) PDCA (Plan Do Check Act) cycle. The analysis step should cover both current and future needs, as far as these can be determined or predicted. Goals and performance assessment, as discussed in Assessing Systems Engineering Performance of Business and Enterprises, can be based on a number of evaluation frameworks, such as direct measures of business performance and effectiveness and the CMMI capability maturity models. There is evidence that many organizations find a positive correlation between business performance and CMMI levels (SEI 2010). This is discussed further in the Economic Value of Systems Engineering.

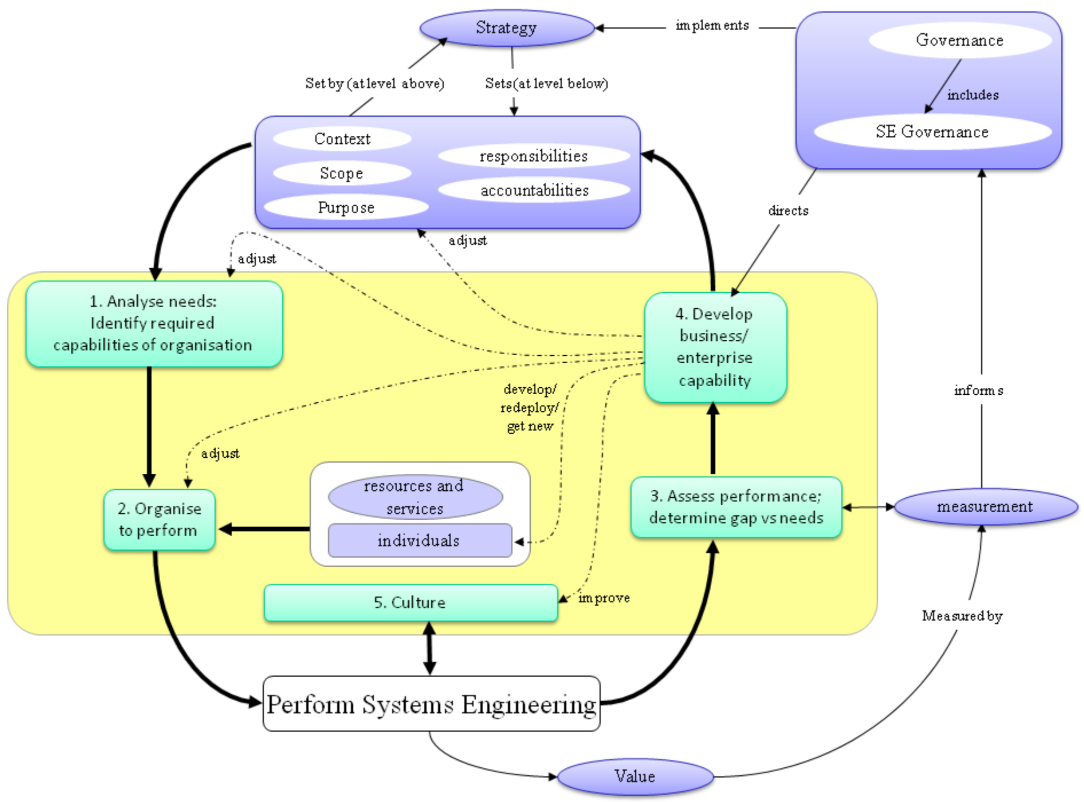

Figure 1. Concept Map for Businesses and Enterprises Topics. (SEBoK Original)

Change Levers

SE managers have a number of possible change levers they can use to develop SE capabilities. The amount of time delay between moving a lever and seeing the effect varies with the type of level, size of the enterprise, culture of the enterprise, and other factors.

Adjust Context, Scope, Purpose, Responsibility, Accountability Business Enterprise

If the other change levers cannot achieve the desired effect, the business or enterprise may have to renegotiate its contribution to the higher level strategy and mission.

Review and Adjust Required Capabilities

In the initial analysis the needed capability may have been over- or under-estimated. The need should be re-evaluated after each rotation of the cycle to make sure the planning assumptions are still valid.

Adjust Organization within Business Enterprise

Adjusting organization and responsibilities so that *"the right people are doing the right things"*, and ensuring that the organization is making full use of their knowledge and skills, is often the easiest change to make (and the one that may have the quickest effect).

A potential risk is that too much organizational churn disrupts relationships and can destabilize the organization and damage performance. Process improvement can be set back by an ill-considered re-organization and can jeopardize any certifications the organization has earned which demonstrate its process capability or performance.

Develop/Train/Redeploy/Get New Resources, Services and Individuals

Resources, services and individuals may include any of the components of organizational SE capability listed in Organizing Business and Enterprises to Perform Systems Engineering.

Levers include subcontracting elements of the work, improving information flows, upgrading facilities, and launching short-term training and/or long term staff development programs. Many organizations consider how they approach these improvements to be proprietary, but organizations such as NASA offer insight on their APPEL website (NASA 2012).

Development of individuals is discussed in Enabling Individuals.

Improve Culture

Culture change is very important, very powerful, but needs to be handled as a long-term game and given long term commitment.

Adjust and Improve Alignment of Measures and Metrics

Measurement drives behavior. Improving alignment of goals and incentives of different parts of the business/enterprise so that everyone works to a common purpose can be a very effective and powerful way of improving business/enterprise performance. This alignment does require some top-down guidance, perhaps a top-down holistic approach, considering the business/enterprise as a system with a clear understanding of how the elements of enterprise capability interact to produce synergistic value (See Assessing Systems Engineering Performance of Business and Enterprises). It is commonly reported that as an organization improves its processes with respect to the CMMI, its approach to metrics and measurement has to evolve.

Change Methods

Doing Everyday Things Better

There is a wealth of sources and techniques, including Kaizen, Deming PDCA (Deming 1994), Lean (Womack and Jones 2003, Oppenheim et al. 2010), Six-Sigma (Harry 1997), and CMMI.

Value stream mapping is a powerful Lean technique to find ways to improve flow and handovers at interfaces.

Managing Technology Readiness

In high-technology industries many problems are caused by attempting to transition new technologies into products and systems before the technology is mature; to make insufficient allowance for the effort required to make the step from technology demonstration to reproducible and dependable performance in a product; or to overestimate the re-usability of an existing product. NASA's TRL (Technology Readiness Level) construct, first proposed by John Mankins in 1995 (Mankins 1995), is widely and successfully used to understand and mitigate technology transition risk. Several organizations beyond NASA, such as the U.S. Department of Defense, even have automation to aid engineers in evaluating technology readiness.

Variations on TRL have even emerged, such as System Readiness Levels (SRL) (Sauser et al. 2006), which recognize that the ability to successfully deliver systems depends on much more than the maturity of the technology base used to create those systems; e.g., there could be surprising risks associated with using two technologies that are relatively mature in isolation, but have never been integrated together before.

Planned Change: Standing Up or Formalizing SE in an Organization

Planned change may include:

- introducing SE to a business (Farncombe and Woodcock 2009);
- improvement/transformation;
- formalizing the way a business or project does SE;
- dealing with a merger/demerger/major re-organization;
- developing a new generation or disruptive product, system, service or product line (Christensen 1997);
- entering a new market; and
- managing project lifecycle transitions: start-up, changing to the next phase of development, transition to manufacture/operation/support, wind down and decommissioning.

CMMI is widely used to provide a framework for planned change in a systems engineering context. Planned change needs to take a holistic approach considering people (knowledge, skills, culture, ability and motivation), process, measurement and tools as a coherent whole. It is now widely believed that tools and process are not a substitute for skills and experience. Instead, they merely provide a framework in which skilled and motivated people can be more effective. So change should start with people rather than with tools.

Before a change is started, it is advisable to baseline the current business performance and SE capability and establish metrics that will show early on whether the change is achieving the desired effect.

Responding to Unforeseen Disruption

Unforeseen disruptions may be internally or externally imposed. Externally imposed disruptions may be caused by

- the customer - win/lose contract, mandated teaming or redirection;
- competitors - current offering becomes less/more competitive, a disruptive innovation may be launched in market; or
- governance and regulatory changes - new processes, certification, safety or environmental standards.

Internal or self-induced disruptions may include

- a capability drop-out due to loss of people, facilities, financing;
- product or service failure in operation or disposal; or
- strategy change (e.g. new CEO, response to market dynamics, or a priority override).

Embedding Change

In an SE context, sustained effort is required to maintain improvements such as higher CMMI levels, Lean and Safety cultures, etc., once they are achieved. There are several useful change models, including Kotter's 8 phases of change (Kotter 1995):

1. Establish a sense of urgency;
2. Create a coalition;
3. Develop a clear vision;
4. Share the vision;
5. Empower people to clear obstacles;
6. Secure short term wins;
7. Consolidate and keep moving; and
8. Anchor the change.

The first six steps are the easy ones. The Chaos Model (Zuijderhoudt 1990; 2002) draws on complexity theory to show that regression is likely if the short term wins are not consolidated, institutionalized and anchored. This explains the oft-seen phenomenon of organizations indulging in numerous change initiatives, none of which sticks because attention moves on to the next before the previous one is anchored.

Change Management Literature

SE leaders (directors, functional managers, team leaders and specialists) have responsibilities, and control levers to implement them, that vary depending on their organization's business model and structure. A great deal of their time and energy is spent managing change in pursuit of short, medium and long term organizational goals: "doing everyday things better"; making change happen, embedding change and delivering the benefit; and coping with the effects of disruptions. Mergers, acquisitions and project start-ups, phase changes, transitions from "discovery" to "delivery" phase, transition to operation, sudden change in level of funding, can all impose abrupt changes on organizations that can destabilize teams, processes, culture and performance. Table 1 below provides both the general management literature and specific systems engineering knowledge.

Table 1. Change Management – Business and SE References. (SEBoK Original)

Area	Business references	SE references
Doing every day things better	Kaizen; Lean (Womack and Jones 2003); 6-Sigma (Harry 1997) Four competencies of Learning Organisation – absorb, diffuse, generate, exploit (Sprenger and Ten Have 1996) Covey's seven habits of very effective people (Covey 1989)	CMMI Forsberg & Mooz, Visualizing project management (Forsberg and Mooz 2005) INCOSE IEWG "Conops for a Systems Engineeriing Educational Community" (Ring and Wymore 2004) INCOSE Lean Enablers for SE (Oppenhein et al. 2010)
Dealing with unplanned disruption	Mitroff, managing crises before they happen (Mitroff and Anagnos 2005); Shell, Scenario Planning (Wack 1985; Ringland 1988)	Scott Jackson, architecting resilient systems (Jackson 2010) Design principles for ultra-large-scale systems (Sillitto 2010)
Driving disruptive innovation	Christensen's Innovator's Dilemma (Christensen 1997) Mintzberg "Rise and fall of strategic planning", (Mintzberg 2000) BS7000, Standard for innovation management (BSI 2008)	
Exploiting unexpected opportunities	Mintzberg, rise and fall of strategic planning (Mintzberg 2000) Mission Command (military), Auftragstechnik (Bungay 2002, 32)	Architecting for Flexibility and Resilience (Jackson 2010) Open system architectures; Lean SE; (Oppenheim et al. 2010) Agile methodologies
Implementing and embedding planned change	Kotter's eight phases of change (Kotter 1995), Berenschot's seven forces (ten Have et al. 2003) Levers of control (Simons 1995) – tension between control, creativity, initiative and risk taking Chaos model, "complexity theory applied to change processes in organisations"; (Zuiderhoudt and Ten Have 1999) Business Process Re-engineering (Hammer and Champy 1993) Senge's 5th discipline (Senge 2006) Change Quadrants (Amsterdam 1999)	"Doing it differently - systems for rethinking construction" (Blockley and Godfrey 2000) INCOSE UK Chapter Z-guides: • Z-2, introducing SE to an organisation (Farncombe and Woodcock 2009); • Z-7, Systems Thinking (Godfrey and Woodcock 2010)
Understanding peoples' motivation, behaviour	Maslow's hierarchy of needs Myers-Briggs Type Indicator; NLP (Neuro-Linguistic Programming) (See for example: Knight 2009) Socio-technical organisation (Taylor and Felten 1993) Core quadrants, (Offman 2001)	INCOSE Intelligent Enterprise Working Group – "enthusiasm", stretch goals (Ring and Wymore 2004) Sommerville, Socio Technical Systems Engineering, Responsibility Mapping (Sommerville et al. 2009)
Understanding culture	Cultural Dimensions, (Hofstede 1994) Compliance Typology (Etzione 1961)	

Helping individuals cope with change	5 C's of individual change, and Rational/emotional axes, Kets De Vries, quoted in "key management models" (Ten Have et al. 2003)	Relationships made easy (Fraser 2010) – rational/emotional, NLP and other methods

References

Works Cited

Blockley, D. and P. Godfrey. 2000. *Doing It Differently – Systems For Rethinking Construction.* London, UK: Thomas Telford, Ltd.

Bungay, S. 2002. *Alamein*. London, UK: Aurum press. First published 2002, Paperback 2003.

BSI. 2008. *Design Management Systems. Guide to Managing Innovation.* London, UK: British Standards Institution (BSI). BS 7000-1:2008.

Christensen, C. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Cambridge, MA, USA: Harvard Business School Press.

Covey, S.R. 1989. *The Seven Habits of Highly Effective People.* Also released as a 15th Anniversary Edition (2004). New York, NY, USA: Simon & Schuster, 1989.

Deming, W.E. 1994. *The New Economics.* Cambridge, MA, USA: Massachusetts Institute of Technology, Centre for Advanced Educational Services.

Etzione, A. 1961. *A Comparative Analysis of Complex Organizations. On Power, Involvement and their Correlates.* New York, NY, USA: The Free Press of Glencoe, Inc.

Farncombe, A. and H. Woodcock. 2009. "Enabling Systems Engineering." Somerset, UK: INCOSE UK Chapter. *Z-2 Guide*, Issue 2.0 (March 2009). Accessed September 14, 2011. Available at http://www.incoseonline.org.uk/Documents/zGuides/Z2_Enabling_SE.pdf.

Forsberg, K. and H. Mooz. 2005. *Visualizing Program Management, Models and Frameworks for Mastering Complex Systems,* 3rd ed. New York, NY, USA: Wiley and Sons, Inc.

Fraser, D. 2010. *Relationships Made Easy: How To Get on with The People You Need to Get on With...and Stay Friends with Everyone Else.* Worcestershire, UK: Hothive Publishing.

Godfrey, P. and H. Woodcock. 2010. "What is Systems Thinking?" Somerset, UK: INCOSE UK Chapter, *Z-7 Guide*, Issue 1.0 (March 2010). Accessed on September 7, 2011. Available at http://www.incoseonline.org.uk/Documents/zGuides/Z7_Systems_Thinking_WEB.pdf.

Hammer, M. and J.A. Champy. 1993. *Reengineering the Corporation: A Manifesto for Business Revolution.* New York, NY, USA Harper Business Books.

Harry, M.J. 1997. *The Nature of Six Sigma Quality*. Schaumburg, IL, USA: Motorola University Press.

Hofstede, G. 1984. *Culture's Consequences: International Differences in Work-Related Values.* Newbury Park, CA, USA and London, UK: Sage Publications Inc.

Jackson, S. 2010. *Architecting Resilient Systems: Accident Avoidance and Survival and Recovery from Disruptions.* A. P. Sage (ed.). Wiley Series in Systems Engineering and Management. New York, NY, USA: Wiley & Sons, Inc.

Knight, S. 2009. *NLP at Work - Neuro Linguistic Programming - The Essence of Excellence,* 1st edition 1995. 3rd edition 2009. London, UK and Boston, MA, USA: Nicholas Brealey Publishing.

Kotter, J. 1995. "Leading Change: Why Transformation Efforts Fail". *Harvard Business Review.* (March-April 1995).

Mintzberg, H. 2000. *The Rise and Fall of Strategic Planning*. Upper Saddle River, NJ, USA: Pearson Education.

Mitroff, I. and G. Anagnos. 2005.*Managing Crises Before They Happen: What Every Executive and Manager Needs to Know about Crisis Management*. New York, NY, USA: AMACOM Press.

Morgan, J. and J. Liker. 2006. *The Toyota Product Development System: Integrating People, Process and Technology.* New York, NY, USA: Productivity Press.

NASA. 2012. "APPEL: Academy of Program/Project & Engineering Leadership." Accessed on September 9, 2012. Available at http://www.nasa.gov/offices/oce/appel/seldp/nasa-se/index.html.

Offman, D.D. 2001. *Inspiration and Quality in Organizations,* (Original title (Dutch): *Bezieling en kwaliteit in organisaties*), 12th Edition. Utrecht, The Netherlands: Kosmos-Z&K.

Oppenheim, B., E. Murman, and D. Sekor. 2010. *Lean Enablers for Systems Engineering*. Systems Engineering. 14(1). New York, NY, USA: Wiley and Sons, Inc.

Ring, J. and A.W. Wymore (eds.) 2004. *Concept of Operations (conops) of A Systems Engineering Education Community (SEEC).* Seattle, WA, USA: INCOSE Education Measurement Working Group (EMWG), INCOSE-TP-2003-015-01.

Ringland, G. 1998. *Scenario Planning: Managing for the Future.* New York, NY, USA: Wiley and Sons, Inc.

Sauser, B., Verma, D., Ramirez-Marquez, J. and Gove, R. 2006. From TRL to SRL: The Concept of System Readiness Levels. Proceedings of the Conference on Systems Engineering Research (CSER), Los Angeles, CA.

SEI. 2010. *Capability Maturity Model Integrated (CMMI) for Development,* version 1.3. Pittsburgh, PA, USA: Software Engineering Institute (SEI)/Carnegie Mellon University (CMU).

Senge, P.M. 2006. *The Fifth Discipline: The Art and Practice of the Learning Organization,* 2nd ed. New York, NY, USA: Doubleday/Currency.

Simons, R. 1995. *Levers of Control, How Managers Use Innovative Control Systems to Drive Strategic Renewal.* Boston, MA, USA: Harvard Business School Press.

Sillitto, H. 2010. "Design Principles for Ultra-Large Scale Systems." Paper in 20th Annual International Council on Systems Engineering (INCOSE) International Symposium. 12-15 July 2010. Chicago, IL, USA. (Reprinted in The Singapore Engineer, IES, April 2011).

Sommerville, I., R. Lock, T. Storer, and J.E. Dobson. 2009. "Deriving Information Requirements from Responsibility Models*. Paper in the 21st International Conference on Advanced Information Systems Engineering (CAiSE). June 2009. Amsterdam, Netherlands. p. 515-529.*

Sprenger, C. and S. Ten Have. 1996. "4 Competencies of a Learning Organisation." (Original title (Dutch): *Kennismanagement als moter van delerende organisatie*), *Holland Management Review,* (Sept–Oct): 73–89.

Taylor, J.C.and D.F. Felten. 1993. *Performance by Design: Sociotechnical Systems in North America.* Englewood Cliffs, NJ, USA: Formerly Prentice Hall, Pearson Education Ltd.

ten Have, S., W.T. Have, F. Stevens, and M. van der Elst. 2003. *Key Management Models - The Management Tools and Practices That Will Improve Your Business.* Upper Saddle River, NJ, USA: Pearson Education Ltd. (Formerly Prentice Hall).

Wack, P. 1985. "Scenarios: Uncharted Waters Ahead." *Harvard Business Review*. (September-October 1985).

Womack, J. and D. Jones. 2003. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation,* Revised Edition. New York, NY, USA: Simon & Schuster.

Zuiderhoudt, W. and B. Ten Have. 1999. *Complexity Theory Applied to Change Processes in Organisations*.

Primary References

Kotter, J. 1995. *Leading Change: Why Transformation Efforts Fail*. *Harvard Business Review.* (March-April 1995).

