Guide to the Systems Engineering Body of Knowledge (SEBoK) version 0.75

Part 5

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Part 5

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Part 5: Enabling Systems Engineering

Systems engineering (SE) activities that support an organization's needs and deliver intended value are enabled (glossary) by many factors, such as the organization's culture, SE workforce competencies, SE tooling and infrastructure, and how the organization grows and deploys its workforce in order to arm it with those competencies. There are as many different ways to enable (glossary) SE performance as there are organizations, and every organization's approach is highly detailed and unique. Nevertheless, the many common practices, methods, and considerations that organizations use can provide a framework to structure the relevant knowledge.

Beyond individuals, there are two levels of organizational structures defined in the SEBoK: Teams (glossary) (which include project teams, program teams, etc.) and businesses (glossary)/enterprises (glossary). A business is a special type of enterprise which usually has a legal structure and a relatively centralized control structure; e.g., as a corporation or a unit of a company or government agency that creates a specific product line or offers specific services. An enterprise may be a traditional business, but can also cross traditional business boundaries; e.g., the healthcare system of a nation is an enterprise which does not have a centralized legal authority and has a very loose form of governance. Throughout this article and related articles, the term "business/enterprise" will usually be shortened to just "business" for readability and to reflect the fact that significant actions to enable SE are primarily conducted by traditional businesses rather than by less well-structured enterprises. The reader should look at Enterprise Systems Engineering in Part 4 of the SEBoK for further elaboration on the distinction between businesses and enterprises and how the systems engineering of enterprises is extremely valuable to define them, influence their behavior and value.

Teams are usually formed for a specific purpose of limited duration, such as creating a new system or upgrading an existing service or product. Once the new system has been created and delivered or the existing service or product has been upgraded and fielded, the team responsible for that effort is usually disbanded and the individuals associated with the effort are assigned to new tasks. For example, the U.S. Federal Aviation Administration formed a team in the last decade to create a new enterprise resource planning system for its operations and dispersed the team after the system was fielded. However, there are exceptions; e.g., the U.S. Air Force's SE Center of Excellence persists indefinitely and the team stays together on successive projects. On the other hand, businesses typically have permanence. They usually offer a portfolio (glossary) of products and services, introduce new ones, retire old ones, and otherwise seek to grow the value of the business. In a corporation, management of that portfolio might be centralized under the direction of the corporate executives. In a non-business enterprise, such as a national healthcare system, there may be only loose coordination of execution among many businesses; e.g., a national healthcare system includes physicians, drug companies, hospitals, government regulatory agencies, etc. A business may offer its products and services to a single customer; e.g., a small supplier that makes a single product solely for a large manufacturer. 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; for example, the Eurofighter Typhoon aircraft was developed by a consortium of three companies that formed a holding company specifically for the purpose of providing support and upgrade services throughout the in-service life of the aircraft.

Part 5 discusses businesses, enterprises, teams, and individuals, and begins with an articulation of strategies that enable SE to be performed well by a business.

Knowledge Areas in Part 5

The four knowledge areas in Part 5 explore the relationships between businesses, teams, and individuals in more depth and point the reader to important information in the literature. They are:

- Systems Engineering Organizational Strategy
- Enabling Businesses and Enterprises to Perform Systems Engineering
- Enabling Teams to Perform Systems Engineering
- Enabling Individuals to Perform Systems Engineering

Key Concepts and Relationships in Part 5

1. A business has context, scope, and purpose; for example, the purpose and scope of Federal Express is the delivery of letters and packages quickly and reliably. There are several other private package delivery companies with which it competes in addition to the public U.S. Postal Service. In a SE sense, these competing companies are part of Federal Express' context.
2. A business creates value for its participants, shareholders, customers, society, and other stakeholders. The relevant stakeholders vary for a business; e.g., Federal Express is a publicly traded company headquartered in the U.S. Its most important stakeholders include its shareholders and the millions of customers it serves daily. The presumption, of course, is that SE activities add value to the business and that the value is greater when SE activities are well aligned to the business context, scope, and purpose, and operate consistently with the business culture.
3. A business assigns resources and services to teams which have context, scope, purpose, responsibilities, and accountabilities. Some of those teams may be devoted to SE activities; e.g., a team that develops system requirements or a system architecture. Other teams may have a broader role, but still include SE activities; e.g., the team that negotiates terms and conditions with a major subcontractor may be led by a specialist in contracting and negotiation, but may include systems engineers who provide technical insights into the system performance and requirements.
4. Teams have various roles that require specific competencies for effective execution; e.g., a SE team that develops a system architecture will require strong competencies in the most critical technologies on which the architecture is dependent and in the application domain of the system, such as finance, transportation, or communication.
5. Individuals who fill those roles have personal competencies; e.g., the chief systems engineer on a project typically possesses strong communication and leadership competencies.
6. Teams have team dynamics that are influenced by the culture of the organization and by the specific individuals on the team and their competencies.
7. Overall performance is driven by the team context, scope, purpose, team dynamics, and the team's composition.
8. A business implements governance to ensure that SE actualizes the overall strategy for the enterprise; e.g., the business may decide what authority the chief systems engineer on a project has and how decisions made by the chief systems engineer are reviewed.
9. The structure of the business is driven, at least in part, by the strategy.
10. Finally, there is an implicit recursion in the relationships between businesses, teams, and individuals; for example, a business which is a large global company may have component businesses, many of which may have further component businesses. A large program team may have component subprogram teams, many of which may have further component project teams, and so forth. Each level of the recursion is enabled and constrained to some degree by the structure, governance, context, and other SE concepts from both higher and lower levels. The specific nature of these constraints varies across organizations.

Key relationships among the main concepts in Part 5 are illustrated in Figure 1 below. Businesses, enterprises, teams, and individuals are the central concepts in the diagram.