Oppenheim, B., E. Murman, and D. Sekor. 2010. *Lean Enablers for Systems Engineering*. *Systems Engineering.* 14(1). New York, NY, USA: Wiley and Sons, Inc.

SEI. 2010. *Capability Maturity Model Integrated (CMMI) for Development*, version 1.3. Pittsburgh, PA, USA: Software Engineering Institute (SEI)/Carnegie Mellon University (CMU).

Senge, P.M. 2006. *The Fifth Discipline: The Art and Practice of the Learning Organization*, 2nd ed. New York, NY, USA: Doubleday/Currency.

Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTg2MTMPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Ny
END_ENCODED_CONTENT

Culture

Establishing and managing cultures, values, and behaviors is a critical aspect of systems engineering, especially in the context of deploying SE within an organization (Fasser and Brettner 2002). The Columbia Accident Investigation Report (NASA 2003, 101), defines *culture (glossary)* as *"the basic values, norms, beliefs, and practices that characterize the functioning of a particular institution."*

Stable safety and process cultures are key to effective SE, and can be damaged by an overly-rapid pace of change, a high degree of churn (see the Nimrod Crash Report, Haddon-Cave 2009), or by change that engineers perceive as arbitrarily imposed by management (see Challenger, discussed below). On the other hand, a highly competitive, adversarial or "blame" culture can impede the free flow of information and disrupt synergies in the workplace.

In the multi-national, multi-business, multi-discipline collaborative projects becoming increasingly prevalent in SE, these factors take on greater importance.

Effective handling of cultural issues is a major factor in the success or failure of SE endeavors.

Systems Thinking and the Culture of the Learning Organization

Improving SE efficiency and effectiveness can be the goal of cultural change. This kind of culture change encourages people to learn to think and act in terms of systems, organizations and their enterprises; and, to take a systems approach as described in Overview of Systems Approaches in Part 2, and by Lawson (2010). See the knowledge area Systems Thinking.

Attaining a *learning organization* culture can be another goal of cultural change. And once the learning organization exists, cultural change in general becomes easier to accomplish.

A learning organization aims to absorb, diffuse, generate, and exploit knowledge (Sprenger and Have 1996). Organizations need to manage formal information and facilitate the growth and exploitation of tacit knowledge. They should learn from experience and create a form of *corporate memory* – including process, problem domain and solution space knowledge, and information about existing products and services. Fassner and Brettner (2002, 122-124) suggest that *shared mental models* are a key aspect of corporate knowledge and culture.

A learning organization culture is enabled by disciplines such as

- **personal mastery** where a person continually clarifies and deepens personal vision, focuses energy upon it, develops patience in seeking it so as to view reality in an increasingly objective way;
- **mental models** where people appreciate that mental models do indeed occupy their minds and shape their actions;
- **shared vision** where operating values and sense of purpose are shared to establish a basic level of mutuality; and
- **team learning** where people's thoughts align, creating a feeling that the team as a whole achieves something greater than the sum of what is achieved by its individual members.

Systems thinking supports these four disciplines, and in so doing becomes the **fifth discipline** and plays a critical role in promoting the learning organization (Senge et al. 1994).

Cultural Shortfalls and How to Change them

Cultural shortfalls that are injurious to a system are described as negative paradigms (glossary) by Jackson (2010) and others. For example, a cultural reluctance to identify true risks (glossary) is the hallmark of the **Risk Denial** paradigm as seen in the Challenger and Columbia cases. When individuals believe a system is safe that in fact is not, that is the **Titanic Effect** paradigm, which is of course named for the ocean liner catastrophe of 1912.

Approaches to Change

Jackson and Erlick (Jackson 2010, 91-119) have found that there is a lack of evidence that a culture can be changed from a success point of view. However, they do suggest the Community of Practice (Jackson 2010, 110-112), an approach founded on the principles of organizational psychology, and discuss the pros and cons of other approaches to culture change, including training, coaching, Socratic teaching, use of teams, independent reviews, standard processes, rewards and incentives, use of cost and schedule margins, reliance on a charismatic executive, and management selection. Shields (2006) provides a similarly comprehensive review.

The Columbia Accident (NASA 2003) and the Triangle fire (NYFIC 1912) official reports, among many others, call for cultural issues to be addressed through improved leadership, usually augmented by the more objective approach of auditing. One form of auditing is the Independent Technical Authority, which

- is separate from the program organization;
- addresses only technical issues, not managerial ones; and
- has the right to take action to avoid failure, including by vetoing launch decisions.

An Independent Technical Authority cannot report to the program manager of the program in question, and it may be formulated within an entirely separate business or enterprise which can view that program objectively. The point of these stipulations is to insure that the Independent Technical Authority is indeed independent.

Management and leadership experts have identified ways to lead cultural change in organizations, apart from specifically safety-related cultural change. For example, Gordon (1961) in his work on the use of analogical reasoning called synectics is one of several who emphasize creative thinking. Kotter (1995) advocates a series of steps to transform an organization.

How Culture Manifests in Individuals and Groups

As a community’s physical, social, and religious environment changes over the generations, cultural beliefs, values, and customs evolve in response, albeit at a slower pace.

Helmreich and Merritt describe the effects of cultural factors in the context of aviation safety, and suggest implications for safety cultures in other domains such as medicine. See (Helmreich and Merritt, 2000) and other writings by the same authors.

We can describe the cultural orientation of an individual in terms of

- national and/or ethnic culture;
- professional culture; and
- organizational culture.

Some particulars of these aspects of culture are sketched below.

National and/or Ethnic Culture

A product of factors such as heritage, history, religion, language, climate, population density, availability of resources, and politics, national culture is acquired in one's formative years and is difficult to change. National culture affects attitudes, behavior, and interactions with others.

National culture may help determine how a person handles or reacts to

- rules and regulations;
- uncertainty; and
- display of emotion, including one’s own.

National culture may also play a role in whether a person

- communicates in a direct and specific style, or the opposite;
- provides leadership in a hierarchical manner, or a consultative one; and
- accepts decisions handed down in superior–inferior relationships, or question them.

Professional Culture

Professional culture acts as an overlay to ethnic or national culture, and usually manifests in a sense of community and in bonding based on a common identity (Helmreich and Merritt 2000). Well-known examples of professional cultures include those of medical doctors, airline pilots, teachers, and the military.

Elements of professional culture may include

- a shared professional jargon
- binding norms for behavior
- common ethical values
- self-regulation
- barriers to entry like selectivity, competition and training
- institutional and/or individual resistance to change
- prestige and status, sometimes expressed in badges or uniforms
- stereotyped notions about members of the profession, in general and/or based on gender

Particularly important elements of professional culture (for example, those that affect safety or survivability) need to be inculcated by extensive training and reinforced at appropriate intervals.

Organizational Culture

An organization's culture builds up cumulatively, determined by factors like its leadership, products and services, relationships with competitors, and role in society.

Compared with one another, organizational cultures are not standardized because what works in one organization seldom works in another. Even so, strength in the following elements normally engenders a strong organizational culture:

- corporate identity;
- leadership;
- morale and trust;
- teamwork and cooperation;
- job security;
- professional development and training;
- empowerment of individuals; and
- confidence, for example in quality and safety practices, or in management communication and feedback.

When the culture of the people in an organization is considered as a whole, organizational culture acts as a common layer shared by all. In spite of this, differing national cultures can produce differences in leadership styles, manager-subordinate relationships, and so on, especially in organizations with a high degree of multinational integration.

Because organizations have formal hierarchies of responsibility and authority, organizational culture is more amenable to carefully-planned change than are either professional or national cultures. If changes are made in a manner that is sympathetic to local national culture (as opposed to that of a distant group head office, for example), they can bring significant performance benefits. This is because organizational culture channels the effects of national and professional cultures into standard working practices.

There are many definitions of culture in the literature. The Columbia Accident Investigation Board (NASA 2003) provides a useful one for understanding culture and engineering.

Culture and Safety

Reason (1997, 191-220) describes a culture which focuses on safety as having four components:

1. A reporting culture which encourages individuals to report errors and near misses, including their own.
2. A just culture which provides *an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information.*
3. A flexible culture which abandons the traditional hierarchical reporting structure in favor of more direct team-to-team communications.
4. A learning culture which is willing to draw the right conclusions from safety-related information and to implement reforms when necessary.

Weick and Sutcliffe (2001, 3) introduce the term High Reliability Organizations (HROs) (glossary). HROs have *fewer than their fair share of accidents* despite operating *under trying conditions* in domains subject to catastrophic events. Examples include *power grid dispatching centers, air traffic control systems, nuclear aircraft carriers, nuclear power generation plants, hospital emergency departments, and hostage negotiation teams.* There are five hallmarks of HROs (Weick and Sutcliffe 2001, 10):

1. **Preoccupation with Failure—**HROs eschew complacency, learn from near misses, and do not ignore errors, large or small.
2. **Reluctance to Simplify Interpretations—**HROs simplify less and see more. They “encourage skepticism towards received wisdom.”
3. **Sensitivity to Operations—**HROs strive to detect “latent failures,” defined by James Reason (1997) as systemic deficiencies that amount to accidents waiting to happen. They have well-developed situational awareness and make continuous adjustments to keep errors from accumulating and enlarging.
4. **Commitment to Resilience—**HROs keep errors small and improvise “workarounds that keep the system functioning.” They have a deep understanding of technology and constantly consider worst case scenarios in order to make corrections.
5. **Deference to Expertise—**HROs “push decision making down.” Decisions are made “on the front line.” They avoid rigid hierarchies and go directly to the person with the expertise.

The US Nuclear Regulatory Agency (2011) focuses mainly on leadership and individual authority in its policy statement on safety culture.

Historical Catastrophes and Safety Culture

The cases described in the table below are some of the many in which official reports or authoritative experts cited culture as a factor in the catastrophic failure of the systems involved.

Example	Cultural Discussion
Apollo	According to Feynman (1988), Apollo was a successful program because of its culture of *"common interest."* The *"loss of common interest"* over the next 20 years then caused *"the deterioration in cooperation, which . . . produced a calamity."*
Challenger	Vaughn (1997) states that rather than taking risks seriously, NASA simply ignored them by calling them normal—what she terms *"normalization of deviance,"* whose result was that *"flying with acceptable risks was normative in NASA culture."*
Columbia	The Columbia Accident Investigation Report (NASA 2003, 102) echoed Feynman's view and declared that NASA had a *"broken safety culture."* The board concluded that NASA had become a culture in which bureaucratic procedures took precedence over technical excellence.
Texas City - 2005	On August 3, 2005, a process accident occurred at the BP refinery in a Texas City refinery in the USA resulting in 19 deaths and more than 170 injuries. The Independent Safety Review Panel (2007) found that a corporate safety culture existed that *"has not provided effective process safety leadership and has not adequately established process safety as a core value across all its five U.S. refineries."* The report recommended *"an independent auditing function."*
The Triangle Fire	On August 11, 1911, a fire at the Triangle shirtwaist factory in New York City killed 145 people, mostly women (NYFIC 1912). The New York Factory Investigating Commission castigated the property owners for their lack of understanding of the *"human factors"* in the case and called for the establishment of standards to address this deficiency.
Nimrod	On September 2, 2006, a Nimrod British military aircraft caught fire and crashed, killing its entire crew of 14. The Haddon-Cave report (Haddon-Cave 2009) found that Royal Air Force culture had come to value staying within budget over airworthiness. Referencing the conclusions of the Columbia Accident Investigation Report, the Haddon-Cave report recommends creation of a system of detailed audits.

Relationship to Ethics

A business's culture has the potential to reinforce or undermine ethical behavior. For example, a culture that encourages open and transparent decision making and behavior makes it harder for unethical behavior to go undetected. The many differences in culture around the world are reflected in different perspectives on what is ethical behavior. This is often reflected in difficulties that international companies face when doing business globally, sometimes leading to scandals because behavior that is considered ethical in one country may be considered unethical in another. See Ethical Behavior for more information about this.

Implications for Systems Engineering

As SE increasingly seeks to work across national, ethnic, and organizational boundaries, systems engineers need to be aware of cultural issues and how they affect expectations and behavior in collaborative working environments. SEs need to present information in an order and a manner suited to the culture and personal style of the audience. This entails choices like whether to start with principles or practical examples, levels of abstraction or use cases, the big picture or the detailed view.

Sensitivity to cultural issues is a success factor in SE endeavors (Siemieniuch and Sinclair 2006).

References

Works Cited

Fasser, Y. and D. Brettner. 2002. *Management for Quality in High-Technology Enterprises.* New York, NY, USA: Wiley.

Feynman, R. 1988. "An Outsider's Inside View of the Challenger Inquiry." *Physics Today.* 41(2) (February 1988): 26-27.

Gordon, W.J.J. 1961. *Synectics: The Development of Creative Capacity.* New York, NY, USA: Harper and Row.

Haddon-Cave, C. 2009. *An Independent Review into the Broader Issues Surrounding the Loss of the RAF Nimrod MR2 Aircraft XV230 in Afganistan in 2006.* London, UK: The House of Commons.

Helmreich, R.L., and A.C. Merritt. 2000. "Safety and Error Management: The Role of Crew Resource Management." In *Aviation Resource Management,* edited by B.J. Hayward and A.R. Lowe. Aldershot, UK: Ashgate. (UTHFRP Pub250). p. 107-119.

Independent Safety Review Panel. 2007. *The Report of the BP U.S. Refineries Independent Safety Panel.* Edited by J.A. Baker. Texas City, TX, USA.

Jackson, S. 2010. *Architecting Resilient Systems: Accident Avoidance and Survival and Recovery from Disruptions.* Hoboken, NJ, USA: John Wiley & Sons.

Kotter, J.P. 1995. "Leading Change: Why Transformation Efforts Fail." *Harvard Business Review.* (March-April): 59-67.

Lawson, H. 2010. *A Journey Through the Systems Landscape.* London, UK: College Publications, Kings College.

NASA. 2003. *Columbia Accident Investigation Report.* Washington, DC, USA: National Aeronautics and Space Administration (NASA). August 2003.

Nuclear Regulatory Agency. 2011. "NRC Issues Final Safety Culture Policy Statement." *NRC News* (14 June 2011). Available at: http://pbadupws.nrc.gov/docs/ML1116/ML11166A058.pdf.

NYFIC. 1912. *Preliminary Report of the New York Factory Investigating Commission*. R. F. Wagner (ed). New York, NY, USA: New York Factory Investigating Commission (NYFIC).

Reason, J. 1997. *Managing the Risks of Organisational Accidents*. Aldershot, UK: Ashgate Publishing Limited.

Senge, P.M., A. Klieiner, C. Roberts, R.B. Ross, and B.J. Smith. 1994. *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization.* New York, NY, USA: Currency Doubleday.

Shields, J.L. 2006. "Organization and Culture Change." In *Enterprise Transformation,* W.B. Rouse (ed.). Hoboken, NJ, USA: John Wiley & Son.

Siemieniuch, C.E. and M.A. Sinclair. 2006. "Impact of Cultural Attributes on Decision Structures and Interfaces." Paper presented at the 11th ICCRTS Coalition Command and Control in the Networked Era. Cambridge, MA, USA. p. 1-20.

Sprenger, C. and S.T. Have. 1996. "4 Competencies of a Learning Organization." (Original title: "Kennismanagement als moter van delerende organisatie"). *Holland Management Review* Sept–Oct, p. 73–89.

Vaughn, D. 1997. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA.* Chicago, IL, USA: University of Chicago Press.

Weick, K.E. and K.M. Sutcliffe. 2001. *Managing the Unexpected: Assuring High Performance in an Age of Complexity*. San Francisco, CA, USA: Jossey-Bass (Jossey-Bass acquired by Hoboken, NJ, USA: Wiley Periodicals, Inc.).

Primary References

Fasser, Y. and D. Brettner. 2002. *Management for Quality in High-Technology Enterprises.* New York, NY, USA: Wiley.

Helmreich, R.L., and A.C. Merritt. 2000. "Safety and Error Management: The Role of Crew Resource Management." In *Aviation Resource Management,* edited by B.J. Hayward and A.R. Lowe. Aldershot, UK: Ashgate. (UTHFRP Pub250). p. 107-119.

Hofstede, G. 1984. *Culture's Consequences: International Differences in Work-Related Values*. London, UK: Sage Publications.

Jackson, S. 2010. *Architecting Resilient Systems: Accident Avoidance and Survival and Recovery from Disruptions.* Hoboken, NJ, USA: John Wiley & Sons.

NASA. 2003. *Columbia Accident Investigation Report.* Washington, DC, USA: National Aeronautics and Space Administration (NASA). August 2003.

Reason, J. 1997. *Managing the Risks of Organisational Accidents*. Aldershot, UK: Ashgate Publishing Limited.

Senge, P.M., A. Klieiner, C. Roberts, R.B. Ross, and B.J. Smith. 1994. *The Fifth Discipline Fieldbook: Strategies and Tools for Building a Learning Organization.* New York, NY, USA: Currency Doubleday.

Additional References

Hofstede, G. 2001. *Culture's Consequences: Comparing Values, Behaviors, Institutions and Organizations Across Nations,* Second Edition. Thousand Oaks, CA, USA: Sage Publications.

Hofstede, G. 2010. *Cultures and Organizations: Software for the Mind,* Third Edition. New York, NY, USA: McGraw Hill.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MzgyMjQPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Enabling Teams

This knowledge area focuses on enabling a team to perform SE. Once that is done using the techniques described here, the knowledge found in Part 3, Systems Engineering and Management, about how to perform SE can be applied. Part 5, Enabling Systems Engineering, to which this knowledge area belongs, explores how systems engineering (SE) is enabled at three levels of organization: the business or enterprise, the team, and the individual.

For the sake of brevity, the term “business” is used to mean “business or enterprise” throughout most of this knowledge area. For a nuanced explanation of what distinguishes a business from a enterprise, see Enabling Systems Engineering.

Topics

Each part of the SEBoK is composed of knowledge areas (KAs). Each KA groups topics together around a theme related to the overall subject of the part. This KA contains the following topics:

- Team Capability
- Team Dynamics
- Technical Leadership in Systems Engineering

Overview

Products, enterprise systems, and services are developed, delivered, and sustained with the contributions of systems engineers, who also coordinate the technical aspects of the multiple projects that comprise a program. These activities require certain individuals to work in a cooperative manner to achieve shared objectives based on a common vision—that is, as teams. Not every group of individuals working together is a team. To perform SE activities efficiently and effectively, the capabilities of and dynamics within the team must be specifically attuned to SE.

Although individuals sometimes perform SE activities, it is more usual to find project teams performing SE activities while providing specialty engineering capabilities (see Systems Engineering and Specialty Engineering). Not all who perform SE activities are labeled “systems engineers.” Thus, electrical, mechanical, and software engineers, service providers, or enterprise architects in IT organizations may lead or be members of teams that perform SE tasks. Those individuals are referred to as systems engineers in this knowledge area, regardless of their job titles within their organizations.

This knowledge area is concerned with methods, tools, and techniques for enabling project teams to perform SE activities. Its first topic, Team Capability, answers the questions

- How do businesses determine value added by SE activities performed by project teams?
- How does an organization determine the efficiency and effectiveness of SE activities performed by project teams?

Its other topic, Team Dynamics, answers the question

- How are group dynamics crucial to enabling systems engineers to perform work and achieve goals?

Topics from elsewhere in the SEBoK that cover related questions include Relationships between Systems Engineering and Project Management and The Influence of Project Structure and Governance on Systems Engineering and Project Management Relationships, which answer the question

- What do managers need to know about managing systems engineers and project teams that perform SE activities?

References

Works Cited

None.

Primary References

Brooks, F. 1995. *The Mythical Man-Month,* Anniversary Edition. Reading, MA, USA: Addison Wesley.

Curtis, B., W.E. Hefley, and S.A. Miller. 2001. *People Capability Maturity Model (P-CMM),* Version 2.0. Pittsburg, PA, USA: Software Engineering Institute (SEI). CMU/SEI-2001-MM-01. Accessed on June 8, 2012. Available at http://www.sei.cmu.edu/library/abstracts/reports/01mm001.cfm.

DeMarco, T. and T. Lister. 1999. *Peopleware: Productive Projects and Teams,* 2nd ed. New York, NY, USA: Dorset House.

Eisner, H. 2008.*Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley and Sons.

Fairley, R.E. 2009. *Managing and Leading Software Projects.* Hoboken, NJ, USA: John Wiley & Sons.

Forsyth, D.R. 2010. *Group Dynamics,* 5th edition. Belmont, CA, USA: Wadsworth, Cengage Learning.

Hase, S. 2000. "Measuring Organisational Capability: Beyond Competence", Paper presented at Future Research, Research Futures: Australian Vocational Education and Training Research Association (AVETRA) Conference (2000). Accessed on June 8, 2012. Available at http://www.avetra.org.au/abstracts_and_papers_2000/shase_full.pdf.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205*. San Diego, CA, USA: International Council on Systems Engineering (INCOSE). INCOSE-TP-2010-003.

NASA. 2011. *Academy of Program/Project and Engineering Leadership (APPEL), NASA APPEL Performance Enhancement.* Accessed on September 15, 2011. Available at http:/ / www. nasa. gov/ offices/ oce/ appel/ performance/index.html.

Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTM2NjEPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya

END_ENCODED_CONTENT

Team Capability

The capability of a team to perform systems engineering (SE) depends on having competent personnel, adequate time, sufficient resources and equipment, and appropriate policies and procedures (Torres and Fairbanks 1996).

The team should have a charter. Staff must be proficient in the needed competencies and must work together with the right attitude, under the right organization, and with appropriate tools, training, and processes such as configuration management and peer review.

Those responsible for the team attaining the desired capability need to organize, staff, develop, and assess the team. Techniques for pilot projects, post-mortem analysis, and lessons learned can be applied as well.

Organizing the Team

Project teams, and the roles of systems engineers within those teams, depend on factors such as the nature, size, and scope of the project, the organization's preferred way of organizing teams, and external constraints such as a larger program in which the project may be embedded. Options range from a dedicated team of systems engineers, to Integrated Product Teams, to teams that include other kinds of engineers that perform systems engineering.

Systems engineers and SE teams may play the roles of technical leads, consultants, or advisers; this also influences the ways in which SE teams are organized. In some organizations, systems engineers and SE teams provide technical leadership; they perform requirements analysis and architectural design, conduct trade studies, and allocate requirements and interfaces to the various elements of a system. In addition, they work with component specialists, develop integration plans and perform system integration, verification, and validation. Depending on the scope of effort, they may also install the system and train the operators and users; provide ongoing services to sustain the system; and retire/replace an aged system. Systems engineers may be housed within a functional unit of an organization and assigned, in matrix fashion, to projects and programs, or they may be permanently attached to a project or program for the duration of that endeavor. They may be organized based, in part, on their domain of expertise, such as finance or telecommunications. For additional information on organizational options see Determining Needed Systems Engineering Capabilities in Businesses and Enterprises.

In other cases, one or more systems engineers may provide consulting or advisory services, as requested, to projects and programs. These engineers may be dispatched from a central pool within an organization, or they may be hired from an outside agency.

An SE team can be organized by job specialization, where each SE team member (or each SE sub-team) plays a different role; for example, requirements engineering, system architecture, integration, verification and validation, field test, and installation and training; in this case the various job specializations are typically coordinated by a lead systems engineer.

Alternatively, an SE team can be organized by subsystem where each SE team member (or SE sub-team) performs the previously indicated functions for each of the subsystems with a top-level team to coordinate requirements allocation, interfaces, system integration, and system verification and validation.

Ideally, roles, responsibilities, and authority will be established for each project or program and used to determine the optimal way to organize the team. Sometimes, however, an *a priori* organizational, project, or program structure may determine the structure, roles, responsibilities, and authority of the SE team within a project or program; this may or may not be optimal.

Within a project, a systems engineer or SE team may occupy a staff position subordinate to the project manager, as indicated in Figure 1 or conversely, the SE team may provide the authoritative interface to the customer with the project manager or management team, serving in a staff capacity, as indicated in Figure 2. In both cases, SE and project management must work synergistically to achieve a balance among product attributes, schedule, and budget. Eisner (2008) lays out various approaches to organizing systems engineers. For additional information see Systems Engineering and Project Management.

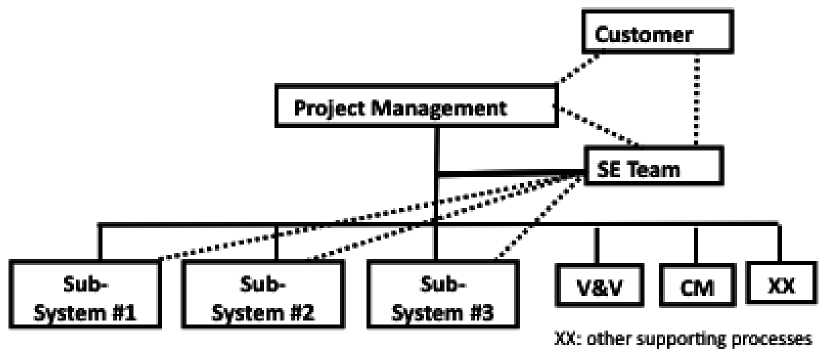

Figure 1. SE Team Subordinate to Project Management. (SEBoK Original)

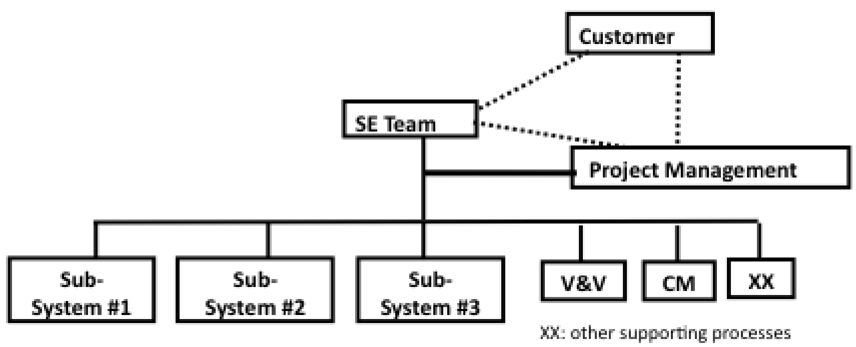

Figure 2. Project Management Subordinate to Systems Engineering. (SEBoK Original)

In scaling up to the program level, the considerations portrayed in Figures 1 and 2 can be generalized so that a top-level SE team provides coordination among the subordinate projects. In this case, each project has an SE team, and within each project the SE team members can be organized in either of the ways indicated in the figures. When scaling up to programs, each of the sub-systems in Figures 1 and 2 are separate, coordinated projects.

The models presented in Figures 1 and 2 can be scaled down to smaller projects, where an individual systems engineer performs the SE activities, either in the subordinate position of Figure 1 or the superior position of Figure 2. In this case, there is a single subsystem (i.e., the system) and the supporting functions may be provided by the systems engineer or by supporting elements of the larger organization.

The roles to be played by members of a SE team are influenced by the structures adopted as part of the organizational strategy of the business in which the team is operating (see Systems Engineering Organizational Strategy). In Product Centered Organizations, for example, an Integrated Product Team (IPT) is assigned to each element of the system breakdown structure (SBS). Each IPT consists of members of the technical disciplines necessary to perform systems engineering functions for that element of the system.

At the program level there is a top-level IPT commonly called a SE and integration team (SEIT), whose purpose is to oversee all of the lower level IPTs. Some specialists, such as reliability and safety engineers, may be assigned to a team to cover all elements within a given level of the SBS. These teams are sometimes called Analysis and Integration teams (AITs), and are created at various levels of the SBS as needed.

Organizing communication and coordination among a group of systems engineers should follow the well known *7 ± 2* rule because the number of communication paths among *N* engineers is *N(N-1)/2*; i.e., the number of links in a fully connected graph (Brooks 1995). There are 10 communication paths among 5 engineers, 21 among 7 engineers, and 36 among 9 engineers. An SE team of more than 10 members (45 paths) should be organized hierarchically with a top-level team leader. Sub-teams can be partitioned by product subsystem or by process work activities (analysis, design, integration).

Staffing the Team

Once the organizational structure of the SE team is understood, the team can be staffed. As noted in Enabling Individuals, competency of an individual is manifest in the knowledge, skills, abilities, and attitudes needed for the individual to perform a specific task efficiently and effectively. Different levels of competency may be needed in different situations. Competencies include occupational competence, social competence, and communication competence. Competent systems engineers, for example, have SE knowledge, skills, and ability; engage in systems thinking; possess emotional intelligence; and have good communication and negotiation skills. In addition, competent systems engineers are typically competent within specific domains (e.g. aerospace, medicine, information technology) and within specific process areas of systems engineering (e.g., requirements, design, verification and validation). (See Part 3, Systems Engineering and Management for more information on specific process areas.) The article on Roles and Competencies includes a summary of SE competency models. Based on the context, these competency models are tailored to match the needs of each project. The roles within the team are defined, and competencies are linked to the roles. The lists of competencies given in those models are most often distributed among the members of a SE team. It is not often that a single individual will possess the full list of competencies given in these models.

In addition to individual competencies to perform SE roles, the collective SE competencies needed by a team depend on additional factors including the domain, the stakeholders, the scope of the effort, criticality of outcome, new initiative versus enhancement, and the responsibilities and authority assigned to the team. For example, collective SE competencies needed to develop the IT enterprise architecture for a small company are quite different from those needed to develop the architecture of an aircraft which is engineered and manufactured in a distributed fashion around the world.

To determine the collective set of competencies an SE team needs to conduct a project or program, perform the following steps:

1. Identify the context, to include
    1. domain
    2. stakeholders
    3. organizational culture
    4. scope of effort
    5. criticality of the product, enterprise endeavor, or service
    6. new initiative or sustainment project
2. Clarify the responsibilities, authority, and communication channels of the systems engineering team
3. Establish the roles to be played by systems engineers, and other project personnel as determined by context, responsibilities, and authority
4. Determine the required competencies and competency levels needed to fill each of the systems engineering roles

5. Determine the number of systems engineers needed to provide the competencies and competency levels for each role
6. Determine the availability of needed systems engineers
7. Make adjustments based on unavailability of needed systems engineers
8. Organize the systems engineering team in a manner that facilitates communication and coordination within the SE team and throughout the project or program
9. Consult stakeholders to ask "What are we missing?"

Competency models and skills inventories, such as INCOSE (2010) and Curtis et al. (2001), can be used as checklists to assist in determining the needed competencies and competency levels for a product, enterprise, or service. (See Roles and Competencies.)

When the needed competencies, competency levels, and capacities have been determined, one of two situations will arise: optimally, the number of systems engineers who have the needed competencies and competency levels to fill the identified roles will be available; or, they will either be unavailable or cannot be provided because of insufficient funding. For example, a new initiative may need a lead engineer, a requirements engineer, a systems architect and a systems integrator-tester to accomplish systems engineering tasks. Budgetary constraints may indicate that only two of the four roles can be supported. Compromises must be made; perhaps the system architect will be the lead engineer and the requirements engineer will also be assigned the tasks of system integration and testing even though he or she does not have the desired skill and experience (i.e., competency level) in integration and testing.

Developing the Team

Before a team that performs SE can be effective, it needs to establish its own identity, norms, and culture. The well-known four stages of *"forming, storming, norming, performing"* (Tuckman 1965, 384-399) indicate that a SE team needs time to form, for the members to get to know and understand each other as well as the tasks to be performed, and to work out how best to work together. It is also important that care is taken to ensure, to the extent possible, assignment of roles and responsibilities that would allow SE team members to satisfy their individual goals (Fraser 2010).

The *cost and time to cohesion* can be minimized by good selection and management of the SE team, consistent training across the business so that team members have a common framework of understanding and language for their work, good "infostructure" to allow easy and useful sharing of information, and shared behavioral norms and values. Conversely, in cross-site, inter-company and international SE teams, more time must be allowed for team formation. SE teams are more effective if attention is given to ensuring that each member's work satisfies their individual goals as well as the team and organizational objectives (Fraser 2010).

According to Stephenson and Weil (1992), capable people are:

> *those who know how to learn; are creative; have a high degree of self-efficacy, can apply competencies in novel as well as familiar situations; and work well with others. In comparison to competency, which involves the acquisition of knowledge and skills, capability is a holistic attribute.*

The results of a survey by Steward Hase (2000) concluded that the following are significant contributors to the human elements of capability:

- Competent People
- Working in Teams
- Visible Vision and Values
- Ensuring Learning Takes Place
- Managing the Complexity of Change
- Demonstrating the Human Aspects of Leadership
- Performing as Change Agents

- Involving People in Change
- Developing Management Talent
- Committing to Organizational Development

These attributes of human capability apply to all members of an organization, including systems engineers, both as individuals and as members of project teams.

DeMarco and Lister (1999) discuss “teamicide” techniques by which management, perhaps unintentionally, practices *sure fire techniques to kill teams*. Teamicide techniques include

- physical separation of team members
- fragmentation of time
- unrealistic schedules
- excessive overtime

Methods for developing and improving SE capabilities within teams include building cohesive teams, conducting pilot projects, participating in and studying post-mortem analyses, and preparation and examination of lessons learned. Members of a cohesive systems engineering team have a strong sense of commitment to the work and to the other team members. Commitment creates synergy, which results in performance greater than the sum of the performance of the individual team members.

Some key indicators of a cohesive systems engineering team (Fairley 2009, 411) are

- clear understanding of systems engineering roles and responsibilities
- shared ownership of systems engineering work products
- willingness of systems engineers to help one another and to help other project members
- good communication channels among systems engineers and with other project elements
- enjoyment of working together

Negations of these indicators—the hallmarks of a dysfunctional team—are

- confusion of systems engineering roles and responsibilities
- protective ownership of systems engineering work products
- unwillingness to help one another
- absence of good communications among systems engineers and with other project elements
- personal dislike of one or more other systems engineering team members

Techniques for building and maintaining cohesive systems engineering teams include

- an appropriate number of systems engineering team members
- a correct mix of systems engineering competencies
- celebration of project milestones
- team participation in off-site events
- social events that include family members

Assessing the Team

Performance evaluation is most often conducted for individuals. Robbins (1998, 576) states the historic belief that individuals are the core building blocks around which organizations are built. However, it is also important to assess the team's capability and performance. To design a system that supports and improves the performance of teams, including SE teams, Robbins offers four suggestions:

1. Tie the SE team's performance and the overall project team's results to the organization's goals
2. Begin with the team's customer (glossary) and the work process the team follows to satisfy customer's needs
3. Measure both team and individual performance and compare them to organizational norms and benchmarks
4. Train the team to create its own measures.

Robbins' approach can be applied in the context of SE:

1. Tie the SE and overall project team's results to the project's and the organization's goals. Use measures that apply to goals the team must achieve. For SE in particular, the team effort should be tied to the product or service which the organization seeks to deliver. The end product for the SE team should not be only the SE work products but the delivered products and services provided by the project. For more information on general SE assessment, see Systems Engineering Assessment and Control.
2. Consider the SE team's customers and more broadly the key stakeholders and the work processes that the SE team follows to satisfy customer needs. SE customers and stakeholders can be internal or external; the internal customers of systems engineering are the other project elements that depend on systems engineering work products and services, which can be evaluated for on-time delivery of quantity and quality. The process steps can be evaluated for waste and cycle time; i.e., efficiency and effectiveness.
3. Assess both individual and team performance. Define the roles of each SE team member in terms of the tasks that must be accomplished to produce the team's work products. For more information on individual assessment, see Assessing Individuals.
4. Finally, have the team define its own measures of achievement of goals. This helps all members of the team to understand their roles, while also building team cohesion.

As an example, NASA's Academy of Program/Project and Engineering Leadership (APPEL) provides a service where team performance is assessed and interventions are provided to the team for specific gaps in performance (NASA 2011). This performance enhancement service increase a project's probability of success by delivering the right support to a project team at the right time. APPEL offers the following assessments:

- Project/Team Effectiveness — Measures effectiveness of a team’s behavioral norms
- Individual Effectiveness — Measures effectiveness of an individual’s behavioral norms
- Project/Team Process Utilization — Measures the extent of a team’s utilization of key processes
- Project/Team Knowledge — Covers topics that NASA project personnel should know in order to perform in their jobs

The APPEL approach can be applied to assessing the performance of a SE team and individual systems engineers.

Further Techniques for Building Team Capability

Further techniques for developing SE capabilities within teams include conducting pilot projects, preparing post-mortem analyses, and participating in and studying lessons learned.

Pilot Projects

Pilot projects are an effective mechanism by which SE teams can build team cohesion, acquire new skills, and practice applying newly acquired skills to projects and programs. Pilot projects can be conducted for the sole purpose of skills acquisition, or additionally they can be conducted to determine the feasibility of a proposed approach to solving a problem. Feasibility studies and acquisition of new team skills can be combined in proof-of-concept studies. Primary inhibitors to conducting SE pilot projects are the time required and diversion of personnel resources.

Post-mortem Analysis

A post-mortem analysis identifies areas for improvement of SE performance in future projects and programs. Inputs to a post-mortem analysis include

- personal reflections and recollections of project personnel and other stakeholders;
- email messages, memos, and other forms of communication collected during a project or program;
- successful and unsuccessful risk mitigation actions taken; and
- trends and issues in change requests and defect reports processed by the change control board.

Team participation in a post-mortem analysis allows SE team members to reflect on past efforts, which can lead to improved team capabilities for future projects or, if the present team is being disbanded, improved individual ability to participate in future systems engineering teams.

Inhibitors for effective post-mortem analysis include not allocating time to conduct the analysis, failure to effectively capture lessons-learned, failure to adequately document results, reluctance of personnel to be candid about the performance of other personnel, and negative social and political aspects of a project or program. Mechanisms to conduct effective post-mortem analyses of SE projects include using a third party facilitator, brainstorming, Strength-Weakness-Opportunity-Threat (SWOT) analysis, fishbone (Ishikawa) diagrams, and mind mapping.

Lessons Learned

Lessons learned in SE include both positive and negative lessons. Experiences gained and documented from past projects and programs can be an effective mechanism for developing and improving the capabilities of a team that performs SE tasks. Studying past lessons learned can aid in team formation during the initiation phase of a new project. Lessons learned during the present project or program can result in improved capabilities for the remainder of the present project and for future projects. Inputs for developing and documenting SE lessons learned include results of past post-mortem analyses plus personal recollections of the team members, informal *war stories*, and analysis of email messages, status reports, and risk management outcomes. Inhibitors for developing and using SE lessons learned include failure to study lessons learned from past projects and programs during the initiation phase of a project, failure to allocate time and resources to developing and documenting lessons learned from the present project or program, and reluctance to discuss problems and issues.

References

Works Cited

Brooks, F. 1995. *The Mythical Man-Month*, anniversary edition. Reading, MA, USA: Addison Wesley.

Curtis, B., W.E. Hefley, and S.A. Miller. 2001. *People Capability Maturity Model (P-CMM)*, version 2.0. Pittsburgh, PA, USA: Software Engineering Institute (SEI). CMU/SEI-2001-MM-01. Accessed April 24, 2013. Available: http://www.sei.cmu.edu/library/abstracts/reports/01mm001.cfm.

DeMarco, T., and T. Lister. 1999. *Peopleware: Productive Projects and Teams*, 2nd ed. New York, NY, USA: Dorset House.

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons.

Fairley, R.E. 2009. *Managing and Leading Software Projects*. Hoboken, NJ, USA: John Wiley & Sons.