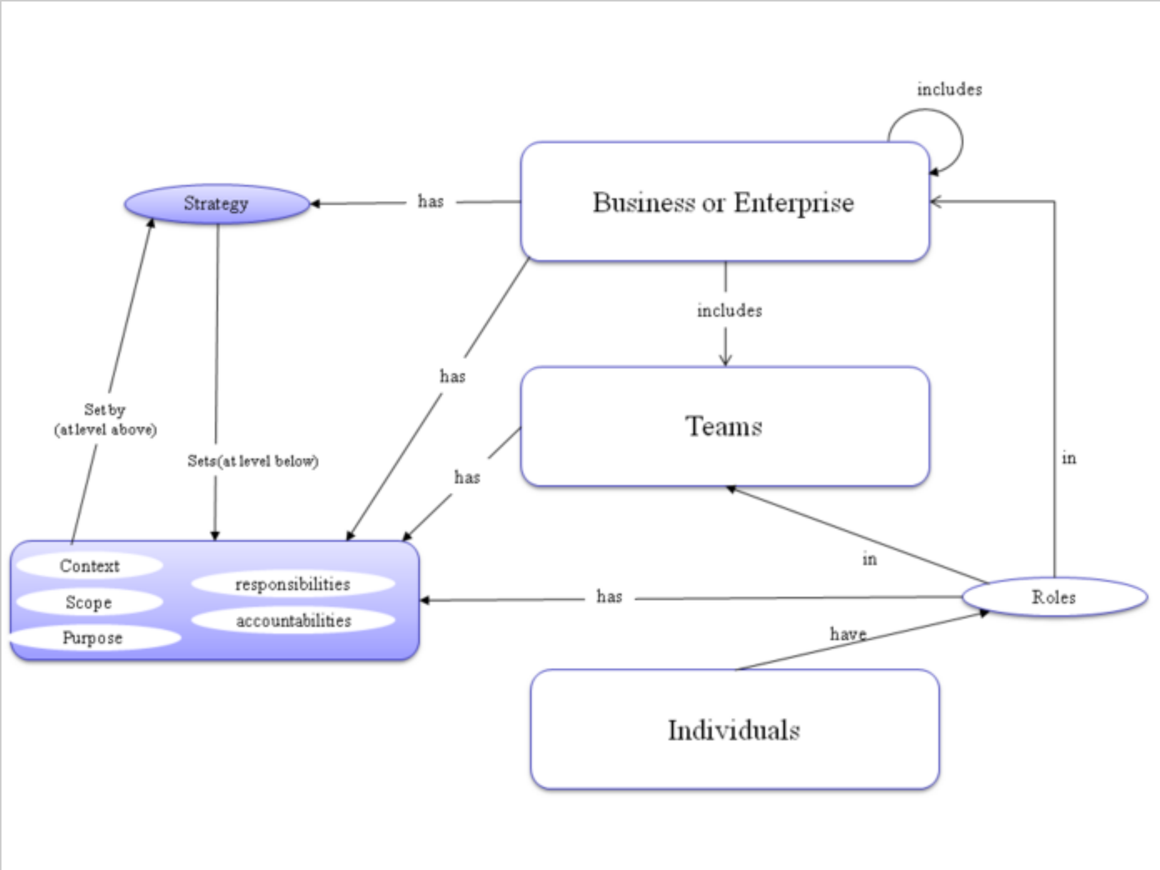

Figure 1. Businesses, Teams, and Individuals in SE (Figure Developed for BKCASE)

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None.

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Systems Engineering Organizational Strategy

Virtually every significant business (glossary) or enterprise (glossary) (BE) that creates products (glossary) and/or services (glossary), benefits from performing a wide variety of SE activities to increase the value (glossary) that those products and services deliver to BE owners, customers, employees, regulators, and other stakeholders (glossary). How the BE goes about organizing to conduct SE activities is important to their effectiveness. For example, every BE has a purpose, context, and scope determined by some of its stakeholders and modified over time to increase the value the BE offers to them. Some BEs are for-profit entities, while others work for the public good. Some BEs have a single site, while others are far-flung "empires" with locations around the globe. 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 in the purpose, context, and scope of a BE shape the strategy for performing SE within the BE.

Topics

The SE Organizational Strategy knowledge area contains the:

- Organizational Purpose
- Value Proposition for Systems Engineering
- Systems Engineering Governance

Primary Considerations

Like all thoughtful strategies, SE strategy is properly driven by the goals of the organization and the resources and constraints available to achieve those goals. SE strategy in particular is influenced by several considerations, especially:

- The purpose of the organization
- What value the organization 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 organization and the systems and services of interest; e.g., is it a single site company or a global venture? Is it a project responsible for a relatively modest product for internal use by a BE, such as a new Web application to track employee training, or is a program creating a new hybrid automobile complete with concerns for engineering, manufacturing, servicing, and distribution?
- The culture of the organization in which the SE activities are performed; e.g., is the organization risk-averse? Do people normally collaborate or work in stove-pipes?

- The organizational 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 enterprise align with the architecture of its major products and services?

SE Strategy Focus

Based on those general considerations, the SE strategy generally addresses:

- How SE activities provide a value proposition for supporting the organizational purpose
- How SE activities are allocated among the various organizational entities
- What competencies are expected from the parts of the organization in order to perform these SE activities
- How those parts of the organization gain these competencies, what the organization needs to do to improve, and how it does so
- Who performs the SE activities within each part of the organization
- How those who perform these SE activities interact with others in the organization.

The strategy is also impacted by the organizational structure, as explained in the next section.

Different Possible Structures for an Organization, and How the Choice Affects SE

Organizations 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, projects, and businesses. There are four common ways of organizing resources to support multiple projects: project organization, matrix organization, functional organization, and integrated organization (CM Guide 2009; Handy 1985; PMI 2008, section 2.4). A large organization would likely apply some combination of these four ways. (Browning 2009) provides a way to optimize project organizational structure.

Project Organization

A project organization is one extreme wherein 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 or 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

Very often a matrix organization is used to give functional specialists a “home” between project assignments. This is a common approach in systems engineering organizations where a SE functional lead is responsible for workforce development and may manage career development by giving individuals a variety of development experiences in different 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.

A Product Centered Organization

In accordance with the heuristic (glossary) that “the product and the process must match” (Rechtin 1991, p. 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 necessary 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.

Some disciplines, such as reliability and safety, may not fit into this hierarchical structure. Separate teams, sometimes called analysis and integration teams (AIT) (glossary) are created for these disciplines. These teams are also sometimes called **functional IPTs**. There is commonly an AIT for each level of the IPT hierarchy.

At the program level, there is a top-level IPT commonly called a systems engineering and integration team (SEIT) (glossary) or an **overarching IPT**. The purpose of the SEIT or overarching IPT is to oversee all the lower level IPTs.

The diagram in Figure 1 shows a typical way in which a program organization maps to the system breakdown structure. This diagram shows only two levels, but in practice there may be many levels.

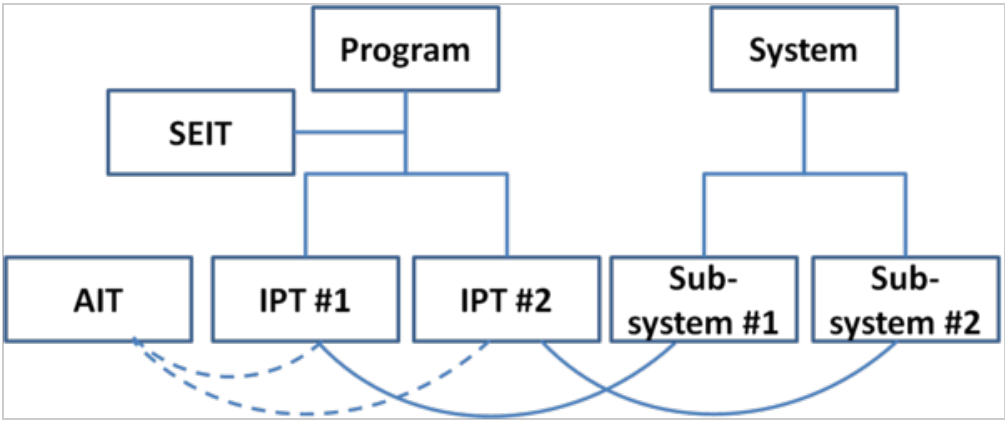

Figure 1. IPT-System Mapping Diagram (Figure Developed for BKCASE)

Interfaces with Other Functions in the Business or Enterprise

Systems engineering is relevant to, and depends on, other organizational functions. Some organizations see SE as purely about project delivery. Others see it as a key enabler for innovation for new and improved products and services. Typical relationships with other organizational functions are shown in the following table. These relationships should all add value to the business, and the need to service these relationships determines the level of SE capacity and capability that needs to be maintained at the higher levels of the enterprise rather than lower level teams.