Fraser, D. 2010. *Relationships Made Easy: How to Get on with The People You Need to Get on with...and Stay Friends with Everyone Else*. Worchestershire, UK: Hothive Books.

Hase, S. 2000. "Measuring Organisational Capability: Beyond Competence." Paper presented at Future Research, Research Futures: Australian Vocational Education and Training Research Association (AVETRA) Conference

(2000). Accessed September 14, 2011. Available: http:/ / www. avetra. org. au/ abstracts_and_papers_2000/ shase_full.pdf.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205*. San Diego, CA, USA: International Council on Systems Engineering (INCOSE). INCOSE-TP-2010-003.

NASA. 2011. *Academy of Program/Project and Engineering Leadership (APPEL), NASA APPEL Performance Enhancement*. Accessed September 15, 2011. Available: http://appel.nasa.gov/team/request-support/.

Robbins, S.P. 1998. *Organizational Behavior: Concepts, Controversies, Applications*, 8th ed. Upper Saddle River, NJ, USA: Prentice Hall. p. 576.

Stephenson, J. and S. Weil. 1992. *Quality in Learning: A Capability Approach in Higher Education*. London, UK: Kogan Page.

Torres, C., and D. Fairbanks. 1996. *Teambuilding: The ASTD Trainer's Sourcebook*. New York, NY, USA: McGraw-Hill.

Tuckman, B. 1965. "Developmental Sequence in Small Groups." *Psychological Bulletin*. 63 (6): 384-99.

Primary References

Brooks, F. 1995. *The Mythical Man-Month*. Anniversary Edition. Reading, MA, USA: Addison Wesley.

Curtis, B., W.E. Hefley, and S.A. Miller. 2001. *People Capability Maturity Model (P-CMM)*, Version 2.0. Pittsburg, PA, USA: Software Engineering Institute (SEI). CMU/SEI-2001-MM-01. Accessed on June 8, 2012. Available at http://www.sei.cmu.edu/library/abstracts/reports/01mm001.cfm.

DeMarco, T. and T. Lister. 1999. *Peopleware: Productive Projects and Teams*. 2nd ed. New York, NY, USA: Dorset House.

Eisner, H. 2008. *Essentials of Project and Systems Engineering Management*. 3rd ed. Hoboken, NJ, USA: John Wiley & Sons.

Fairley, R.E. 2009. *Managing and Leading Software Projects*. Hoboken, NJ, USA: John Wiley & Sons.

Hase, S. 2000. "Measuring Organisational Capability: Beyond Competence". Paper presented at Future Research, Research Futures: Australian Vocational Education and Training Research Association (AVETRA) Conference (2000). Accessed on June 8, 2012. Available at http://www.avetra.org.au/abstracts_and_papers_2000/shase_full.pdf.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205*. San Diego, CA, USA: International Council on Systems Engineering (INCOSE). INCOSE-TP-2010-003.

NASA. 2011. *Academy of Program/Project and Engineering Leadership (APPEL), NASA APPEL Performance Enhancement.* Accessed on May 2, 2014. Available at http://appel.nasa.gov/team/request-support/.

Torres, C. and D. Fairbanks. 1996. *Teambuilding: The ASTD Trainer's Sourcebook*. New York, NY, USA: McGraw-Hill.

Additional References

Fasser, T. and D. Brettner. 2002. *Management for Quality in High Technology Enterprises.* New York, NY, USA: Wiley.

INEEL 2004. *A Project Management and Systems Engineering Structure for a Generation IV Very High Temperature Reactor.* Idaho Falls, ID, USA: Idaho National Engineering and Environmental Laboratory, NEEL/CON-04-02175. Accessed on September 14, 2011. Available at http://www.inl.gov/technicalpublications/Documents/2808490.pdf.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTA0NTEPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Team Dynamics

A systems engineering (SE) team (glossary) is a group of individuals who cooperatively perform a collection of SE tasks based on a shared vision and a common set of engineering objectives. Applying the practical considerations of group dynamics is essential to enabling SE teams to successfully perform SE activities. The interplay of the behaviors of humans in groups is varied, changing, and inescapable. Nevertheless, study of these behaviors has yielded valuable insight and knowledge on the dynamics of individuals within groups. The awareness and application of group dynamics is crucial to facilitating systems engineers' performance of work and achievement of their goals.

The study of group dynamics was initially within the province of psychology and later within sociology. The importance of group dynamics to successful teams has led other disciplines such as business management to study and apply team dynamics.

History

The origins of the study of group dynamics began with Gustave Le Bon. Le Bon wrote *La psychologie des fouls* in 1895, which was translated into English as *The Crowd: A Study of the Popular Mind* a year later. Sigmund Freud wrote *Group Psychology and the Analysis of the Ego* in 1922 responding to Le Bon's work. Kurt Lewin is acknowledged as the "founder of social psychology", coining the term **group dynamics**. He founded the Research Center for Group Dynamics at the Massachusetts Institute of Technology in 1945, relocating in 1948 to the University of Michigan. Wilfred Bion studied group dynamics from a psychoanalytical perspective. He help found the Tavistock Institute of Human Relations in 1947. In that same year, both the Research Center for Group Dynamics and the Tavistock Institute of Human Relations founded the journal *Human Relations*. The study of group dynamics is now worldwide, active, and well established.

Nature of Groups

Groups are endemic to human existence and experience; humans are by nature social animals. Consequentially, an informed understanding of the nature of groups is very useful in enabling teams to perform SE. Research into group behavior reveals that the nature of a group can be described by interaction, goals, interdependence, structure, unity, and stage. (Forsyth 2010, 5-10)

Interaction

Communication (both verbal and non-verbal) among members within a group produces constantly changing and varied interactions. Group dynamics are more than the sum of the interactions between individual members; group interactions create synergistic behaviors and results. Interactions can be placed into two categories (1) socio-emotional interactions and (2) task interactions (Bales 1950, 1999).

Goals

All groups exist for the purpose of achieving one or more goals. The goals provide the basis for the group's tasks. The tasks accomplished by the group can be categorized into activities and characterized by a Circumplex Model (McGrath 1984, 61), which establishes four quadrants, where the X-axis is *choose* vs. *execute* and the Y-axis is *generate* vs. *negotiate*.

Interdependence

Interdependence is *the state of being dependent to some degree on other people, as when one's outcomes, actions, thoughts, feelings, and experiences are determined in whole or in part by others*. Interdependence can be categorized into five types (1) mutual, reciprocal; (2) unilateral; (3) reciprocal, unequal; (4) serial; and (5) multi-level. (Forsyth 2010, 8)

Structure

Structure includes the organization and patterned behaviors of a group. Structure can be deliberately devised and/or emergently observed. Most groups have both kinds of structures, which are evinced in the roles and norms of the group. *The roles of leader and follower are fundamental ones in many groups, but other roles — information seeker, information giver, elaborator, procedural technician, encourager, compromiser, harmonizer — may emerge in any group* (Benne and Sheats 1948; Forsyth 2010, 9). Norms are the rules that govern the actions of group members; norms can include both formal and informal rules.

Cohesion

The *interpersonal forces that bind the members together in a single unit with boundaries that mark who is in the group and who is outside of it* constitute a group's cohesion (Dion 2000). Cohesion is an essential quality of group; it can vary from weak to strong. A team cannot perform effectively without strong group cohesion.

Stage

Groups exhibit stages of development. Being comprised of people, it is not surprising that groups collectively demonstrate the dynamics and growth of the individuals that constitute the group members. The most well-known and wide-spread model of the stages of group development was developed by Bruce Tuckman. The initial model identified the sequence of group development as (1) Forming, (2) Storming, (3) Norming, and (4) Performing (Tuckman 1965). He later added a final stage to the model: (5) Adjourning (Tuckman and Jensen 1977). While Tuckman's model is sequential, others have observed that groups actually may recursively and iteratively progress through the different stages (Forsyth 2010, 20).

Practical Considerations

The dynamics associated with creating, nurturing, and leading a team that will successfully achieve the team's goals is important and challenging. Although psychologists and sociologists have conducted and continue to conduct research to understand team dynamics, the profession of business management has additionally sought to develop practical guidance for utilizing and applying this knowledge to foster high-performance teams. Accordingly, business management has focused its contribution to the field of team dynamics by publishing practical guidebooks to analyze the problems and focus on developing solutions to the problems of team dynamics (see Additional References). There are many consultancy firms throughout the world that assist organizations with the application of practical knowledge on team dynamics. Successful systems engineering teams would do well to not ignore, but rather take advantage of this knowledge.

References

Works Cited

Bales, R.F. 1950. *Interaction Process Analysis: A Method for The Study of Small Groups.* Reading, MA, USA: Addison-Wesley.

Bales, R.F. 1999. *Social Interaction Systems: Theory and Measurement.* New Brunswick, NJ, USA: Transaction.

Benne, K.D. and P. Sheats. 1948. "Functional Roles of Group Members." *Journal of Social Issues.* 4 (2): 41-49. Blackwell Publishing Ltd.

Dion, K.L. 2000. "Group Cohesion: From 'Field of Forces' to Multidimensional Construct." *Group Dynamics: Theory, Research, and Practice.* 4 (1): 7-26. Washington DC, USA: American Psychological Association.

Forsyth, D.R. 2010. *Group Dynamics,* 5th edition. Belmont, CA, USA: Wadsworth, Cengage Learning.

McGrath, J.E. 1984. *Groups: Interaction and Performance.* Upper Saddle River, NJ, USA: Prentice Hall.

Tuckman, B.W. 1965. "Developmental Sequence in Small Groups." *Psychological Bulletin.* 63 (6):384-399. Washington DC, USA: American Psychological Association.

Tuckman, B.W. and M.C. Jensen. 1977. "Stages of Small Group Development Revisited." *Group and Organization Management* 2 (4): 419-427. Thousand Oaks, CA, USA: Sage Publications.

Primary References

Forsyth, D.R. 2010. *Group Dynamics,* 5th edition. Belmont, CA, USA: Wadsworth, Cengage Learning.

Additional References

Scholtes, P.R., B.L. Joiner, and B.J. Streibel. 2003. *The Team Handbook,* 3rd edition. Edison, NJ, USA: Oriel Inc.

Larson, C.E. and F.M.J. LaFaso. 1989. *Teamwork: What Must Go Right, What Can Go Wrong.* Newbury Park, CA, USA: Sage Publications, Inc.

Lencioni, P. 2002. *The Five Dysfunctions of a Team: A Leadership Fable*. San Francisco, CA, USA: Jossey-Bass.

Lencioni, P. 2005. *Overcoming the Five Dysfunctions of a Team.* San Francisco, CA, USA: Jossey-Bass.

McShane, S.L. and M.A. Von Glinow. 2010. *Organizational Behavior: Emerging Knowledge and Practice for the Real World.* New York, NY, USA: McGraw-Hill/Irwin.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTI5NDUPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Technical Leadership in Systems Engineering

Technical leadership in systems engineering is exhibited by effectively communicating a vision, strategy, method, or technique needed to achieve a shared goal, which is accepted and enacted by team members, technical personnel, managers, and other project/program stakeholders. A systems engineering leader may lead a team of systems engineers for a project or program, or may be the only systems engineer who leads a team of members from the various disciplines involved in the project or program (e.g., other engineers, IT personnel, service providers). There is a vast amount of literature addressing leadership issues from multiple points of view, including philosophical, psychological, and emotional considerations (Yukl 2013). This article is concerned with the pragmatic aspects of the leading team members involved in a systems engineering project. Related knowledge areas and articles are in Part 5 Enabling Systems Engineering and the Part 6 knowledge area Systems Engineering and Project Management.

Attributes of Effective Leaders

Some commonly cited attributes of effective leaders are listed in Table 1 below.

Table 1. Attributes of Effective Leaders (Fairley 2009).
Reprinted with permission of the IEEE Computer Society. All other rights are reserved by the copyright owner.

Listening carefully	Maintaining enthusiasm
Delegating authority	Saying “thank you”
Facilitating teamwork	Praising team for achievements
Coordinating work activities	Accepting responsibility for shortcomings
Facilitating communication	Coaching and training
Making timely decisions	Indoctrinating newly assigned personnel
Involving appropriate stakeholders	Reconciling differences and resolving conflicts

Speaking with individual team members on a frequent basis	Helping team members develop career paths and achieve professional goals
Working effectively with the project/program manager and external stakeholders	Reassigning, transferring, and terminating personnel as necessary

Characteristics that result in effective leadership of systems engineering activities include behavioral attributes, leadership style, and communication style. In addition, a team leader for a systems engineering project or program has management responsibilities that include, but are not limited to: developing and maintaining the systems engineering plan, as well as establishing and overseeing the relationships between the project/program manager and project/program management personnel.

Behavioral Attributes

Behavioral attributes are habitual patterns of behavior, thought, and emotion that remain stable over time (Yukl 2013). Positive behavioral attributes enable a systems engineering leader to communicate effectively and to make sound decisions, while also taking into consideration the concerns of all stakeholders. Desirable behavioral attributes for a systems engineering leader include characteristics such as (Fairley 2009):

- Aptitude - This is exhibited by the ability to effectively lead a team. Leadership aptitude is not the same as knowledge or skill but rather is indicative of the ability (either intuitive or learned) to influence others. Leadership aptitude is sometimes referred to as charisma or as an engaging style.
- Initiative - This is exhibited by enthusiastically starting and following through on every leadership activity.
- Enthusiasm - This is exhibited by expressing and communicating a positive, yet realistic attitude concerning the project, product, and stakeholders.
- Communication Skills - These are exhibited by expressing concepts, thoughts, and ideas in a clear and concise manner, in oral and written forms, while interacting with colleagues, team members, managers, project stakeholders, and others.
- Team Participation - This is exhibited by working enthusiastically with team members and others when collaborating on shared work activities.
- Negotiation - This is the ability to reconcile differing points of view and achieve consensus decisions that are satisfactory to the involved stakeholders.
- Goal Orientation – This involves setting challenging but not impossible goals for oneself, team members, and teams.
- Trustworthiness - This is demonstrated over time by exhibiting ethical behavior, honesty, integrity, and dependability in taking actions and making decisions that affect others.

Weakness, on the other hand, is one example of a behavioral attribute that may limit the effectiveness of a systems engineering team leader.

Personality Traits

“Personality traits” was initially introduced in the early 1900's by Carl Jung, who published a theory of personality based on three continuums: introversion-extroversion, sensing-intuiting, and thinking-feeling. According to Jung, each individual has a dominant style which includes an element from each of the three continuums. Jung also emphasized that individuals vary their personality traits in the context of different situations; however, an individual’s dominant style is the preferred one, as it is the least stressful for the individual to express and it is also the style that an individual will resort to when under stress (Jung 1971). The Myers-Briggs Type Indicator (MBTI), developed by Katherine Briggs and her daughter Isabel Myers, includes Jung’s three continuums, plus a forth continuum of judging-perceiving. These four dimensions characterize 16 personality styles for individuals designated by letters, such as ISTP (Introverted, Sensing, Thinking, and Perceiving). An individual’s personality type indicator is determined through the answers the person has provided on a questionnaire (Myers 1995). MBTI profiles are widely used by job counselors to match an individual's personality type to job categories in which the individual would be "most comfortable and effective". Matching is based on the results of having applied the MBTI model to several thousands of subjects who have described themselves as comfortable and effective in their jobs. The MBTI has also been applied to group dynamics and leadership styles. Most studies indicate that groups perform better when a mixture of personality styles work together to provide different perspectives. Some researchers claim that there is evidence suggests that positive leadership styles are most closely related to an individual's position on the judging-perceiving scale of the MBTI profile (Hammer 2001). Those on the judging side of the scale are most likely to be "by the book" managers, while those on the perceiving side of the scale are most likely to be "people-oriented" leaders. "Judging" in the MBTI model does not mean judgmental; rather, a judging trait indicates a quantitative orientation and a perceiving trait indicates a qualitative orientation. The MBTI has its detractors (http://en.wikipedia.org/wiki/Myers-Briggs_Type_Indicator#Criticism), (Nowack 1996); however, MBTI personality styles can provide insight into effective and ineffective modes of interaction and communication among team members and team leaders. For example, an individual with a strongly Introverted, Thinking, Sensing, and Judging personality index (ITSJ) may have difficulty interacting with an individual who has a strongly Extroverted, Intuiting, Feeling, Perceiving personality index (ENFP).

Leadership Styles and Communication Styles

There is a vast amount of literature pertaining to leadership styles and there are many models of leadership. Most of these leadership models are based on some variant of Jung's psychological types. One of the models, the Wilson Social Styles, integrates leadership styles and communication styles (Wilson 2004). The Wilson model characterizes four kinds of leadership styles:

- Driver leadership style - This is exhibited when a leader focuses on the work to be accomplished and on specifying how others must do their jobs.
- Analytical-style leadership - This emphasizes collecting, analyzing, and sharing data and information. An analytical leader asks others for their opinions and recommendations to gather information.
- Amiable leadership style – This is characterized by emphasis on personal interactions and on asking others for their opinions and recommendations.
- Expressive leadership style – Like the amiable style, this also focuses on personal relationships, but an expressive leader tells others rather than asking for opinions and recommendations.

When taken to extremes, each of these styles can result in weakness of leadership. By focusing too intently on the work, "drivers" can provide too much or too little guidance and direction. Too little guidance occurs when the individual is preoccupied with her or his personal work, while too much guidance results in micromanagement, which limits the personal discretion for team members. Drivers may also be insensitive to interpersonal relationships with team members and others. Analytical leaders may provide too much information or may fail to provide information that is obvious to them, but not their team members. They do not like to discuss things they already know or that are irrelevant to the task at hand. Like driver-style leaders, they may be insensitive to interpersonal relationships with other individuals. Amiable leaders focus on interpersonal relationships in order to get the job done. They may exhibit a dislike of those who fail to interact with them on a personal level and may fail to show little concern for those who show little personal interest in them. Expressive leaders also focus on interpersonal relationships. In the extreme, an expressive leader may be more interested in stating their opinions than in listening to others. Additionally, they may play favorites and ignore those who are not favorites. While these characterizations are gross oversimplifications, they serve to illustrate leadership styles that may be exhibited by systems engineering team leaders. Effective team leaders are able to vary their leadership style to accommodate the particular context and the needs of their constituencies without going to extremes; but as emphasized by Jung, each individual has a preferred comfort zone that is least stressful and to which an individual will resort during times of added pressure.

Communication Styles

An additional characterization of the Wilson model is the preferred style of communication for different leadership styles, which is illustrated by the dimensions of assertiveness and responsiveness.

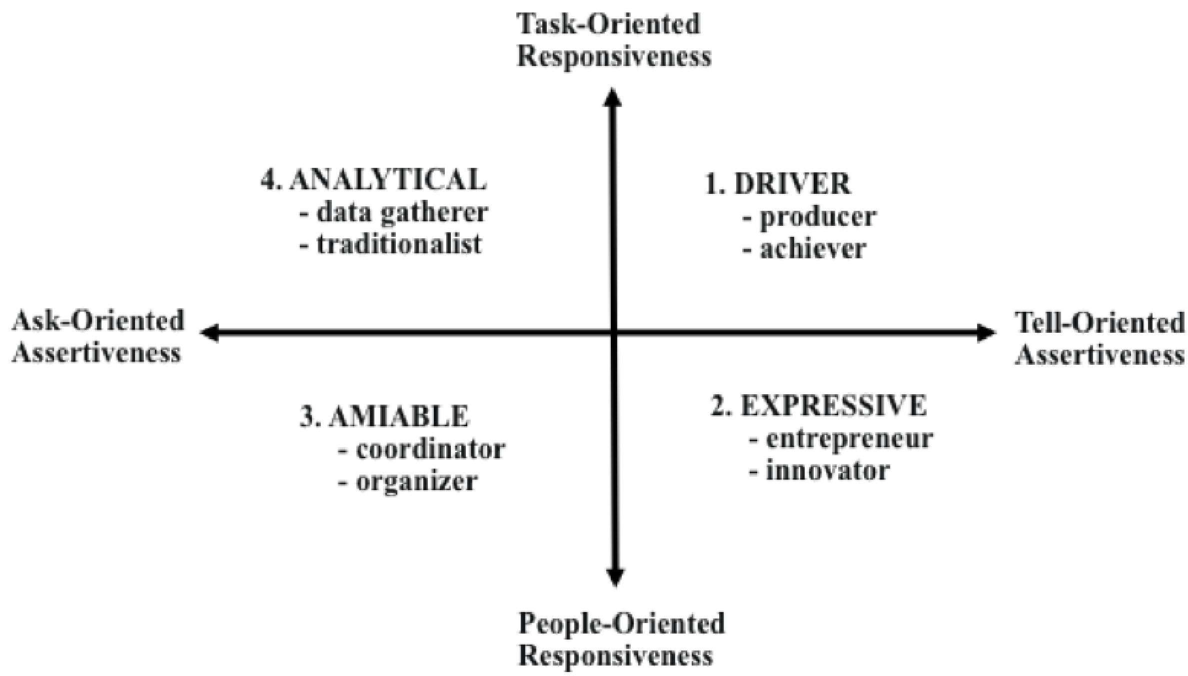

Figure 1. Dimensions of Communication Styles (Fairley 2009). Reprinted with permission of the IEEE Computer Society. All other rights are reserved by the copyright owner.

Task-oriented assertiveness is exhibited in a communication style that emphasizes the work to be done rather than on the people who will do the work, while the people-oriented communication style addresses personnel issues first and tasks secondly. A tell-oriented communication style involves telling rather than asking, while an ask-oriented assertiveness emphasizes asking over telling. Movies, plays, and novels often include caricatures of extremes in the assertiveness and responsiveness dimensions of Wilson communication styles. An individual's communication style may fall anywhere within the continuums of assertiveness and responsiveness, from extremes to more moderate styles and may vary considering the situation. Examples include:

- Driver communication style exhibits task-oriented responsiveness and tell-oriented assertiveness.
- Expressive communication style shares tell-oriented assertiveness with the driver style, but favors people-oriented responsiveness.
- Amiable communication style involves asking rather than telling (as does the analytical style) and emphasizes people relationships over task orientation (as does the expressive style).
- Analytical communication style exhibits task-oriented responsiveness and ask-oriented assertiveness.

The most comfortable communication occurs when individuals share the same communication styles or share adjacent quadrants in Figure 1. Difficult communication may occur when individuals are in diagonal quadrants; for example, communication between an extreme amiable style and an extreme driver style. Technical leaders and others can improve communications by being aware of different communication styles (both their own and others) and by modifying their communication style to accommodate the communication styles of others.

Management Responsibilities

Leading a systems engineering team involves communicating, coordinating, providing guidance, and maintaining progress and morale. Managing a project, according to the PMBOK® Guide (PMBOK 2013), involves application of the five process groups of project management: initiating, planning, executing, monitoring and controlling, and closing. Colloquially, systems engineering project/program management is concerned with making and updating plans and estimates, providing resources, collecting and analyzing product and process data, working with the technical leader to control work processes and work products, as well as managing the overall schedule and budget. Good engineering managers are not necessarily good technical leaders and good technical leaders are not necessarily good engineering managers; the expression of different personality traits and skill sets is required. Those who are effective as both managers and leaders have both analytical and interpersonal skills, although their comfort zone may be in one of managing or leading. Two management issues that are typically the responsibility of a systems engineering team leader are:

- Establishing and maintaining the division of responsibility among him or herself, the systems engineering team leader, and the project/program manager.
- Developing, implementing, and maintaining the systems engineering plan (SEP).

Relationships between systems engineering and project management are addressed in the Part 6 Knowledge Area (KA) of the SEBoK, Systems Engineering and Project Management. Also, see the Part 5 KA Enabling Teams for a discussion of the relationships between a project/program manager and a systems engineering technical leader.

The System Engineering Plan (SEP) is, or should be, the highest-level plan for managing the Systems Engineering effort and the technical aspects of a project or program. It defines how a project will be organized and conducted in terms of both performing and controlling the Systems Engineering activities needed to address a project's system requirements and technical content. It can have a number of secondary technical plans that provide details on specific technical areas and supporting processes, procedures, tools. Also, see the Planning article in Part 3, which includes a section on Systems Engineering Planning Process Overview.

In United States DoD acquisition programs, the System Engineering Plan (SEP) is a Government produced document which assists in the development, communication, and management of the overall systems engineering (SE) approach that guides all technical activities of the program. It provides direction to developers for program execution. The developer uses the SEP as guidance for producing the System Engineering Management Plan (SEMP), which is a separate document and usually a contract deliverable that aligns with the SEP. As the SEP is a Government produced and maintained document and the SEMP is a developer/contractor developed and maintained document, the SEMP is typically a standalone, coordinated document.

The following SEP outline from (ODASD 2011) serves as an example (see https://acc.dau.mil/ILC_SEP for a discussion of the outline).

1. **Introduction – Purpose and Update Plan**
2. **Program Technical Requirements**
    1. Architectures and Interface Control
    2. Technical Certifications
3. **Engineering Resources and Management**
    1. Technical Schedule and Schedule Risk Assessment
    2. Engineering Resources and Cost/Schedule Reporting
    3. Engineering and Integration Risk Management
    4. Technical Organization
    5. Relationships with External Technical Organizations
    6. Technical Performance Measures and Metrics
4. **Technical Activities and Products**

1. Results of Previous Phase SE Activities
2. Planned SE Activities for the Next Phase
3. Requirements Development and Change Process
4. Technical Reviews
5. Configuration and Change Management Process
6. Design Considerations
7. Engineering Tools

5. **Annex A – Acronyms**

SEP templates are often tailored to meet the needs of individual projects or programs by adding needed elements and modifying or deleting other elements. A systems engineering team leader typically works other team members, the project/program manager (or management team), and other stakeholders to develop the SEP and maintain currency of the plan as a project evolves. Some organizations provide one or more SEP templates and offer guidance for developing and maintaining an SEP. Some organizations have a functional group that can provide assistance in developing the SEP.

References

Works Cited

Fairley, R.E. *Managing and Leading Software Projects*. Hoboken, NJ, USA: John Wiley & Sons. ISBN 978-0470294550.

Hammer, A.L. 2001.*Myers-Briggs Type Indicator Work Styles Report.* Mountain View, CA: Consulting Psychologists Press. Available: http://www.cpp.com/images/reports/smp261182.pdf.

Jung, Carl Gustav. 1971.*Psychological Type*. Collected Works of C.G. Jung, Volume 6. Princeton, NJ: Princeton University Press. ISBN 0-691-09774.

Myers, I.B., and P.B. Myers. 1995. Gifts Differing: Understanding Personality Type, 2nd ed. Mountain View, CA: Davies-Black Publishing under special license from CPP, Inc.

Nowack, K. 1996.*Is the Myers Briggs Type Indicator the Right Tool to Use? Performance in Practice*. Alexandria, VA: American Society of Training and Development (ASTD).

ODASD. 2011. *Systems Engineering Plan Outline*, version 1.0. Arlington, VA: Office Deputy Assistant Secretary of Defense (ODASD) Systems Engineering (SE) Division. Available: https://acc.dau.mil/ILC_SEP.

PMI. 2013. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 5th ed. Newtown Square, PA, USA: Project Management Institute (PMI).

Wilson, L. 2004. The Social Styles Handbook. Belgium: Nova Vista Publishing.

Yukl, G. 2013. *Leadership in Organizations*, 8th ed. Upper Saddle River, NJ, USA: Pearson.

Primary References

Fairley, R.E. 2009. Managing and Leading Software Projects. Hoboken, NJ, USA: John Wiley & Sons.

Myers, I.B., and P.B. Myers. 1995. Gifts Differing: Understanding Personality Type, 2nd ed. Mountain View, CA: Davies-Black Publishing under special license from CPP, Inc.

Wilson, Larry. 2004. The Social Styles Handbook. Belgium: Nova Vista Publishing.

Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTcxNzgPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaaX
END_ENCODED_CONTENT

Enabling Individuals

This knowledge area focuses on enabling an individual to perform SE, and addresses the roles of individuals in the SE profession, how individuals are developed for and assessed in these roles, and what ethical behavior is expected of them. Once an individual is enabled to perform SE using the techniques described here, the individual can apply the knowledge found in Part 3, Systems Engineering and Management, about how to perform SE.

Part 5, Enabling Systems Engineering, to which this knowledge area belongs, explores how systems engineering (SE) is enabled at three levels of organization: the business or enterprise, the team, and the individual. Ultimately, individuals perform SE tasks within a team or business.

For the sake of brevity, the term “business” is used to mean “business or enterprise” throughout most of this knowledge area. For a nuanced explanation of what distinguishes a business from a enterprise, see Enabling Systems Engineering.

Topics

Each part of the SEBoK is composed of knowledge areas (KAs]. Each KA groups topics together around a theme related to the overall subject of the part. This KA contains four topics:

- Roles and Competencies discusses allocation of SE roles, which sets of competencies (glossary) correspond to particular roles, and what competency models are current in the SE world.
- Assessing Individuals discusses how to determine the level of individual proficiency and quality of performance.
- Developing Individuals explains how SE competency is acquired.
- Ethical Behavior describes the ethical standards that apply to individuals and organizations.

Context

The following brief review of terms and concepts provides context for the topics in this knowledge area.

Individuals, Teams, Businesses, and Enterprises

The ability to perform SE resides in individuals, teams, and businesses. An expert systems engineer possesses many competencies at a high level of proficiency, but no one can be highly proficient in all possible competencies. Collectively, a team and a business might possess all needed competencies at a high level of proficiency. A business performs the full range of SE roles, may have dedicated functions to perform specific SE roles, and may have a strategy for combining individual, team, and business abilities to execute SE on a complex activity. Individuals within the business may be responsible for performing one or more roles.

For descriptions of SE roles and competencies from the literature, see Roles and Competencies.

Competency, Capability, Capacity, and Performance

The final execution and performance of SE is a function of competency, capability, and capacity. There is some complexity here. For example:

- There is disagreement in the literature about whether the term competency applies to the individual level only, or can be correctly used at the team, project, and enterprise levels as well.
- Capability encompasses not just human capital, but processes, machines, tools, and equipment as well. Even if an individual has an outstanding level of competency, having to perform within a limited timeframe might degrade the results. Capacity accounts for this.

Systems Engineering Competency

Competency is built from knowledge, skills, abilities, and attitudes (KSAA). What is inherent in an individual may be subsequently developed through education, training, and experience. Traditionally, SE competencies have been developed primarily through experience, but recently, education and training have taken on a much greater role.

SE competency must be viewed through its relationships to the systems life cycle, the SE discipline, and the domain in which the engineer practices SE.

Competency Models

SE competency models can be used to explicitly state and actively manage the SE competencies within in an organization.

Competency models for SE typically include

- technical KSAAs;
- “soft” KSAAs such as leadership and communications;
- KSAAs that focus on the domains within which SE is to be practiced;
- a set of applicable competencies; and
- a scale for assessing the level of individual proficiency in each competency (often subjective, since proficiency is not easily measured).

See Roles and Competencies for descriptions of publicly available SE competency models.

References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTIyNTQPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Roles and Competencies

Enabling individuals to perform systems engineering (glossary) (SE) requires an understanding of SE competencies, roles, and tasks; plus knowledge, skills, abilities, and attitudes (KSAA). Within a business (glossary) or enterprise, SE responsibilities are allocated to individuals through the definition of SE roles associated with a set of task. For an individual, a set of KSAAs enables the fulfillment of the competencies needed to perform the tasks associated with the assigned SE role. SE competencies reflect the individual's KSAAs, which are developed through education, training, and on-the-job experience. Traditionally, SE competencies build on innate personal qualities and have been developed primarily through experience. Recently, education and training have taken on a greater role in the development of SE competencies.

Relationship of SE Competencies and KSAAs

There are many ways to define competency. It can be thought of as a measure of the ability to use the appropriate KSAAs to successfully complete specific job-related tasks (Whitcomb, Khan, White 2014). Competencies align with the tasks that are expected to be accomplished for the job position (Holt and Perry 2011). KSAAs belong to the individual. In the process of filling a position, organizations have a specific set of competencies associated with tasks that are directly related to the job. A person possesses the KSAAs that enable them to perform the desired tasks at an acceptable level of competency.

The KSAAs are obtained and developed from a combination of several sources of learning including education, training, and on-the-job experience. By defining the KSAAs in terms of a standard taxonomy, they can be used as learning objectives for competency development (Whitcomb, Khan, White 2014). Bloom's Taxonomy for the cognitive and affective domains provides this structure (Bloom 1956, Krathwohl 2002). The cognitive domain includes knowledge, critical thinking, and the development of intellectual skills, while the affective domain describes growth in awareness, attitude, emotion, changes in interest, judgment, and the development of appreciation (Bloom 1956). The affective does not refer to additional topics which a person learns about, but rather to a transformation of the person in relation to the original set of topics learned. Cognitive and affective processes within Bloom's taxonomic classification schema refer to levels of observable actions, which indicate learning is occurring. Bloom's Taxonomy for the cognitive and affective domains define terms as categories of levels that can be used for consistently defining KSAA statements (Krathwohl 2002):

Cognitive Domain

- Remember
- Understand
- Apply
- Analyze
- Evaluate
- Create

Affective Domain

- Receive
- Respond
- Value
- Organize
- Characterize

Both cognitive and affective domains should be included in the development of systems engineering competency models, because the cognitive domain learning concerns the consciously developed knowledge about the various subjects and the ability to perform tasks, whilst the affective learning concerns the interest in or willingness to use particular parts of the knowledge learned and the extent to which the systems engineer is characterized by taking approaches which are inherently systemic. Using the affective domain in the specification of KSAAs, is also important as every piece of information we process in our brains goes through our affective (emotional) processors before it is integrated by our cognitive processors (Whitcomb and Whitcomb 2013).

SE Competency Models

Contexts in which individual competency models are typically used include

- **Recruitment and Selection:** Competencies define categories for behavioral event interviewing (BEI), increasing the validity and reliability of selection and promotion decisions.
- **Human Resources Planning and Placements:** Competencies are used to identify individuals to fill specific positions and/or identify gaps in key competency areas.
- **Education, Training, and Development:** Explicit competency models let employees know which competencies are valued within their organization. Curriculum and interventions can be designed around desired competencies.

Commonality and Domain Expertise

No single individual is expected to be proficient in all the competencies found in any model. The organization, overall, must satisfy the required proficiency in sufficient quantity to support business needs. Organizational capability is not a direct summation of the competency of the individuals in the organization, since organizational dynamics play an important role that can either raise or lower overall proficiency and performance. The articles Enabling Teams and Enabling Businesses and Enterprises explore this further.

SE competency models generally agree that systems thinking, taking a holistic view of the system that includes the full life cycle, and specific knowledge of both technical and managerial SE methods are required to be a fully capable systems engineer. It is also generally accepted that an accomplished systems engineer will have expertise in at least one domain of practice. General models, while recognizing the need for domain knowledge, typically do not define the competencies or skills related to a specific domain. Most organizations tailor such models to include specific domain KSAAs and other peculiarities of their organization.

INCOSE Certification

Certification is a formal process whereby a community of knowledgeable, experienced, and skilled representatives of an organization, such as the International Council on Systems Engineering (INCOSE), provides formal recognition that a person has achieved competency in specific areas (demonstrated by education, experience, and knowledge). (INCOSE nd). The most popular credential in SE is offered by INCOSE, which requires an individual to pass a test to confirm knowledge of the field, requires experience in SE, and recommendations from those who have knowledge about the individual's capabilities and experience. Like all such credentials, the INCOSE certificate does not guarantee competence or suitability of an individual for a particular role, but is a positive indicator of an individual's ability to perform. Individual workforce needs often require additional KSAAs for any given systems engineer, but certification provides an acknowledged common baseline.

Domain- and Industry-specific Models

No community consensus exists on a specific competency model or small set of related competency models. Many SE competency models have been developed for specific contexts or for specific organizations, and these models are useful within these contexts.

Among the domain- and industry-specific models is the Aerospace Industry Competency Model (ETA 2010), developed by the Employment and Training Administration (ETA) in collaboration with the Aerospace Industries Association (AIA) and the National Defense Industrial Association (NDIA), and available online. This model is designed to evolve along with changing skill requirements in the aerospace industry. The ETA makes numerous competency models for other industries available online (ETA 2010). The NASA Competency Management System (CMS) Dictionary is predominately a dictionary of domain-specific expertise required by the US National Aeronautics and Space Administration (NASA) to accomplish their space exploration mission (NASA 2009).

Users of models should be aware of the development method and context for the competency model they plan to use, since the primary competencies for one organization might differ from those for another organization. These models often are tailored to the specific business characteristics, including the specific product and service domain in which the organization operates. Each model typically includes a set of applicable competencies along with a scale for assessing the level of proficiency.

SE Competency Models — Examples

Though many organizations have proprietary SE competency models, published SE competency models can be used for reference. Table 1 lists information about several published SE competency models, and links to these sources are shown below in the references section. Each model was developed for a unique purpose within a specific context and validated in a particular way. It is important to understand the unique environment surrounding each competency model to determine its applicability in any new setting.

Table 1. Summary of Competency Models. (SEBoK Original)

Competency Model	Date	Author	Purpose	Development Method	Competency Model
INCOSE UK WG	2010	INCOSE	Identify the competencies required to conduct good systems engineering	INCOSE Working Group	(INCOSE 2010), (INCOSE UK 2010)
ENG Competency Model	2013	DAU	Identify competencies required for the DoD acquisition engineering professional.	DoD and DAU internal development	(DAU 2013)
NASA APPEL Competency Model	2009	NASA	To improve project management and systems engineering at NASA	NASA internal development - UPDATE IN WORK	(NASA 2009)
MITRE Competency Model	2007	MITRE	To define new curricula systems engineering and to assess personnel and organizational capabilities	Focus groups as described in (Trudeau 2005)	(Trudeau 2005), (MITRE 2007)
CMMI for Development	2007	SEI	Process improvement maturity model for the development of products and services	SEI Internal Development	(SEI 2007), (SEI 2004)

Other models and lists of traits include: Hall (1962), Frank (2000; 2002; 2006), Kasser et al. (2009), Squires et al. (2011), and Armstrong et al. (2011). Ferris (2010) provides a summary and evaluation of the existing frameworks for personnel evaluation and for defining SE education. Squires et al. (2010) provide a competency-based approach that can be used by universities or companies to compare their current state of SE capability development against a government-industry defined set of needs. SE competencies can also be inferred from standards such as ISO-15288 (ISO/IEC/IEEE 15288 2015) and from sources such as the INCOSE *Systems Engineering Handbook* (INCOSE 2012), the INCOSE Systems Engineering Certification Program, and CMMI criteria (SEI 2007). Whitcomb, Khan, and White describe the development of a systems engineering competency model for the United States Department of Defense based on a series of existing competency models (Whitcomb, Khan, and White 2013; 2014).

To provide specific examples for illustration, more details about three SE competency model examples follow. These include:

- The International Council on Systems Engineering (INCOSE) UK Advisory Board model (INCOSE 2010), (INCOSE UK 2009);
- The DAU ENG model (DAU 2013); and
- The NASA Academy of Program/Project & Engineering Leadership (APPEL) model (NASA 2009)

INCOSE SE Competency Model

The INCOSE model was developed by a working group in the United Kingdom (Cowper et al. 2005). As Table 2 shows, the INCOSE framework is divided into three theme areas - systems thinking, holistic life cycle view, and systems management - with a number of competencies in each. The INCOSE UK model was later adopted by the broader INCOSE organization (INCOSE 2010).