Table 1 – Systems Engineering relationships with other functions in businesses and enterprises (Figure Developed for BKCASE)

SE contributes to other function	SE requires from other function	Areas where SE and other function should collaborate
Research and technology		
Future client needs; Architecture road maps; SE architectural framework for managing dependencies and information flows; Maturity criteria	Future technology capabilities; Predictions of standards evolution; Concept demonstrators; Tools and models	Future product architectures; Novel system concepts; Research and technology pull-through; Prioritize research and technology to address capability gaps; Tailored SE for research and technology projects; SE research; Innovation platforms; Technology road mapping
Human Resources		
Define SE competencies; Report on staff performance; Future SE staff needs; Training requirements	Definition of grade structure and hiring/ promotion criteria; Training budget; Training provision	Develop SE training for practitioners and other functions; Managing team performance

Strategy and Business Development		
Enterprise opportunity assessment; Product line architecting; Understanding trends and implications of future needs; Model/analyze extended enterprise value stream; Critical SE and architectural dependencies; Competitor capabilities	Business case analysis; Future markets; Preferred partners; Preferred suppliers; Priorities for SE capability development; Customer feedback	Enterprise opportunity identification and management; "Make, team or buy" decisions; Product road mapping; Crisis management; Business development; Alignment of goals across the enterprise; Managing external relationships
Bid and Program		
As above at project level; Systems engineering planning for whole system lifecycle; Architecture; Independent peer review; Technical metrics for SE process and system performance	As above at project level; Task authorization and prioritization; Earned Value Management process	Detailed project planning and control; Risk identification and management; Managing customer relationship; Managing and controlling changes
Engineering Operations		
Architecture constraints/ patterns; Competence requirements for SE roles; SE process, tools, models, methods, coaching, reviewers; Validation of plans and design, standards; SE metrics requirements; Shortfall/excess in forward load; Requirements for SE enabling systems	Metrics reports; Forward load estimate; Current SE issues in ops	Risk assessment; "Make team buy" decisions for subsystems and SE capabilities; Load balancing and prioritization; Anomaly resolution
Service delivery/Deployed operations		
Change impact analysis Design and validation of upgrades and reconfiguration for new missions	Decommissioning; Refurbishment	Changes to operational architecture, e.g. Force Realignment Anomaly resolution

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Organizational Purpose

In a systems engineering (SE) context, the goal at any level of an organization is to develop, deploy, and enable effective SE to add value to the organization’s business according to the organization's purpose, context, and scope. This organizational purpose supersedes the organization's vision in the long run and keeps the organization moving forward in times when the vision is too distant or is not met. [Note: In the U.S. **mission** is the accepted terminology for a statement of the purpose of the organization and **vision** states what the organization aspires to be within a stated period of time.]

(Senge 2006, p. 263) asserts that "A company that lacks purpose worthy of commitment fails to foster commitment. It forces people to lead fragmented lives that can never tap the passion, imagination, willingness to take risks, patience, persistence, and desire for meaning that are cornerstones of long-term financial success".

The kind of business determines the scope and diversity of SE across the organization.

Four Systems Engineering Drivers

The focus of SE capabilities in an organization will depend on its purpose and its current situation and is likely to be driven by one or more of these four factors:

- Do current business better
- Cope with a disruption in the market, a competitive threat, or changing customer expectations and ways of doing business
- Reposition the business in its value chain
- Launch a new generation product, or enter a new market

To the extent that SE deployment is a significant change project, its success will hinge significantly on its alignment to the organization's purpose and goals.

Business Purpose, Context and Scope

Every organization has a purpose, a context within which it has to operate, and a scope of influence, activities, and responsibilities. These are defined by its sponsors and investors, and modified by which of its activities turn out to be most valued by its “customers."

SE at the organizational level aims to develop, deploy, and enable effective systems engineering to add value to the organization’s business. The detailed how, what, and why will depend on the nature of the organization's business. The rest of this article explores the different kinds of SE businesses and how these differences affect the way the business conducts SE.

Three Basic Business Models

There are three basic types of business models. The biggest differences between the three business models are where the requirements risks lie and how an understanding of user needs and usage environment is fed into the design and delivery process. The way SE supports the business is different in each case.

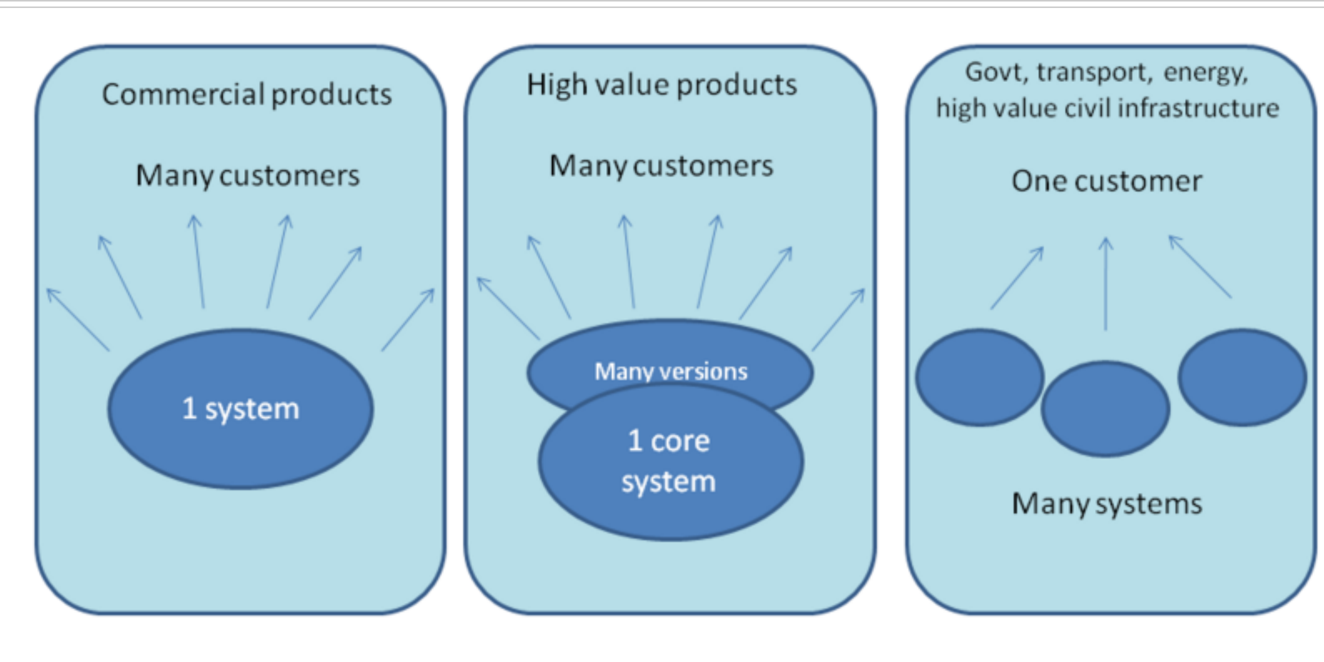

Figure 1. 3 Kinds of System Business (Figure Developed for BKCASE)

Commercial products are the systems and services 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 commercial product development is a form of systems engineering with adapted techniques for requirements elicitation and validation.