Table 2. INCOSE UK Working Group Competency (INCOSE UK 2010).

Systems Thinking	System Concepts	
	Super-System Capability Issues	
	Enterprise and Technology Environment	
Hollistic Lifecycle View	Determining and Managing Stakeholder Requirements	
	Systems Design	Architectural Design
		Concept Generation
		Design For...
		Functional Analysis
		Interface Management
		Maintain Design Integrity
		Modeling and Simulation
		Select Preferred Solution
		System Robustness
	Systems Intergration & Verification	
	Validation	
	Transition to Operation	
Systems Engineering Management	Concurrent Engineering	
	Enterprise Integration	
	Integration of Specialties	
	Lifecycle Process Definition	
	Planning, Monitoring, and Controlling	

United States DoD Engineering Competency Model

The model for US Department of Defense (DoD) acquisition engineering professionals (ENG) includes 41 competency areas, as shown in Table 3 (DAU 2013). Each is grouped according to a “Unit of Competence” as listed in the left-hand column. For this model, the four top-level groupings are analytical, technical management, professional, and business acumen. The life cycle view used in the INCOSE model is evident in the ENG analytical grouping, but is not cited explicitly. Technical management is the equivalent of the INCOSE SE management, but additional competencies are added, including software engineering competencies and acquisition. Selected general professional skills have been added to meet the needs for strong leadership required of the acquisition engineering professionals. The business acumen competencies were added to meet the needs of these professionals to be able to support contract development and oversight activities and to engage with the defense industry.

Table 3. DoD Competency Model (DAU 2013) Defense Acquisition University (DAU)/U.S. Department of Defense (DoD).

Analytical (11)	1. Mission-Level Assessment
	2. Stakeholder Requirements Definition
	3. Requirements Analysis
	4. Architecture Design
	5. Implementation
	6. Intergration
	7. Verification
	8. Validation
	9. Transition
	10. Design Considerations
	11. Tools and Techniques
Technical Management (10)	12. Decision Analysis
	13. Technical Planning
	14. Technical Assessment
	15. Configuration Management
	16. Requirements Management
	17. Risk Management
	18. Data Management
	19. Interface Management
	20. Software Engineering
	21. Acquisition

Professional (10)	22. Problem Solving
	23. Strategic Thinking
	24. Professional Ethics
	25. Leading High-Performance Teams
	26. Communication
	27. Coaching and Mentoring
	28. Managing Stakeholders
	29. Mission and Results Focus
	30. Personal Effectiveness/Peer Interaction
	31. Sound Judgment
Business Acumen (10)	32. Industry Landscape
	33. Organization
	34. Cost, Pricing, and Rates
	35. Cost Estimating
	36. Financial Reporting and Metrics
	37. Business Strategy
	38. Capture Planning and Proposal Process
	39. Supplier Management
	40. Industry Motivation, Incentives, Rewards
	41. Negotiations

NASA SE Competency Model

The US National Aeronautics and Space Administration (NASA) APPEL website provides a competency model that covers both project engineering and systems engineering (APPEL 2009). There are three parts to the model, one that is unique to project engineering, one that is unique to systems engineering, and a third that is common to both disciplines. Table 4 below shows the SE aspects of the model. The project management items include project conceptualization, resource management, project implementation, project closeout, and program control and evaluation. The common competency areas are NASA internal and external environments, human capital and management, security, safety and mission assurance, professional and leadership development, and knowledge management. This 2010 model is adapted from earlier versions. (Squires at al. 2010, 246-260) offer a method that can be used to analyze the degree to which an organization’s SE capabilities meet government-industry defined SE needs.

Table 4. SE Portion of the APPEL Competency Model (APPEL 2009). Released by NASA APPEL.

System Design	SE 1.1 - Stakeholder Expectation Definition & Management
	SE 1.2 - Technical Requirements Definition
	SE 1.3 - Logical Decomposition
	SE 1.4 - Design Solution Definition
Product Realization	SE 2.1 - Product Implementation
	SE 2.2 - Product Integration
	SE 2.3 - Product Verification
	SE 2.4 - Product Validation
	SE 2.5 - Product Transition
Technical Management	SE 3.1 - Technical Planning
	SE 3.2 - Requirements Management
	SE 3.3 - Interface Management
	SE 3.4 - Technical Risk Management
	SE 3.5 - Configuration Management
	SE 3.6 - Technical Data Management
	SE 3.7 - Technical Assessment
	SE 3.8 - Technical Decision Analysis

Relationship of SE Competencies to Other Competencies

SE is one of many engineering disciplines. A competent SE must possess KSAAs that are unique to SE, as well as many other KSAAs that are shared with other engineering and non-engineering disciplines.

One approach for a complete engineering competency model framework has multiple dimensions where each of the dimensions has unique KSAAs that are independent of the other dimensions (Wells 2008). The number of dimensions depends on the engineering organization and the range of work performed within the organization. The concept of creating independent axes for the competencies was presented in Jansma and Derro (2007), using technical knowledge (domain/discipline specific), personal behaviors, and process as the three axes. An approach that uses process as a dimension is presented in Widmann et al. (2000), where the competencies are mapped to process and process maturity models. For a large engineering organization that creates complex systems solutions, there are typically four dimensions:

1. **Discipline** (e.g., electrical, mechanical, chemical, systems, optical);
2. **Life Cycle** (e.g., requirements, design, testing);
3. **Domain** (e.g., aerospace, ships, health, transportation); and
4. **Mission** (e.g., air defense, naval warfare, rail transportation, border control, environmental protection).

These four dimensions are built on the concept defined in Jansma and Derro (2007) and Widmann et al. (2000) by separating discipline from domain and by adding mission and life cycle dimensions. Within many organizations, the mission may be consistent across the organization and this dimension would be unnecessary. A three-dimensional example is shown in Figure 1, where the organization works on only one mission area so that dimension has been eliminated from the framework.

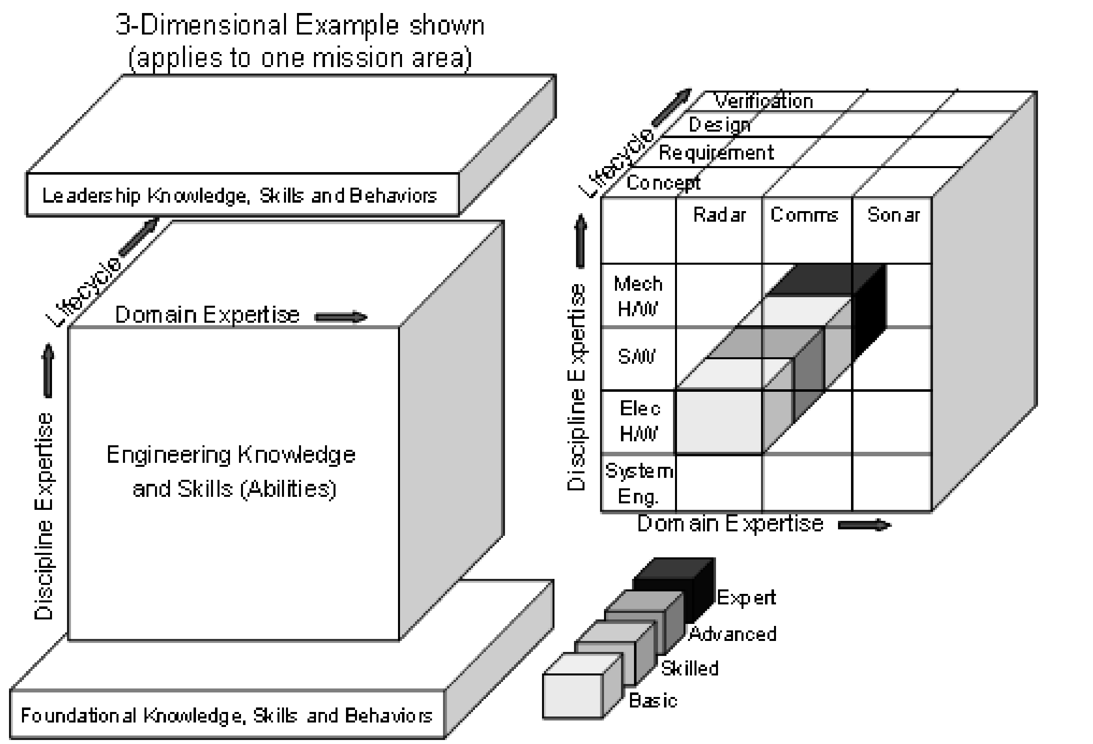

Figure 1. Layered and Multi-dimensional in the Engineering Layer (IEEE 2008). Reprinted with permission of © Copyright IEEE – All rights reserved. All other rights are reserved by the copyright owner.

The discipline, domain, and life cycle dimensions are included in this example, and some of the first-level areas in each of these dimensions are shown. At this level, an organization or an individual can indicate which areas are included in their existing or desired competencies. The sub-cubes are filled in by indicating the level of proficiency that exists or is required. For this example, blank indicates that the area is not applicable, and colors (shades of gray) are used to indicate the levels of expertise. The example shows a radar electrical designer that is an expert at hardware verification, is skilled at writing radar electrical requirements, and has some knowledge of electrical hardware concepts and detailed design. The radar electrical designer would also assess his or her proficiency in the other areas, the foundation layer, and the leadership layer to provide a complete assessment.

References

Works Cited

Armstrong, J.R., D. Henry, K. Kepcher, and A. Pyster. 2011. "Competencies Required for Successful Acquisition of Large, Highly Complex Systems of Systems." Paper presented at 21st Annual International Council on Systems Engineering (INCOSE) International Symposium (IS), 20-23 June 2011, Denver, CO, USA.

Bloom, Benjamin S., Max D. Engelhart, Edward J. Furst, Walker H. Hill, and David R. Krathwohl. 1956. *Taxonomy of Educational Objectives.* New York: David McKay.

Cowper, D., S. Bennison, R. Allen-Shalless, K. Barnwell, S. Brown, A. El Fatatry, J. Hooper, S. Hudson, L. Oliver, and A. Smith. 2005. *Systems Engineering Core Competencies Framework*. Folkestone, UK: International Council on Systems Engineering (INCOSE) UK Advisory Board (UKAB).

DAU. 2013. *ENG Competency Model*, 12 June 2013 version. in Defense Acquisition University (DAU)/U.S. Department of Defense Database Online. Accessed on June 3, 2015. Available at https://dap.dau.mil/workforce/Documents/Comp/ENG%20Competency%20Model%2020130612_Final.pdf.

ETA. 2010. *Career One Stop: Competency Model Clearing House: Aerospace Competency Model.* in Employment and Training Administration (ETA)/U.S. Department of Labor. Washington, DC. Accessed on September 15, 2011. Available at http://www.careeronestop.org//competencymodel/pyramid.aspx?AEO=Y.

Ferris, T.L.J. 2010. "Comparison of Systems Engineering Competency Frameworks." Paper presented at the 4th Asia-Pacific Conference on Systems Engineering (APCOSE), Systems Engineering: Collaboration for Intelligent Systems, 3-6 October 2010, Keelung, Taiwan.

Frank, M. 2000. "Engineering Systems Thinking and Systems Thinking." *Systems Engineering.* 3(3): 163-168.

Frank, M. 2002. "Characteristics of Engineering Systems Thinking – A 3-D Approach for Curriculum Content." *IEEE Transaction on System, Man, and Cybernetics.* 32(3) Part C: 203-214.

Frank, M. 2006. "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST)." *Systems Engineering.* 9(2): 91-103. (Republished in *IEEE Engineering Management Review.* 34(3)(2006):48-61).

Hall, A.D. 1962. *A Methodology for Systems Engineering*. Princeton, NJ, USA: D. Van Nostrand Company Inc.

Holt, Jon, and Perry, Simon,*A Pragmatic Guide to Competency, Tools, Frameworks, and Assessment.*BCS, The Chartered Institute for IT, Swindon, UK, 2011.

INCOSE. 2011. "History of INCOSE Certification Program." Accessed April 13, 2015 at http://www.incose.org/certification/CertHistory

INCOSE. 2012. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 3.2.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.2.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205.* San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

INCOSE UK. 2010. "Systems Engineering Competency Framework," Accessed on June 3, 2015. Available at, <http://www.incoseonline.org.uk/Normal_Files/Publications/Framework.aspx?CatID=Publications&SubCat=INCOSE

Jansma, P.A. and M.E. Derro. 2007. "If You Want Good Systems Engineers, Sometimes You Have to Grow Your Own!." Paper presented at IEEE Aerospace Conference. 3-10 March, 2007. Big Sky, MT, USA.

Kasser, J.E., D. Hitchins, and T.V. Huynh. 2009. "Reengineering Systems Engineering." Paper presented at the 3rd Annual Asia-Pacific Conference on Systems Engineering (APCOSE), 2009, Singapore.

Krathwohl, David. *A Revision of Bloom's Taxonomy: An Overview.* 2002.

Menrad, R. and H. Lawson. 2008. "Development of a NASA Integrated Technical Workforce Career Development Model Entitled: Requisite Occupation Competencies and Knowledge – The ROCK." Paper presented at the 59th International Astronautical Congress (IAC), 29 September-3 October, 2008, Glasgow, Scotland.

MITRE. 2007. "MITRE Systems Engineering (SE) Competency Model." Version 1.13E. September 2007. Accessed on June 3, 2015. Available at, http://www.mitre.org/publications/technical-papers/systems-engineering-competency-model.

NASA. 2009. *NASA Competency Management Systems (CMS): Workforce Competency Dictionary,* revision 7a. U.S. National Aeronautics and Space Administration (NASA). Washington, D.C.

NASA. 2009. *Project Management and Systems Engineering Competency Model.* Academy of Program/Project & Engineering Leadership (APPEL). Washington, DC, USA: US National Aeronautics and Space Administration (NASA). Accessed on June 3, 2015. Available at http://appel.nasa.gov/competency-model/.

SEI. 2007. *Capability Maturity Model Integrated (CMMI) for Development,* version 1.2, Measurement and Analysis Process Area. Pittsburg, PA, USA: Software Engineering Institute (SEI)/Carnegie Mellon University (CMU).

SEI. 2004. *CMMI-Based Professional Certifications: The Competency Lifecycle Framework,* Software Engineering Institute, CMU/SEI-2004-SR-013. Accessed on June 3, 2015. Available at http://resources.sei.cmu.edu/library/asset-view.cfm?assetid=6833.

Squires, A., W. Larson, and B. Sauser. 2010. "Mapping space-based systems engineering curriculum to government-industry vetted competencies for improved organizational performance." *Systems Engineering*. 13 (3): 246-260. Available at, http://dx.doi.org/10.1002/sys.20146.

Squires, A., J. Wade, P. Dominick, and D. Gelosh. 2011. "Building a Competency Taxonomy to Guide Experience Acceleration of Lead Program Systems Engineers." Paper presented at the Conference on Systems Engineering Research (CSER), 15-16 April 2011, Los Angeles, CA.

Wells, B.H. 2008. "A Multi-Dimensional Hierarchical Engineering Competency Model Framework." Paper presented at IEEE International Systems Conference, March 2008, Montreal, Canada. Whitcomb, Clifford, Rabia Khan, and Corina White. 2014. "Systems Engineering Competency FY14 Technical Report." Naval Postgraduate School Technical Report, Monterey, CA. https://calhoun.nps.edu/handle/10945/44705

Whitcomb, Clifford, Leslie Whitcomb. 2013. Effective Interpersonal and Team Communication Skills for Engineers. IEEE Press, John Wiley and Sons.

Whitcomb, Clifford, Rabia Khan, and Corina White. 2013. "Systems Engineering Competency FY13 Technical Report." Naval Postgraduate School Technical Report, Monterey, CA. Accessed on June 4, 2015. Available at, https://calhoun.nps.edu/handle/10945/43424.

Whitcomb, Clifford, Rabia Khan, and Corina White. 2014. "Systems Engineering Competency FY14 Technical Report." Naval Postgraduate School Technical Report, Monterey, CA. Accessed on June 4, 2015. Available at, https://calhoun.nps.edu/handle/10945/44705.

Widmann, E.R., G.E. Anderson, G.J. Hudak, and T.A. Hudak. 2000. "The Taxonomy of Systems Engineering Competency for The New Millennium." Presented at 10th Annual INCOSE Internal Symposium, 16-20 July 2000, Minneapolis, MN, USA.

Primary References

DAU. 2013. *ENG Competency Model*, 12 June 2013 version. in Defense Acquisition University (DAU)/U.S. Department of Defense Database Online. Accessed on June 3, 2015. Available at https://dap.dau.mil/workforce/Documents/Comp/ENG%20Competency%20Model%2020130612_Final.pdf.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205.* San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

Additional References

Whitcomb, Clifford, Jessica Delgado, Rabia Khan, Juli Alexander, Corina White, Dana Grambow, Paul Walter. 2015. "The Department of the Navy Systems Engineering Career Competency Model." Proceedings of the Twelfth Annual Acquisition Research Symposium. Naval Postgraduate School, Monterey, CA..

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTk1ODMPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Assessing Individuals

The ability to fairly assess individuals is a critical aspect of enabling individuals. This article describes how to assess the systems engineering (glossary) (SE) competencies needed and possessed by an individual, as well as that individual’s SE performance.

Assessing Competency Needs

If an organization wants to use its own customized competency model, an initial decision is *make vs. buy*. If there is an existing SE competency model that fits the organization's context and purpose, the organization might want to use the existing SE competency model directly. If existing models must be tailored or a new SE competency model developed, the organization should first understand its context.

Determining Context

Prior to understanding what SE competencies are needed, it is important for an organization to examine the situation in which it is embedded, including environment, history, and strategy. As Figure 1 shows, MITRE has developed a framework characterizing different levels of systems complexity. (MITRE 2007, 1-12) This framework may help an organization identify which competencies are needed. An organization working primarily in the *traditional program domain* may need to emphasize a different set of competencies than an organization working primarily in the *messy frontier*. If an organization seeks to improve existing capabilities in one area, extensive technical knowledge in that specific area might be very important. For example, if stakeholder involvement is characterized by multiple equities and distrust, rather than collaboration and concurrence, a higher level of competency in being able to balance stakeholder requirements might be needed. If the organization's desired outcome builds a fundamentally new capability, technical knowledge in a broader set of areas might be useful.

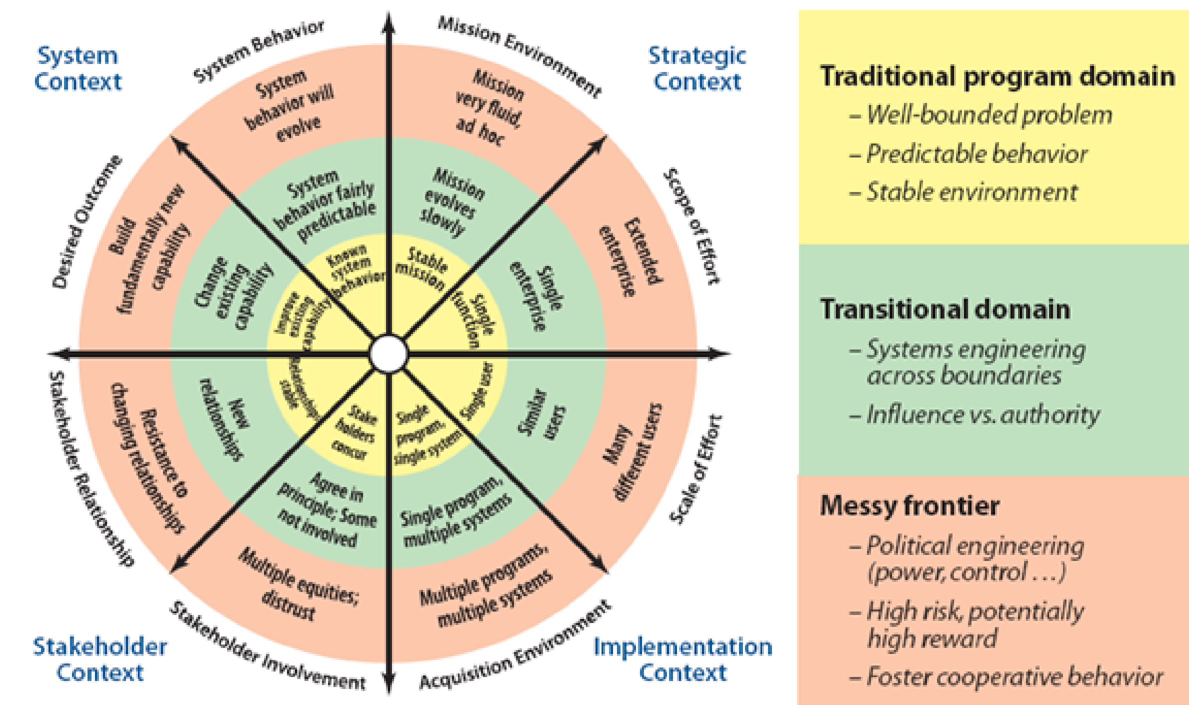

Figure 1. MITRE Enterprise Systems Engineering Framework (MITRE 2007). Reprinted with permission of © 2011. The MITRE Corporation. All Rights Reserved. All other rights are reserved by the copyright owner.

In addition, an organization might consider both its current situation and its forward strategy. For example, if an organization has previously worked in a traditional systems engineering context (MITRE 2007) but has a strategy to transition into enterprise systems engineering (ESE) work in the future, that organization might want to develop a competency model both for what was important in the traditional SE context and for what will be required for ESE work. This would also hold true for an organization moving to a different contracting environment where competencies, such as the ability to properly tailor the SE approach to *right size* the SE effort and balance cost and risk, might be more important.

Determining Roles and Competencies

Once an organization has characterized its context, the next step is to understand exactly what SE roles are needed and how those roles will be allocated to teams and individuals. To assess the performance of an individual, it is essential to explicitly state the roles and competencies required for that individual. See the references in Roles and Competencies for guides to existing SE standards and SE competency models.

Assessing Individual SE Competency

In order to demonstrate competence, there must be some way to qualify and measure it, and this is where competency assessment is used (Holt and Perry 2011). This assessment informs the interventions needed to further develop individual SE KSAA upon which competency is based. Described below are possible methods which may be used for assessing an individual's current competency level; an organization should choose the correct model based on their context, as identified previously.

Proficiency Levels

In order to provide a context for individuals and organizations to develop competencies, a consistent system of defining KSAAs should be created. One popular method is based on Bloom’s taxonomy (Bloom 1984), presented below for the cognitive domain in order from least complex to most complex cognitive ability.

- **Remember**: Recall or recognize terms, definitions, facts, ideas, materials, patterns, sequences, methods, principles, etc.
- **Understand**: Read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, etc.
- **Apply**: Know when and how to use ideas, procedures, methods, formulas, principles, theories, etc.
- **Analyze**: Break down information into its constituent parts and recognize their relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario.
- **Evaluate**: Make judgments about the value of proposed ideas, solutions, etc., by comparing the proposal to specific criteria or standards.
- **Create**: Put parts or elements together in such a way as to reveal a pattern or structure not clearly there before; identify which data or information from a complex set is appropriate to examine further or from which supported conclusions can be drawn.

One way to assess competency is to assign KSAAs to proficiency level categories within each competency. Examples of proficiency levels include the INCOSE competency model, with proficiency levels of: awareness, supervised practitioner, practitioner, and expert (INCOSE 2010). The Academy of Program/Project & Engineering Leadership (APPEL) competency model includes the levels: participate, apply, manage, and guide, respectively (Menrad and Lawson 2008). The U.S. National Aeronautics and Space Administration (NASA), as part of the APPEL (APPEL 2009), has also defined proficiency levels: technical engineer/project team member, subsystem lead/manager, project manager/project systems engineer, and program manager/program systems engineer. The Defense Civilian Personnel Advisory Service (DCPAS) defines a 5-tier framework to indicate the degree to which employees perform competecnies as awareness, basic, intermediate, advanced, and expert.

The KSAAs defined in the lower levels of the cognitive domain (remember, understand) are typically foundational, and involve demonstration of basic knowledge. The higher levels (apply, analyze, evaluate, and create) reflect higher cognitive ability. Cognitive and affective processes within Bloom’s taxonomy refer to levels of observable actions that indicate learning is occuring (Whitcomb, Delgado, Khan, Alexander, White, Grambow, Walter 2015). The Bloom’s domain levels should not be used exclusively to determine the proficiency levels required for attainment or assessment of a competency. Higher level cognitive capabilites belong across proficiency levels, and should be used as appropriate to the KSAA involved. These higher level terms infer some observbable action or outcome, so the context for assessing the attainment of the KSAA, or a group of KSAAs, related to a competency needs to be defined. For example, applying SE methods can be accomplished on simple subsystems or systems and so perhaps belong in a lower proficiency level such as supervised practitioner. Applying SE methods to complex enterprise or systems of systems, may belong in the practitioner or even the expert level. The determination of what proficiency level is desired for each KSAA is determined by the organization, and may vary among different organizations.

Quality of Competency Assessment

When using application as a measure of competency, it is important to have a measure of *goodness*. If someone is applying a competency in an exceptionally complex situation, they may not necessarily be successful in this application. An individual may be *managing and guiding*, but this is only helpful to the organization if it is being done well. In addition, an individual might be fully proficient in a particular competency, but not be given an opportunity to use that competency; for this reason, it is important to understand the context in which these competencies are being assessed.

Individual SE Competency versus Performance

Even when an individual is highly proficient in an SE competency, context may preclude exemplary performance of that competency. For example, an individual with high competency in risk management may be embedded in a team or an organization which ignores that talent, whether because of flawed procedures or some other reason. Developing individual competencies is not enough to ensure exemplary SE performance.

When SE roles are clearly defined, performance assessment at least has a chance to be objective. However, since teams are most often tasked with accomplishing the SE tasks on a project, it is the team's performance which ends up being assessed. (See Team Capability). The final execution and performance of SE is a function of competency, capability, and capacity. (See Enabling Teams and Enabling Businesses and Enterprises.)

References

Works Cited

Academy of Program/Project & Engineering Leadership (APPEL). 2009. NASA's Systems Engineering Competencies. Washington, DC, USA: U.S. National Aeronautics and Space Administration. Available at: http://www.nasa.gov/offices/oce/appel/pm-development/pm_se_competency_framework.html.

Bloom, B. S. 1984. *Taxonomy of Educational Objectives.* New York, NY, USA: Longman.

Holt, Jon, and Simon Perry. 2011. *A Pragmatic Guide to Competency, Tools, Frameworks, and Assessment.* BCS, The Chartered Institute for IT, Swindon, UK.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205*. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

Menrad, R. and H. Lawson. 2008. "Development of a NASA Integrated Technical Workforce Career Development Model Entitled: Requisite Occupation Competencies and Knowledge – The ROCK." Paper presented at the 59th International Astronautical Congress (IAC). 29 September-3 October 2008. Glasgow, Scotland.

MITRE. 2007. *Enterprise Architecting for Enterprise Systems Engineering*. Warrendale, PA, USA: SEPO Collaborations, SAE International. June 2007.

Whitcomb, Clifford, Jessica Delgado, Rabia Khan, Juli Alexander, Corina White, Dana Grambow, Paul Walter. 2015. "The Department of the Navy Systems Engineering Career Competency Model." Proceedings of the Twelfth Annual Acquisition Research Symposium. Naval Postgraduate School, Monterey, CA.

Primary References

Academy of Program/Project & Engineering Leadership (APPEL). 2009. *NASA's Systems Engineering Competencies.* Washington, DC, USA: U.S. National Aeronautics and Space Administration (NASA). Accessed on May 2, 2014. Available at http:/ / appel. nasa. gov/ career-resources/ project-management-and-systems-engineering-competency-model/.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205.* San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

Additional References

Holt, J., and S. Perry. 2011. *A pragmatic guide to competency: tools, frameworks and assessment*. Swindon, UK: British Computer Society.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
Nzk4NDQPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

Developing Individuals

Developing each individual’s systems engineering (SE) competencies(glossary) is a key aspect of enabling individuals. The goal may be to develop competency in a broad range of SE competencies or a single aspect of SE, and it is important to know exactly which SE competencies are desired. This article describes strategies to develop SE competencies in individuals.

Closing Competency Gaps

Delivering excellent systems that fulfill customer needs is the primary goal of the organization. Developing *the capability* to deliver such systems is a secondary goal, and while necessary, is not sufficient. To attain both of these goals, the organization must assess itself and effect a strategy to identify and close competency gaps.

To identify competency gaps, an organization may take two basic steps:

1. Listing desired competencies, as discussed in Roles and Competencies; and
2. Assessing the competencies of individual systems engineers, as discussed in Assessing Individuals.

Models useful for listing competencies include the International Council on Systems Engineering (INCOSE) United Kingdom Advisory Board model (Cowper et al. 2005; INCOSE 2010), the ENG Competency Model (DAU 2013), and the Academy of Program/Project & Engineering Leadership (APPEL 2009) model (Menrad and Lawson 2008).

Once the organization knows the SE competencies it needs to develop to close the competency gaps it has identified, it may choose from the several methods (Davidz and Martin 2011) outlined in the table below.

Table 1. SE Competency Development Framework. (SEBoK Original)

<html>

Goal	Objective	Method
PRIMARY GOAL = Delivery of excellent systems to fulfill customer needs	Focus on successful performance outcome	Corporate intiatives
	Focus on performance of project team	Team coaching of project team for performance enhancement
SECONDARY GOAL = Competency to deliver excellent systems to fulfill customer needs	Develop individual competency	Training courses
		Job rotation
		Mentoring
		Hands-on experience
		Develop a few hand-picked individuals
		University educational degree program
		Customized educational program
		Combination program - education, training, job rotation, mentoring, hands-on experience
		Course certificate program
	Ensure individual competency through certification	Certification program
	Filter those working in systems roles	Use individual characteristics to select employees for systems roles
	Ensure organizational competency through certification	ISO 9000
	Develop organizational systems competency through processes	Process improvement using an established framework
		Concept maps to identify the thought processes of senior systems engineers
		Standarize systems policies and procedures for consistency
		Systems engineering web portal
		Systems knowledge management repository
		On-call organizational experts
		Rotating professor who works at company part-time and is at university part-time

</html>

System Delivery

Some organizations mount initiatives which focus directly on successful system delivery. Others focus on project team performance, in some cases by offering coaching, as a means to ensure successful system delivery.

One example of the latter approach is the performance enhancement service of the US National Aeronautics and Space Administration (NASA) Academy of Program/Project & Engineering Leadership (APPEL), which assesses team performance and then offers developmental interventions with coaching (NASA 2010).

Organizations pursue multiple paths towards developing the capability to deliver excellent systems, including

- developing the competency of individuals;
- developing the competency of the organization through processes (Davidz and Maier 2007); and

- putting measures should in place to verify the efficacy of the selected methods.

Individual Competency

An organization may choose a combination of methods to develop individual systems competency. General Electric's Edison Engineering Development Program (GE 2010) and Lockheed Martin's Leadership Development Programs (Lockheed Martin 2010) are examples among the many combination programs offered within companies.

Whether or not the program is specifically oriented to develop systems skills, the breadth of technical training and experience, coupled with business training, can produce a rich understanding of systems for the participant. Furthermore, new combination programs can be designed to develop specific systems-oriented skills for an organization.

Methods for developing individual competency include

- **classroom or online training courses**, a traditional choice for knowledge transfer and skill acquisition. Here, an instructor directs a classroom of participants. The method of instruction may vary from a lecture format to case study work to hands-on exercises. The impact and effectiveness of this method varies considerably based on the skill of the instructor, the effort of the participants, the presentation of the material, the course content, the quality of the course design process, and the matching of the course material to organizational needs. These types of interventions may also be given online. Squires (2011) investigates the relationship between online pedagogy and student perceived learning of SE competencies.
- **job rotation**, where a participant rotates through a series of work assignments that cut across different aspects of the organization to gain broad experience in a relatively short time.
- **mentoring**, where a more experienced individual is paired with a protégé in a developmental relationship. Many organizations use mentoring, whose impact and effectiveness vary considerably. Success factors are the tenable pairing of individuals, and the provision of adequate time for mentoring.
- **hands-on experience**, where organizations provide for their engineers to get hands-on experience that they would otherwise lack. A research study by Davidz on enablers and barriers to the development of systems thinking showed that systems thinking is developed primarily by experiential learning (Davidz 2006; Davidz and Nightingale 2008, 1-14). As an example, some individuals found that working in a job that dealt with the full system, such as working in an integration and test environment, enabled development of systems thinking.
- **selecting individuals** who appear to have high potential and focusing on their development. Hand-selection may or may not be accompanied by the other identified methods.
- **formal education**, such as a university degree program. A growing number of SE degree programs are offered worldwide (Lasfer and Pyster 2011). Companies have also worked with local universities to set up customized educational programs for their employees. The company benefits because it can tailor the educational program to the unique needs of its business. In a certificate program, individuals receive a certificate for taking a specific set of courses, either at a university or as provided by the company. There are a growing number of certificate programs for developing systems competency.

Individual Certification

Organizations may seek to boost individual systems competency through certification programs. These can combine work experience, educational background, and training classes. Certifications are offered by local, national, and international professional bodies.

SE organizations may encourage employees to seek certification from the International Council on Systems Engineering (INCOSE 2011) or may use this type of certification as a filter (see **Filters**, below). In addition, many companies have developed their own internal certification measures. For example, the Aerospace Corporation has an Aerospace Systems Architecting and Engineering Certificate Program (ASAECP). (Gardner 2007)

Filters

Another approach to developing individual competency is to select employees for systems roles based on certain characteristics, or filters. Before using a list of characteristics for filtering, though, an organization should critically examine

1. how the list of individual characteristics was determined, and
2. how the characteristics identified enable the performance of a systems job.

Characteristics used as filters should

- enable one to perform a systems job
- be viewed as important to perform a systems job, or
- be necessary to perform a systems job.

A necessary characteristic is much stronger than an enabling one, and before filtering for certain traits, it is important to understand whether the characteristic is an enabler or a necessity.

Finally, it is important to understand the extent to which findings are generally applicable, since a list of characteristics that determine success in one organization may not be generalizable to another organization.

Organizational Capability

Once an organization has determined which SE capabilities are mission critical (please see Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises), there are many different ways in which an organization can seek to develop or improve these capabilities. Some approaches seen in the literature include the following:

- Organizations may choose to develop organizational systems capability through processes. One method organizations may choose is to pursue process improvement using an established framework. An example is the Capability Maturity Model® Integration (CMMI) process improvement approach (SEI 2010, 1).
- Concept maps - graphical representations of engineering thought processes - have been shown to be an effective method of transferring knowledge from senior engineering personnel to junior engineering personnel (Kramer 2007, 26-29; Kramer 2005). These maps may provide a mechanism for increasing knowledge of the systems engineering population of an organization.
- An organization may also choose to develop organizational systems competencies by standardizing systems policies and procedures. An example from NASA is their *NASA Systems Engineering Processes and Requirement* (NASA 2007).
- Some organizations use a web portal to store and organize applicable systems engineering knowledge and processes, which assists in developing organizational systems competency. An example is the Mission Assurance Portal for the Aerospace Corporation (Roberts et al. 2007, 10-13).
- Another approach being considered in the community is the development of a rotating professor role, where the person would work at the company and then be at a university to strengthen the link between academia and industry.
- Another approach is to alter organizational design to foster and mature a desired competency. For example, an organization that identifies competency in the area of reliability as critical to its SE success may develop a reliability group, which will help foster growth and improvement in reliability competencies.

Organizational Certification

Certification at the organizational level exists also, and can be a means for ensuring competency. ISO certification is one example (ISO 2010). Before taking this approach, the organization should verify that the capabilities required by the certification are indeed the systems capabilities it seeks. For more on determining appropriate organizational capabilities, see Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises.

Repositioning the Product Life Cycle

An organization may also choose to reposition its product life cycle philosophy to maintain system competency. For example, NASA has done this with its APPEL program (APPEL 2009).

Since the systems competencies of individuals are primarily developed through experiential learning, providing experiential learning opportunities is critical. Shortening the product life cycle is one way to ensure that individuals acquire the full range of desired competency sooner.

Maintaining Competency Plans

An organization that has developed an SE competency plan should consider how to maintain it. How, and how often, will the competency plan be re-examined and updated? The maintenance process should account for the ongoing evolution of global contexts, business strategies, and the SEBoK. The process for assessing competencies and taking action to improve them must be part of the normal operations of the organization and should occur periodically.

References

Works Cited

Academy of Program/Project & Engineering Leadership (APPEL). 2009. NASA's Systems Engineering Competencies. Washington, D.C.: U.S. National Aeronautics and Space Association. Accessed on September 15, 2011. Available at http://www.nasa.gov/offices/oce/appel/pm-development/pm_se_competency_framework.html.

Cowper, D., S. Bennison, R. Allen-Shalless, K. Barnwell, S. Brown, A. El Fatatry, J. Hooper, S. Hudson, L. Oliver, and A. Smith. 2005. *Systems Engineering Core Competencies Framework.* Folkestone, UK: International Council on Systems Engineering (INCOSE) UK Advisory Board (UKAB).

Davidz, H.L. and J. Martin. 2011. "Defining a Strategy for Development of Systems Capability in the Workforce". *Systems Engineering*. 14(2): 141-143.

Davidz, H.L. and M.W. Maier. 2007. "An Integrated Approach to Developing Systems Professionals." Paper presented at the 17th Annual International Council on Systems Engineering (INCOSE) International Symposium, 24-28 June 2007. San Diego, CA, USA.

Davidz, H.L., and D. Nightingale. 2008. "Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers." *Systems Engineering*. 11(1): 1-14.

Davidz, H.L. 2006. *Enabling Systems Thinking to Accelerate the Development of Senior Systems Engineers.* Dissertation. Massachusetts Institute of Technology (MIT), Cambridge, MA, USA.

Gardner, B. 2007. "A Corporate Approach to National Security Space Education." *Crosslink,* the Aerospace Corporation Magazine of Advances in Aerospace Technology. 8(1) (Spring 2007):10-5. Accessed April 23, 2013. Available at: http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/crosslink/V8N1.pdf.

GE. 2010. *Edison Engineering Development Program (EEDP) in General Electric.* Accessed on September 15, 2011. Available at http://www.gecareers.com/GECAREERS/jsp/us/studentOpportunities/leadershipPrograms/eng_program_guide.jsp.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205.* San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

INCOSE. 2011. "Systems Engineering Professional Certification." In *International Council on Systems Engineering* online. Accessed April 13, 2015. Available at: http://www.incose.org/certification/.

Kramer, M.J. 2007. "Can Concept Maps Bridge The Engineering Gap?" *Crosslink*, the Aerospace Corporation Magazine of Advances in Aerospace Technology. 8(1) (Spring 2007): 26-9. Accessed April 23, 2013. Available at: http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/crosslink/V8N1.pdf.

Kramer, M.J. 2005. *Using Concept Maps for Knowledge Acquisition in Satellite Design: Translating 'Statement of Requirements on Orbit' to 'Design Requirements.* Dissertation. Ft. Lauderdale, FL, USA: Graduate School of Computer and Information Sciences, Nova Southeastern University.

Lasfer, K. and A. Pyster. 2011. "The Growth of Systems Engineering Graduate Programs in the United States." Paper presented at Conference on Systems Engineering Research, 15-16 April 2011. Los Angeles, CA, USA.