High-value products and services are often customized uniquely for each customer. In a **product platform** or **product line approach**, a high-value product or service is customized for each customer or market segment using common elements. This is more complex both technically and organizationally than the other models. Typically, the organization identifies common and variable aspects of solutions and the likely market window when a given generation of product and technology will be competitive. Then it develops common technology, product or service “platforms” that allow faster, cheaper and lower risk response to customer requirements. This places heavy demands on systems engineering coordination across projects and business units and requires a particular approach to requirements management and architecting, as well as standardized interfaces and test environments. Careful management is needed to make sure the benefits of the approach and the flexibility it offers are realized in practice. Two particular risks are that project teams may deviate from the product policy under pressure to meet specific customer requirements or perceptions; or, conversely, the teams may attempt to apply a common solution across too wide of a market segment. 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; Nokia and Motorola cellphones; and Lexmark and Hewlett-Packard printers. 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).

Government, transport, energy, high value infrastructure 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 contract-driven style of systems engineering 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.

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.

5 kinds of organizational contexts for SE

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

- A business with multiple project teams
- A project that spans multiple businesses
- An SE team within either of the above
- A business with a single project team
- 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 2, which illustrates the fundamental form of an extended enterprise. This also shows how organizational structure tends to match system structure.

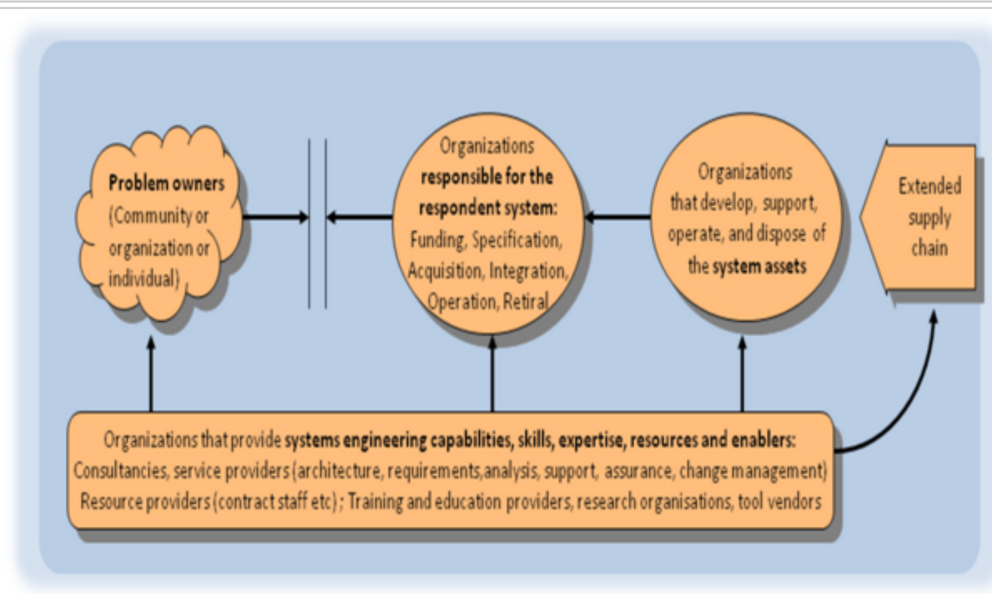

Figure 2. Organization Coupling Diagram (Figure Developed for BKCASE (Adapted from Lawson 2010))

The “problem owners” are the people, communities, or organizations involved in and affected by the “problem situation”. Example problems they face, and the ultimate value of the system of interest, might be to defend a country, improve transport links in a community, or deal with an environmental challenge. The “respondent system” might be a new fighter aircraft, a new or improved transportation infrastructure, or new low-emission electricity generation systems. 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 3.

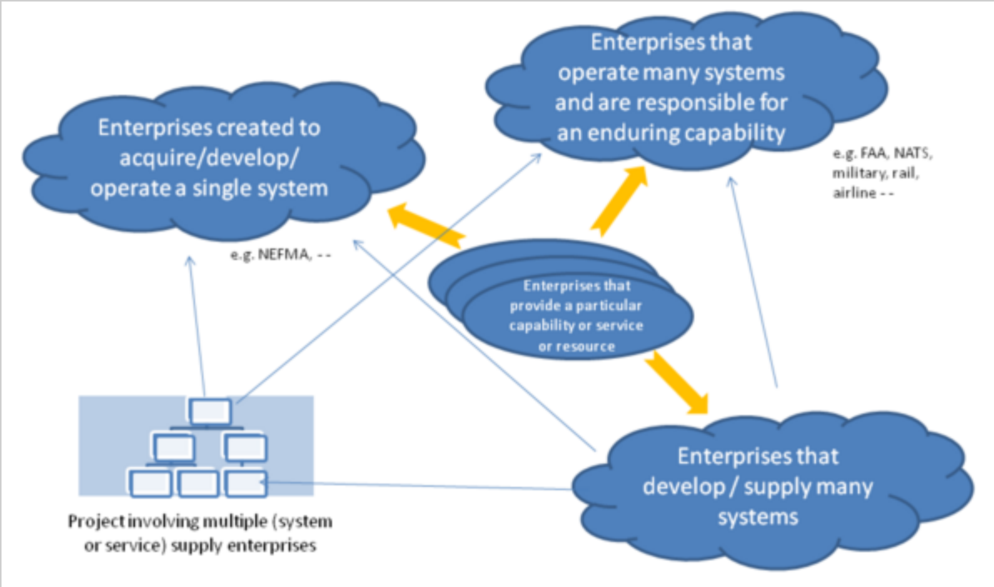

Figure 3. Systems Enterprises and Organizations (Figure Developed for BKCASE)

Systems Engineering in the Extended enterprise

As systems become more interconnected, organizations become more interdependent and thus need to manage much higher levels of complexity. Organizational complexity is now a major risk factor in system development and operation. (Sillitto 2010a; Jackson 2010) A major system development such as Eurofighter Typhoon is an “extended enterprise” that involves all of the five types of organization listed above. Each government customer operates an enduring military mission capability of which the Typhoon is a major component. The NEFMA (now NATO Eurofighter and Tornado Management Agency (NETMA)) acquisition agency was formed for the sole purpose of delivering a single project—to acquire the Typhoon from a multi-national industrial collaboration, and to supply the same basic system with minor variations to several national air forces. The development project is “a project organization involving multiple supply businesses” led by a consortium of major defense contractors and supported by an extended group of suppliers, each of which is “an organization that develops many systems." The entire supply chain is supported by a plethora of specialists providing training, tools, skills, and resources.

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Value Proposition for Systems Engineering

The importance and worth of systems engineering to an individual, team (glossary), or business (glossary)/enterprise (glossary) is related to the level to which systems engineering supports their challenges and aligns with their goals.

Challenges

Individuals and organizations today face many challenges that can be addressed through the disciplined approach offered by systems engineering. These challenges are caused by a combination of increasing systems complexities and global trends, as shown below.

- Increasing system complexities (Lambs and Rhodes 2007; Kalawsky 2009):
  - Design density increasing – what was once considered a large complex system integrated by connecting many individual units, now fits on the footprint of a small chip (Hemani 2004).

- Design breadth increasing – systems are expanding in focus from a set of interacting devices to interacting components to interacting subsystems (Hemani 2004; Shiroma et al. 2011).
- System functionality increasing – systems once used for a single purpose are being designed to deal with multiple missions and/or applications (Shiroma et. al 2011).
- Number of system parameters increasing – the number of parameters that need to be controlled during the design process is increasing and will potentially become overwhelming (Kalawsky 2009).

- Global trends:
  - Dwindling resources – needs are outpacing resources; for example, the aging of the workforce is impacting human capital (Davidz, Nightingdale and Rhodes 2005).
  - Increasing programmatic challenges – projects are scheduled over longer time periods at a higher overall total ownership cost and new technologies are being developed that impact the projects across the life cycle while legacy systems are being used long beyond their original life expectancy; in some cases this forces new systems to work with older systems that were never designed to be interoperable.
  - Greater international collaboration – today's systems are often developed by organizations that cross many countries, and projects under development are comprised of multiple teams separated geographically. These team members are potentially from different cultures and this is becoming the norm rather than the exception. In addition, there have been a sequence of mergers and acquisitions over the last decade in both commercial and defense markets.
  - Increasing scale of competition – in parallel with increasing collaboration, competition has expanded from local to regional to national to global.

Alignment and Value

How goals and measures are aligned across the organization will strongly influence the effectiveness of systems engineering efforts and the benefits delivered by systems engineering to the organization. Some examples follow:

- Blockley and Godfrey (2000) describe techniques that were used successfully to deliver a major infrastructure contract (Heathrow Terminal 5) 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 throughout an extended enterprise, provided the enterprise boundary is chosen correctly and considers the whole value stream (Womack and Jones 1996; 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 aspects required for through-lifecycle success of each element of the system as an integrated “building block”.
- In a similar vein, Blockley (2010) suggests that taking a holistic view of “a system as a process” allows a more coherent and successful approach to organization and system design, considering each element as both a part of a bigger system of interest, and as a whole system (a “holon”) in its own right.
- (Elliott and Deasley 2007) advocates six guiding principles to make 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.

Measuring the Value of SE

Many researchers have evaluated the return on investment (ROI), or value, of applying systems engineering in the organization. Although the validity of findings in this area remains controversial, a growing number of researchers have sought to establish a quantitative basis for understanding the value of SE. (Mar and Honour 2002) found that the use of systems engineering on a project appears to be positively correlated with cost and schedule savings. Leveraging data from past projects, Eric Honour found 10-15% (Honour 2003) and 15-20% (Honour 2004) as the optimal percentage of early systems engineering efforts that optimize the value of systems engineering over the life of the project. (Boehm, Valerdi, and Honour 2008) concluded that the larger the system is, the higher the potential ROI will be.

(Hamann, Zandbergen, and Zijdemans 2009, 2) analyzed six space projects that were completed from 1995 to 2005 and found that:

> "…there appears to be a clear positive correlation between the SE effort applied and the project result. It appears also that the positive effects mainly show up in the cost and schedule results of the project, the technical quality of the project result being generally of a rather satisfactory level."

(Vanek, Jackson, Grzybowski, and Whiting 2010) conducted 19 interviews of systems engineers and project managers within Corning on the range and effectiveness of systems engineering techniques on their projects and found that the strongest performing projects had a higher use of systems engineering techniques than the struggling projects.

(Honour 2010) identifies 14 characterization parameters that account for 70% of the variability between the systems engineering activities on the programs and the program success measures used. These were divided into quantitative and subjective parameters as shown below.

- Quantitative:
  - System size
  - Development methods
  - Level of integration
  - Definition at start
  - Life cycle stage
  - Proof difficulty
  - Development autonomy
- Subjective:
  - Team understanding
  - Program/System complexity
  - Installation differences
  - Team process capability
  - Need for and use of SE tools
  - Technology risk
  - System applicability

Honour's characterization parameters were developed from extensive previous research performed, most notably by:

- (Honour 2004) - Value of systems engineering research;
- (Valerdi 2004) - Constructive Systems Engineering Cost Model COSYSMO research; and
- (Elm, et al. 2008) - Results from a survey of 46 projects performed by major government contractors and subcontractors on systems engineering effectiveness.

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Systems Engineering Governance

Governance of Systems Engineering (SE) is the process and practice through which a Team (glossary), Business (glossary), or Enterprise (glossary) 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 organizational structure, enforced through tools, and understood through measures of compliance and effectiveness. SE governance in large organizations is often explicit and codified in policy. In small organizations, it is often tacit and simply understood in how the organization works. One of the key implementation steps when an organization defines its SE strategy is to establish its SE governance model, which should be tailored to the particular context in which the organization 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 personalities occupying key management positions.

Governance Practice

The term "governance" for development organizations was popularized first in reference to how Information Technology (IT) is overseen in organizations. (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 business value for most corporations and government agencies led to the transformation of the Chief Information Officer into a key senior manager. Explicit governance of IT became important to enabling a business 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 a team, business, or 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 and 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, and 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 organizational 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 group organizes to conduct SE activities either conform to policies established at the level above, or are captured in that group'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 RACI (responsible, accountable, consulted, informed) matrix (PMI 2010) or something similar. Responsibility in large organizations can easily become diffuse. Sommerville et. al. (2009, 515-529) discusses the relationship between information and responsibility, and describes 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 contracting typically brings additional regulation and oversight, driving a group to greater rigor and 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 for example Jackson (2010).

Governance models vary widely depending on the context in which the business operates. For example, Linux, the greatest success of the open source community, has a governance model that is dramatically different than those of traditional companies. J.T. 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.

Project Governance

A systems engineering project or team exists within a larger business or enterprise that has taken on responsibility for part or all of a systems engineering project. This responsibility and budget are delegated to the project or team. Because the business remains legally responsible, holds the risk, and incurs the opportunity cost of the resources allocated, it normally imposes financial, technical and organizational governance obligations on the project or team. The project or team will use a mixture of dedicated resource, shared resource and shared services from the parent organization. The team remains fully responsible for selection and management of any contracted-in resource.