Lockheed Martin. 2010. *Training and Leadership Development Programs for College Applicants in Lockheed Martin Corporation.* Bethesda, MD, USA. Accessed on August 30, 2012. Available at http:/ / www. lockheedmartinjobs.com/leadership-development-program.asp.

NASA. 2010. *Academy of Program/Project & engineering leadership (APPEL): Project life cycle support in U.S. National Aeronautics and Space Administration (NASA).* Washington, DC, USA: U.S. National Air and Space Administration (NASA). Accessed on September 15, 2011. Available at http://www.nasa.gov/offices/oce/appel/ performance/lifecycle/161.html.

NASA. 2007. *NASA Procedural Requirements: NASA Systems Engineering Processes and Requirements*. Washington, DC, USA: U.S. National Aeronautic and Space Administration (NASA). NPR 7123.1A.

Roberts, J., B. Simpson, and S. Guarro. 2007. "A Mission Assurance Toolbox." *Crosslink*, the Aerospace Corporation Magazine of Advances in Aerospace Technology. 8(2) (Fall 2007): 10-13.

SEI. 2007. *Capability Maturity Model Integrated (CMMI) for Development*, version 1.2, Measurement and Analysis Process Area. Pittsburgh, PA, USA: Software Engineering Institute (SEI)/Carnegie Mellon University (CMU).

Squires, A. 2011. *Investigating the Relationship between Online Pedagogy and Student Perceived Learning of Systems Engineering Competencies*. Dissertation. Stevens Institute of Technology, Hoboken, NJ, USA.

Primary References

Academy of Program/Project & Engineering Leadership (APPEL). 2009. *NASA's Systems Engineering Competencies*. Washington, DC, USA: U.S. National Aeronautics and Space Administration (NASA). Accessed on May 2, 2014. Available at http:/ / appel. nasa. gov/ career-resources/ project-management-and-systems-engineering-competency-model/.

DAU. 2013. *ENG Competency Model*, 12 June 2013 version. in Defense Acquisition University (DAU)/U.S. Department of Defense Database Online. Accessed on September 23, 2014. Available at https:/ / acc. dau. mil/ CommunityBrowser.aspx?id=657526&lang=en-US

Davidz, H.L. and J. Martin. 2011. "Defining a Strategy for Development of Systems Capability in the Workforce". *Systems Engineering.* 14(2): 141-143.

INCOSE. 2010. *Systems Engineering Competencies Framework 2010-0205*. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2010-003.

Additional References

None.

< Previous Article | Parent Article | Next Article >

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MTQ4NDIPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2Nya
END_ENCODED_CONTENT

Ethical Behavior

If the competency(glossary) of the systems engineer is a matter of KSAA—knowledge, skills, abilities, and attitudes—then the word “attitudes” must have an ethical dimension. The ethical framework that guides the SE's actions insures that the SE ultimately does good and not harm. Ethical standards apply both to individuals and to organizations. This section discusses the moral foundations of ethics, and the elements of ethical conduct that are especially relevant to systems engineering.

Ethics and Morals in Systems Engineering

Like other people, systems engineers have morals: guiding personal thoughts and feelings about what is right and wrong. All of us also share, with other members of various communities to which we belong, ethics: standards that say what conduct is appropriate and what is not (Whitbeck 2007).

Morals are part of a person's character, the result of upbringing, culture, and other environmental influences. **Ethics** apply morals within the frame of a social system, which could be professional, business, academic, recreational, cultural, political, religious, or even familial. While a person’s moral code is usually considered immutable, one's ethics may need to account for new situations as one's profession or role in life changes. Tensions may exist between an engineer's responsibilities to society and those to the customer, the employer, or even the family, resulting in ethical dilemmas, and creating situations where morals come into play.

There is no shortage of discussion on ethics. Ethical codes are promulgated by professional and other organizations. **Professions** here refers to occupations that require learning and advanced knowledge and which safeguard or promote the well-being of others and of society as a whole.

Systems engineers have two ethical responsibilities over and above those of most other engineering professions:

- While engineers in general use their professional skills to address customer needs and desires, systems engineering (SE) helps *determine* those needs and desires in the course of defining and managing requirements.

SEs have an obligation to ensure that problem or program definition is influenced solely by the interests of the customer or user, not by those of the systems engineer or his firm.
- Systems engineers typically integrate and oversee the work of others whose expertise differs from their own. This makes the obligation to widen one's understanding and to seek competent advice from other professionals more acute in SE than in other disciplines.

Caroline Whitbeck's *Ethics in Engineering Practice and Research* explains what ethical behavior means for engineering professionals. Like most books on ethics, this one starts by clarifying the differences between ethics and morals, which can seem somewhat obscure at times (Whitbeck 2007).

A sampling of areas where ethics figure in the engineering of modern systems are described below.

Data Confidentiality and Security, Surveillance, and Privacy

Privacy, confidentiality, and security in systems which touch Personally Identifiable Information (PII) have an ethical dimension for the systems engineers responsible for developing those systems.

Laws and Regulations

Systems are typically developed in societies, sometimes involving international communities, which have laws concerning contracts, intellectual property, freedom of information, and employment. The requirements and restraints of those laws govern the practice of the systems engineer, who must be aware of the laws and must consider their implications for the partnerships that system development entails.

Whether or not they are stated in the system requirements document or provided by the customer, laws and regulations do in fact impose system requirements. SEs are responsible for knowing and applying relevant laws and regulations. This means recognizing other people's proprietary interests by safeguarding their intellectual property (trade secrets, copyrights, trademarks, and patents), and giving them credit for performing work and making innovations.

Cultural Issues

Since systems engineers develop and maintain products used by humans globally, it is important that they understand the historical and cultural aspects of their profession and the related context in which their products will be used. System engineers need to be aware of societal diversity and act without prejudice or discrimination.

Ethical Considerations in the Systems Engineering Method

Naturally, SE approaches to meeting customer needs must integrate SE ethics.

Codes of Ethics and Professional Conduct

Codes of ethics are promulgated by the IEEE (IEEE 2009), the National Society of Professional Engineers (NSPE) (NSPE 2007), the International Council on Systems Engineering (INCOSE 2006) and other engineering organizations.

The INCOSE Code of Ethics enunciates fundamental ethical principles like honesty, impartiality, integrity, keeping abreast of knowledge, striving to increase competence, and supporting educational and professional organizations. Based on these principles, the code identifies the systems engineer's fundamental duties to society and the public, and the rules of practice that systems engineers should follow to fulfill those duties.

According to the INCOSE Code of Ethics, it is the systems engineer's duty to

- guard the public interest and protect the environment, safety, and welfare of those affected by engineering activities and technological artifacts;

- accept responsibility for one's actions and engineering results, including being open to ethical scrutiny and assessment;
- proactively mitigate unsafe practice;
- manage risk using knowledge gained by applying a whole-system viewpoint and understanding of systemic interfaces; and
- promote the understanding, implementation, and acceptance of prudent SE measures.

Enforcing Ethics

Many organizations enforce ethics internally by means of ethics policies. These polices typically include rules such as the following:

- There shall be no exchange of favors between anyone in the organization and entities with which it does business, such as suppliers, customers, or regulatory agencies.
- Product information, for example, test data, shall be reported accurately and completely to the contracting agency.
- There shall be no conflict of interest between the organization and entities with which it does business.

Favors can consist of providing money, reimbursement of travel or entertainment expenses, other items of equivalent value, or inappropriate job offers. Conflict of interest can arise when the personal or professional financial interests or organizational ties of an engineer are potentially at odds with the best interests of the customer or the engineer's employer. Since conflict of interest and other ethical transgressions can be hard to define, care must be taken to design ethics policies that are observable and enforceable. Internal audit functions or external regulatory agencies may enforce ethical rules at the individual, team, organizational, or enterprise level. Punishment for violating ethics policies can include termination and other disciplinary actions.

Unlike self-employed physicians who may choose to not do something specific, many systems engineers are individuals employed by organizations. Depending on the organizational context, an issue in conflict with the company might result in giving up the job. This may result in additional ethical considerations.

Responsibility to Society

Engineers who create products and services for use in society have an obligation to serve the public good. Additionally, the IEEE Code of Ethics states that engineers have an obligation to foster the professional development and ethical integrity of colleagues (IEEE 2015). Because of the criticality and scope of many systems, systems engineers, operating in teams within projects and on behalf of the public in delivery of products, have special responsibility. Poorly designed systems or services can have calamitous effects on society. The INCOSE Code of Ethics asserts the responsibility of systems engineers to "guard the public interest and protect the environment, safety, and welfare of those affected by engineering activities and technological artifacts" (INCOSE 2006).

References

Works Cited

IEEE. 2009. *IEEE Code of Ethics*. in IEEE [database online]. Accessed September 7, 2012. Available: http://www.ieee.org/ethics.

IEEE. 2015. *IEEE Code of Ethics*. Accessed April 6, 2015. Available: http://www.ieee.org/about/corporate/governance/p7-8.html.

INCOSE. 2006. *INCOSE Code of Ethics*. in International Council on Systems Engineering [database online]. Accessed April 13, 2015. Available: http://www.incose.org/about/leadershiporganization/codeofethics.

NSPE. 2007. *NSPE Code of Ethics for Engineers.* Alexandria, VA, USA: National Society of Professional Engineers. NSPE publication #1102. Accessed on September 15, 2011. Available: http://www.nspe.org/resources/

ethics.

Whitbeck, C. 2007. *Ethics in Engineering Practice and Research*. New York, NY, USA: Cambridge University Press.

Primary References

Whitbeck, C. 2007. *Ethics in Engineering Practice and Research.* New York, NY, USA: Cambridge University Press.

Additional References

National Institute for Ethics in Engineering. "National Institute for Engineering Ethics." In the Murdough Center for for Engineering Professionalism. Hosted by Texas Technical University. Accessed on September 15, 2011. Available at http://www.murdough.ttu.edu/pd.cfm?pt=NIEE.

OnlineEthics.org. "Online Ethics Center (OEC)." Accessed September 8, 2011. Available at: http:/ / www. onlineethics.org/.

Martin, M. and R. Schinzinger. 2004. *Ethics in Engineering,* 4th ed. New York, NY, USA: McGraw-Hill.

Penn State. "Ethics: Books." In Penn State College of Engineering. Accessed September 8, 2011. Available at: http:/ /www.engr.psu.edu/ethics/books.asp.

Smith, J.H. (ed). 2008. *Engineering Ethics – Concepts, Viewpoint, Cases and Codes.* National Institute for Engineering Ethics, Texas Technical University.

< Previous Article | Parent Article | Next Article (Part 6)>

SEBoK v. 1.4 released 29 June 2015

SEBoK Discussion

Please provide your comments and feedback on the SEBoK below. You will need to log in to DISQUS using an existing account (e.g. Yahoo, Google, Facebook, Twitter, etc.) or create a DISQUS account. Simply type your comment in the text field below and DISQUS will guide you through the login or registration steps. Feedback will be archived and used for future updates to the SEBoK. *If you provided a comment that is no longer listed, that comment has been adjudicated. You can view adjudication for comments submitted prior to SEBoK v. 1.0 at SEBoK Review and Adjudication. Later comments are addressed and changes are summarized in the Letter from the Editor and Acknowledgements and Release History.*

If you would like to provide edits on this article, recommend new content, or make comments on the SEBoK as a whole, please see the SEBoK Sandbox [1].

ENCODED_CONTENT
MzgyMjQPGRpdiBpZD0iZGlzcXVzX3RocmVhZCI+PC9kaXY+CjxzY3JpcHQgdHlwZT0idGV4dC9qYXZhc2NyaX
END_ENCODED_CONTENT

Article Sources and Contributors

Enabling Systems Engineering *Source*: http://sebokwiki.org/d/index.php?oldid=50216 *Contributors*: Apyster, Asquires, Bkcase, Blawson, Dfairley, Dhenry, Dholwell, Gparnell, Hsillitto, Janthony, Jgercken, Kguillemette, Smenck2, Wikiexpert, Zamoses

Enabling Businesses and Enterprises *Source*: http://sebokwiki.org/d/index.php?oldid=50638 *Contributors*: Apyster, Asquires, Bkcase, Dhenry, Dholwell, Hdavidz, Hsillitto, Jgercken, Rbeasley, Rturner, Sjackson, Skmackin, Smenck2, Wikiexpert, Ymordecai, Zamoses

Systems Engineering Organizational Strategy *Source*: http://sebokwiki.org/d/index.php?oldid=49441 *Contributors*: Afaisandier, Apyster, Asquires, Bkcase, Dfairley, Dhenry, Hsillitto, Jgercken, Kguillemette, Mhenshaw, Skmackin, Smenck2, Wikiexpert, Ymordecai, Zamoses

Determining Needed Systems Engineering Capabilities in Businesses and Enterprises *Source*: http://sebokwiki.org/d/index.php?oldid=50461 *Contributors*: Apyster, Asquires, Bkcase, Dhenry, Dholwell, Groedler, Hdavidz, Hsillitto, Jgercken, Kguillemette, Mhenshaw, Rbeasley, Rmadachy, Rturner, Sjackson, Smenck2, Wikiexpert, Ymordecai, Zamoses

Organizing Business and Enterprises to Perform Systems Engineering *Source*: http://sebokwiki.org/d/index.php?oldid=50408 *Contributors*: Apyster, Asquires, Bkcase, Dhenry, Dholwell, Hdavidz, Hsillitto, Jgercken, Kguillemette, Mhenshaw, Qwang, Rbeasley, Sjackson, Smenck2, Wikiexpert, Ymordecai, Zamoses

Assessing Systems Engineering Performance of Business and Enterprises *Source*: http://sebokwiki.org/d/index.php?oldid=50418 *Contributors*: Apyster, Asquires, Bkcase, Dhenry, Dholwell, Hdavidz, Hsillitto, Jgercken, Mhenshaw, Rbeasley, Smenck2, Wikiexpert, Ymordecai, Zamoses

Developing Systems Engineering Capabilities within Businesses and Enterprises *Source*: http://sebokwiki.org/d/index.php?oldid=50448 *Contributors*: Apyster, Asquires, Bkcase, Dhenry, Dholwell, Hdavidz, Hsillitto, Jgercken, Mhenshaw, Rbeasley, Smenck2, Wikiexpert, Ymordecai, Zamoses

Culture *Source*: http://sebokwiki.org/d/index.php?oldid=50195 *Contributors*: Apyster, Bkcase, Dhenry, Dholwell, Gparnell, Hsillitto, Jgercken, Jsnoderly, Kguillemette, Mhenshaw, Rbeasley, Rturner, Sjackson, Smenck2, Wikiexpert, Zamoses

Enabling Teams *Source*: http://sebokwiki.org/d/index.php?oldid=50196 *Contributors*: Apyster, Asquires, Bkcase, Dfairley, Dhenry, Dholwell, Gparnell, Jgercken, Kguillemette, Smenck2, Wikiexpert, Zamoses

Team Capability *Source*: http://sebokwiki.org/d/index.php?oldid=50197 *Contributors*: Apyster, Asquires, Bkcase, Dfairley, Dhenry, Dholwell, Gparnell, Hdavidz, Jgercken, Kguillemette, Skmackin, Smenck2, Wikiexpert, Zamoses

Team Dynamics *Source*: http://sebokwiki.org/d/index.php?oldid=49115 *Contributors*: Apyster, Asquires, Bkcase, Dfairley, Dhenry, Dholwell, Janthony, Jgercken, Skmackin, Smenck2, Wikiexpert, Zamoses

Technical Leadership in Systems Engineering *Source*: http://sebokwiki.org/d/index.php?oldid=51009 *Contributors*: Bkcase, Cnielsen, Eleach, Hdavidz, Kguillemette, Smenck2

Enabling Individuals *Source*: http://sebokwiki.org/d/index.php?oldid=51010 *Contributors*: Apyster, Asquires, Bkcase, Dfairley, Dhenry, Dholwell, Gparnell, Hdavidz, Janthony, Jgercken, Skmackin, Smenck2, Wikiexpert, Zamoses

Roles and Competencies *Source*: http://sebokwiki.org/d/index.php?oldid=51427 *Contributors*: Apyster, Asquires, Bkcase, Cnielsen, Dfairley, Dhenry, Dholwell, Gparnell, Hdavidz, Janthony, Jgercken, Kguillemette, Mhenshaw, Radcock, Skmackin, Smenck2, Thilburn, Wikiexpert, Zamoses

Assessing Individuals *Source*: http://sebokwiki.org/d/index.php?oldid=50827 *Contributors*: Apyster, Asquires, Bkcase, Cnielsen, Dhenry, Dholwell, Gparnell, Hdavidz, Janthony, Jgercken, Kguillemette, Mhenshaw, Skmackin, Smenck2, Wikiexpert, Zamoses

Developing Individuals *Source*: http://sebokwiki.org/d/index.php?oldid=50447 *Contributors*: Apyster, Asquires, Bkcase, Cnielsen, Dhenry, Dholwell, Gparnell, Hdavidz, Janthony, Jgercken, Kguillemette, Mhenshaw, Skmackin, Smenck2, Wikiexpert, Zamoses

Ethical Behavior *Source*: http://sebokwiki.org/d/index.php?oldid=50840 *Contributors*: Apyster, Asquires, Bkcase, Ccalvano, Dfairley, Dhenry, Dholwell, Gparnell, Hdavidz, Janthony, Jgercken, Kguillemette, Sjackson, Skmackin, Smenck2, Wikiexpert, Zamoses

Image Sources, Licenses and Contributors

File:Organizational_coupling_diagram_v2.png *Source*: http://sebokwiki.org/d/index.php?title=File:Organizational_coupling_diagram_v2.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:System_enterprises_and_organizations_v2.png *Source*: http://sebokwiki.org/d/index.php?title=File:System_enterprises_and_organizations_v2.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Culture_competence_team_performance_and_individual_competence.png *Source*: http://sebokwiki.org/d/index.php?title=File:Culture_competence_team_performance_and_individual_competence.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Part_5_(Organization)_Concept_maps_additions_hgs_15_Aug.png *Source*: http://sebokwiki.org/d/index.php?title=File:Part_5_(Organization)_Concept_maps_additions_hgs_15_Aug.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Picture1_HGS.png *Source*: http://sebokwiki.org/d/index.php?title=File:Picture1_HGS.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:TPM_Chart_from_INCOSE_SELIG.png *Source*: http://sebokwiki.org/d/index.php?title=File:TPM_Chart_from_INCOSE_SELIG.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Concept_map_for_businesses_and_enterprises_topics.png *Source*: http://sebokwiki.org/d/index.php?title=File:Concept_map_for_businesses_and_enterprises_topics.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Fairley_Fig_1_(2)_Layer_1.png *Source*: http://sebokwiki.org/d/index.php?title=File:Fairley_Fig_1_(2)_Layer_1.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Fairley_Fig_2_Layer_1.png *Source*: http://sebokwiki.org/d/index.php?title=File:Fairley_Fig_2_Layer_1.png *License*: unknown *Contributors*: Smenck2, Smurawski

File:Dimensions_of_Communication_Styles.png *Source*: http://sebokwiki.org/d/index.php?title=File:Dimensions_of_Communication_Styles.png *License*: unknown *Contributors*: Smenck2

File:Layered_and_Multi-dimensional_in_the_Engineering_Layer.PNG *Source*: http://sebokwiki.org/d/index.php?title=File:Layered_and_Multi-dimensional_in_the_Engineering_Layer.PNG *License*: unknown *Contributors*: Janthony, Smenck2, Smurawski

File:MITRE_Enterprise_Systems_Engineering_Framework.PNG *Source*: http://sebokwiki.org/d/index.php?title=File:MITRE_Enterprise_Systems_Engineering_Framework.PNG *License*: unknown *Contributors*: Janthony, Smenck2, Smurawski