The project or team is responsible to the parent organization for delivering the assigned task within agreed parameters of cost, time, quality, and cash management. It also has an explicit or implicit responsibility for maintaining or enhancing the parent organization's capability and reputation and for refreshing organizational knowledge. This involves a web of knowledge and relationships both explicit and implicit.

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).

Wider Relationships

Organizations often invest in relationships outside formal contractual relationships. Senior systems engineers participate in professional bodies such as the International Council on Systems Engineering (INCOSE) and the Institute of Electrical and Electronics Engineers (IEEE), support teaching and research at universities, and contribute to professional and business networks within their organization, within their supply chain and in their local region. Such activities can create great value to the organization and its wider ecosystem through mutual learning, benchmarking and inspiring innovation, and could benefit from coordination to make sure they add value, and do not waste effort or breach contractual or other business obligations.

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Primary References

No primary references have been identified for version 0.75. Please provide any recommendations on primary references in your review.

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Enabling Businesses and Enterprises to Perform Systems Engineering

To enable systems engineering within a business (glossary) or enterprise (glossary) (hereafter just called "business" as a shorthand because a business is a specific type of enterprise that usually has sufficiently strong central authority and motivation to take steps to enable systems engineering (SE)), the business could establish a strong central governance approach to how SE is managed across its various components, projects, programs, and teams; e.g., the business could mandate a standard SE process, career path, technical authority, and toolset to be used by all systems engineers in the business. Clearly, the feasibility of that approach would depend on the authority of the business management. Some businesses have sufficiently centralized authority that such a mandate could be issued, supported, and enforced. For others with decentralized authority, this would not be possible or practical. At the other extreme, the business could allow each component and team to establish its own way in governing SE, making independent decisions about process, career path, technical authority, and toolsets. Most large businesses use a blend of approaches that fit the culture, context, purpose, and personalities of the business. A business is itself a system and can benefit from being viewed that way. The information on systems offered throughout the SEBoK can help enable a business to better perform SE.

Topics

This knowledge area contains the following topics:

- Deciding on Desired Systems Engineering Capabilities within 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

Businesses usually adopt or enhance their SE capability for one of four reasons:

- To do current business better (typically a combination of faster, better, cheaper)
- To respond to a disruption in the market place requiring them to change the way they do business - a competitive threat or new demands from customers
- To reposition the business in its value chain or open up a new market
- To develop a new generation product or service.

Logical flow between topics

The way in which they enable SE should be driven by those reasons, tempered by the context, culture, and other factors in which the business operates.

One illustrative flow between the topics is shown in the Figure 1 diagram, which is essentially a "plan-do-check-act" cycle (Deming 1994).

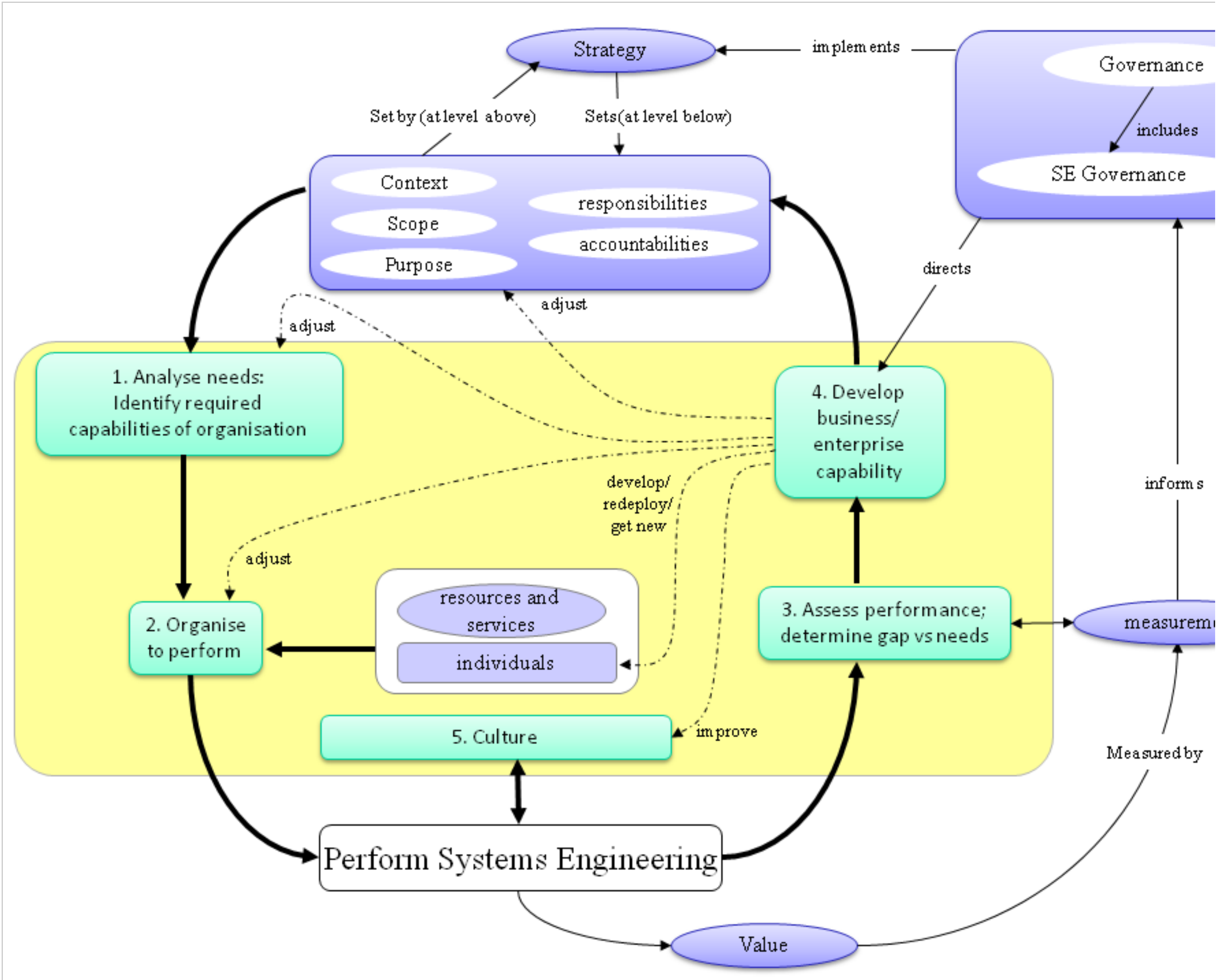

Figure 1. Concept Map for Businesses and Enterprises Topics (Figure Developed for BKCASE)

Analyze Needs

- Systems Engineering Governance sets the Systems Engineering Organizational Strategy, which is constrained by the purpose, context, scope, responsibilities and accountabilities of the business. These may be developed by Enterprise Systems Engineering or Capability Engineering activities, and/or flowed down from the level above, and/or negotiated with peers
- The business assesses what SE capabilities it needs to fulfill its Organizational Purpose; that assessment may include participation of stakeholders from across the business, such as the business executive team, and leaders from various groups such as engineering, finance, and marketing; (see Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises).

Organize to Perform

- The business organizes to perform SE, allocating responsibilities and resources to the various actors responsible for SE activities (see Organizing Business and Enterprises to Perform Systems Engineering)

Perform Systems Engineering

- SE is performed in support of business products and services (see Systems Engineering and Management in Part 3)

Assess Performance; Determine Gaps Versus Needs

- Performance is assessed (see Assessing Systems Engineering Performance of Business and Enterprises)

- Any gap between needed and achieved performance is identified.

Develop Business/Enterprise Capability

If there is a gap between actual and needed capabilities, measures are taken to develop or improve the capabilities using the available levers to:

- Develop, redeploy or obtain new facilities, tools, services, and individuals;
- Improve culture;
- Adjust organization;
- Adjust and align measures, goals and incentives;
- Adjust the definition of the required capabilities;
- If necessary, renegotiate scope, context, purpose, responsibility and accountability.

(See Developing Systems Engineering Capabilities within Businesses and Enterprises)

Businesses vary enormously in purpose, scope, size, culture and history. The way the business prepares to perform Systems Engineering needs to be tailored according to the specific situation and will depend greatly on the level of understanding of the added value of systems engineering, as well as the organization's maturity and homogeneity.

This Knowledge Area discusses the implementation of SE in Business (glossary) and in Enterprise (glossary), and is also relevant to extended enterprises and to projects that involve multiple organizations. This latter case is a particularly difficult challenge because the teams within the project have duties both to the project and to their parent business and enterprise, and must fit into both cultures and process environments.

The detailed topics in this Knowledge Area go into further detail on how a business determines and prioritizes the SE capabilities it needs (Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises), organizes to do Systems Engineering and integrates SE with its other functions (Organizing Business and Enterprises to Perform Systems Engineering), assesses SE performance (Assessing Systems Engineering Performance of Business and Enterprises), develops and improves its capabilities through organizational learning (Developing Systems Engineering Capabilities within Businesses and Enterprises) and the impact of Culture.

Goals, Measures and Alignment in an Organization

The alignment of goals and measures across the business strongly affects the effectiveness of SE effort and the benefit delivered by SE to the business. For example:

- (Blockley, D. and P. Godfrey. 2000) describes techniques used successfully to deliver a major infrastructure contract on time and within budget, in an industry normally plagued by adversarial behavior.

- Lean thinking (Womack and Jones 2003; Oppenheim et al. 2010) provides a powerful technique for aligning purpose to customer value – provided the enterprise boundary is chosen correctly and considers the whole value stream.

- (Fasser, Y. and Brettner, D. 2002, 18-19) sees an organization as a system, and advocate three principles for organizational design: “increasing value for the ultimate customer”, “strict discipline”, and “simplicity”.

- EIA 632 (EIA 1999) advocates managing all the aspects required for through-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) advocates six guiding principles for making systems that work: “debate, define, revise and pursue the purpose”; “think holistic”; "follow a systematic procedure”; "be creative”; "take account of the people”; and “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 http://www.incoseonline.org.uk/Documents/zGuides/Z2_Enabling_SE.pdf (Farncombe and Woodcock 2009) and http://www.incoseonline.org.uk/Documents/zGuides/Z3_Why_invest_in_SE.pdf (Farncombe and Woodcock 2009).

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Deciding on Desired Systems Engineering Capabilities within

Businesses and Enterprises

Enabling Businesses and Enterprises to Perform Systems Engineering includes deciding on the desired systems engineering (SE) capabilities within the business (glossary) or enterprise (glossary) (hereafter, this article generally just uses the term "business" because a business is a special form of enterprise and non-business enterprises generally don't have enough central authority to take actions to enable SE). Ideally, a decision on the desired capabilities is made in the context of the Organizational Purpose must be understood, and then the value that SE can provide is determined. Required SE capabilities flow down from the business strategy; understanding the value that SE can provide within the organization in support of the Organizational Purpose and business strategy is the starting point for deciding the desired SE capabilities. This topic summarizes the issues that drive the decisions about desired SE capabilities for a business. Because SE has to take into account the factors that differentiate organizations, this topic also discusses the organizational design decisions and issues that may arise, as well as how SE may interact with other functional areas in the organization, and what needs to be done to ensure that SE delivers a high value to an organization.

Once the SE capabilities of the business are determined, these capabilities are divided among various organizations, teams, and individuals. Determination of team SE capability is discussed in Determining Needed Systems Engineering Capabilities in Teams, and the individual SE competencies are discussed in Roles and Competencies.

The capability (glossary) to perform SE includes factors such as having competent personnel, adequate time, sufficient resources, tools, and equipment, and appropriate policies and procedures. The SE capability of a business is dependent on all these factors. Social dynamics at the team and organizational levels also influence the realization of SE capability.

Relationship of this Topic to Enterprise Systems Engineering

Enterprise Systems Engineering and Capability Engineering techniques can be used to establish needed SE capabilities. Architecture modeling and analysis enables better understanding of the dependencies between the capabilities of components in the business. 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, including the factors shown in Table 1;
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 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, and the summary table below, illustrates some of the contextual factors and drivers that influence 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.

- If the organization is the problem owner, the focus will be on identifying and scoping the system problem, understanding the nature of the appropriate respondent system, defining its interdependencies and interoperability with other current and envisaged systems, and establishing the capacity and capability to acquire, integrate, and operate the relevant system assets to deliver the intended benefit. It may be appropriate for such organizations to use enterprise SE and capability SE approaches.

- If the organization is the system operator, the focus will be on establishing all the necessary components of capability (glossary) to deliver the required services to the problem owner, 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.
  - The US Department of Defense defines the components of capability as DOTMLPF; i.e., 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.

- If the organization is a prime contractor, it will 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. Depending on the level of complexity and scale, this may require enterprise SE (see Enterprise Systems Engineering) as well as "traditional" product SE (see Product Systems Engineering for more information and references to the literature).

- If the organization is a subsystem/component developer, it will focus on understanding the critical customer and system integrator issues for the subsystem or component of interest to the developed, establish the component or subsystem boundary definition, and integrate critical technologies, possibly in an innovative way, to create a competitive solution. Often, the business model at this level of the supply chain will favor solutions that 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).

- If the organization is a specialist service provider, it will focus on specific process capabilities and competences which are sold on a time and materials or work package basis to other enterprises.

Where the Enterprise Operates in the Lifecycle

The core SE competencies and capabilities developed by the enterprise will depend on the system life cycle (glossary) phase(s) in which it operates.

- In the concept phase, SE requires the capability to identify a "problem situation," define the context and potential concept of operations for a solution system, assess the feasibility and affordability of a range of possible solutions in broad terms, analyze needs, determine appropriate options for further consideration, and refine the definition to allow the development of system requirements for the solution.

- In the development phase, SE requires the capability (including staff competence, organizational capability, enabling infrastructure, etc.) to perform the following:
  - engage with concept studies to ensure the business addresses opportunities in which it is competent;
  - influence concept studies to ensure that the specifications will be feasible and understood by the development organization;
  - establish the amount of trade space that remains at the end of the concept study to calibrate the scope for innovation and optimization in the development program;
  - secure appropriate development work on appropriate terms;
  - perform the system development activities defined in Part 3 of the SEBoK, Systems Engineering and Management, including architecture design, detailed definition of the system elements and their interfaces, integration, verification, qualification, and validation; and
  - produce definition data to allow the solution to be implemented, set to work, supported, operated, and safely disposed of.

- The manufacturing phase requires the capability to perform the following:
  - configure the manufacturing and logistics systems for the system assets;
  - manufacture, test, certify, control the configuration of, and deliver system assets; and
  - provide spares, repairs, and manage obsolescence as part of a logistic support service.

- The in-service phase requires the capability to perform the following:
  - maintain business continuity during the transition into the operation of the new system;
  - bring the system into service;
  - integrate its capabilities into "business as usual";
  - manage and sustain all components of capability, including people, processes, and logistical support;
  - maintain knowledge of the configuration of the deployed system(s);
  - monitor system performance and effectiveness during operation; and
  - reconfigure the system to recover from performance drop-off and respond to emerging needs.

This requires the business to be able to perform SE at an appropriate operational tempo, which varies with how the enterprise delivers value.

- The retirement phase requires the capability for ensuring the safe retirement of systems and keeping them in a state ready for re-activation ("mothballed"), dismantling and recycling, or safe disposal of the assets and their constituent parts.

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; i.e., the design-to-order for contracted solutions, focus on satisfying explicit requirements, whereas market-driven businesses, including those offering service products such as air travel or package delivery, have to be more aware of implicit responsibilities.

Nature of Responsibility to Customers

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

- an outcome; i.e., the intended benefits the system is expected to provide;
- an output; i.e., deliver or operate the system or part of it against agreed acceptance criteria;
- an activity; i.e., perform a specified set of tasks; and
- a resource; i.e., provide a specified resource.

The SE approach will have to be different in each case. The first case requires enterprise SE. The second case requires product SE. The third case requires service SE and the last case requires focus on the individual competence of its staff.

Scale of Systems

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

- Level 1: Subsystem and technical artifacts – The focus will be on product SE and on technology integration to achieve function and performance, and on managing the business or enterprise capability synergistically across multiple projects and product lines.
- Level 2: Project systems – The focus will be on product SE with cross-discipline and human integration to achieve system level function, performance, and behavior to deliver the required services in the appropriate operational environment.
- Level 3: Business systems – The focus will be on enterprise SE to establish required enterprise capabilities, on service SE 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 SE, on flow through for the co-operating and competing supply chains, and on the long-term economic and environmental sustainability of the overall industry.
- Level 5: Societal systems – Enterprise SE is used to analyze and attempt to optimize societal systems (see Singapore Water Management Vignette in Part 7 of the SEBoK).

Sillitto and Godfrey have proposed extending this model to cover sustainability issues by adding two additional layers, the "ecosystem" and the "geosystem" (Sillitto 2011).

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, that have to do with the level of cross-disciplinary integration involved (Elliot et al. 2007).

- 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.
- In multiple disciplines (e.g., software, hardware, optics, *and* mechanical), the SE focus is on holistic integration of multiple technologies and skills to achieve a balanced system solution.
- In socio-technical systems integration, the SE focus is on getting people and the non-human parts of the system working synergistically. (For an example, see Sommerville et al. (ref to be confirmed)).

Sillitto and Godfrey have proposed extending this model properly to cover sustainability issues by adding one additional level, "Environmental Integration" (Sillitto 2011). They describe 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 an enterprise 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 enterprise 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, and 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 enterprise 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. Preferably, this should be in the context of a wider improvement plan across the business, and be the early steps of a strategic plan for SE (see article about improving capability - REF).

In the other cases, the business is going through disruptive change and the early priority will be to use systems thinking and enterprise SE approaches to scope the change. The plan needs to be driven strategically as a major change initiative to have a good chance of success.

Type of System or Service

There are three distinct flavors of products or service types (see Organizational Purpose):

- 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.
- 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.
- 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.

Summary Table

The table below summarizes the discussion above.

Table 1. Environmental factors in organizing to perform SE in a business or enterprise (Table Developed for BKCASE)

Environmental Factor	Examples
Where the SE activities are performed in the value chain	Whether the organization is: ▪ The problem owner, ▪ System operator, ▪ Prime contractor, ▪ Subsystem/component developer ▪ Or specialist service provider
Where the business or enterprise operates in the life cycle	▪ Concept ▪ Development ▪ Manufacturing ▪ In-service ▪ Retired
Nature of responsibility to end users	▪ Explicit: clear requirements, prescriptive legislation ▪ Implicit: fitness for purpose, product liability
Nature of responsibility to customers	▪ Outcome: deliver the intended benefits the system is expected to provide ▪ Output: deliver or operate the system or part of it against agreed acceptance criteria ▪ Activity: perform specified processes ▪ Resource: provide specified resource.
Scale of systems at which the organization operates	▪ Level 1: Subsystem and technical artifacts ▪ Level 2: Project systems ▪ Level 3: Business systems ▪ Level 4: Industry systems ▪ Level 5: Societal systems
Complexity of systems integration task – Stupples' levels	▪ Within a discipline (e.g., software or electronics) ▪ Multiple disciplines (e.g., software, hardware, optics, and mechanical) ▪ Socio technical systems integration ▪ Environmental integration
Criticality of system and certification requirements	▪ Safety, Security ▪ Ethics, Environment, etc.
Nature of contract	▪ Fixed price or cost plus ▪ Mandated work share arrangements
Nature and predictability of problem domain	▪ Well defined and slowly changing steady state ▪ Poorly defined and rapidly changing, operators subject to unpredictable and evolving threats (e.g., defense)

Fundamental risks and design drivers in solution domain	▪ Stable, low rate of technology evolution, systems use mature technology ▪ Rapid technology evolution, pressure to bring new technologies rapidly to market/ into operational use ▪ Lead time expectations versus level of integrity/certification
Competitive situation and business goals	▪ Do existing business better ▪ Recover from a competitive shock or a shift in clients' expectations ▪ Develop a new generation product or service ▪ Enter a new market ▪ Reposition the business or enterprise in the value chain
Type of system or service	▪ Product or productized service ▪ Custom solution (product or service) ▪ Tailored solution based on standard product and/or service elements

Required SE Roles

Enterprise Systems Engineering techniques can be used to establish needed SE capabilities from first principles. This implies the need for a business SE team, either permanent or ad hoc, that has both the necessary enterprise SE skills and the necessary influence with senior decision makers in the organization.

After understanding the context for the business, the next step is to determine the required SE capabilities. 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.

The SE roles and competencies the organization needs to develop depend on the capabilities it needs to do its business and on the type of organizational model selected for the business. Existing SE competency models can be used to assist in determining the needed capabilities. An example is the INCOSE SE Competencies Framework (INCOSE 2010b). (See Roles and Competencies for more information on competency models.)

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).

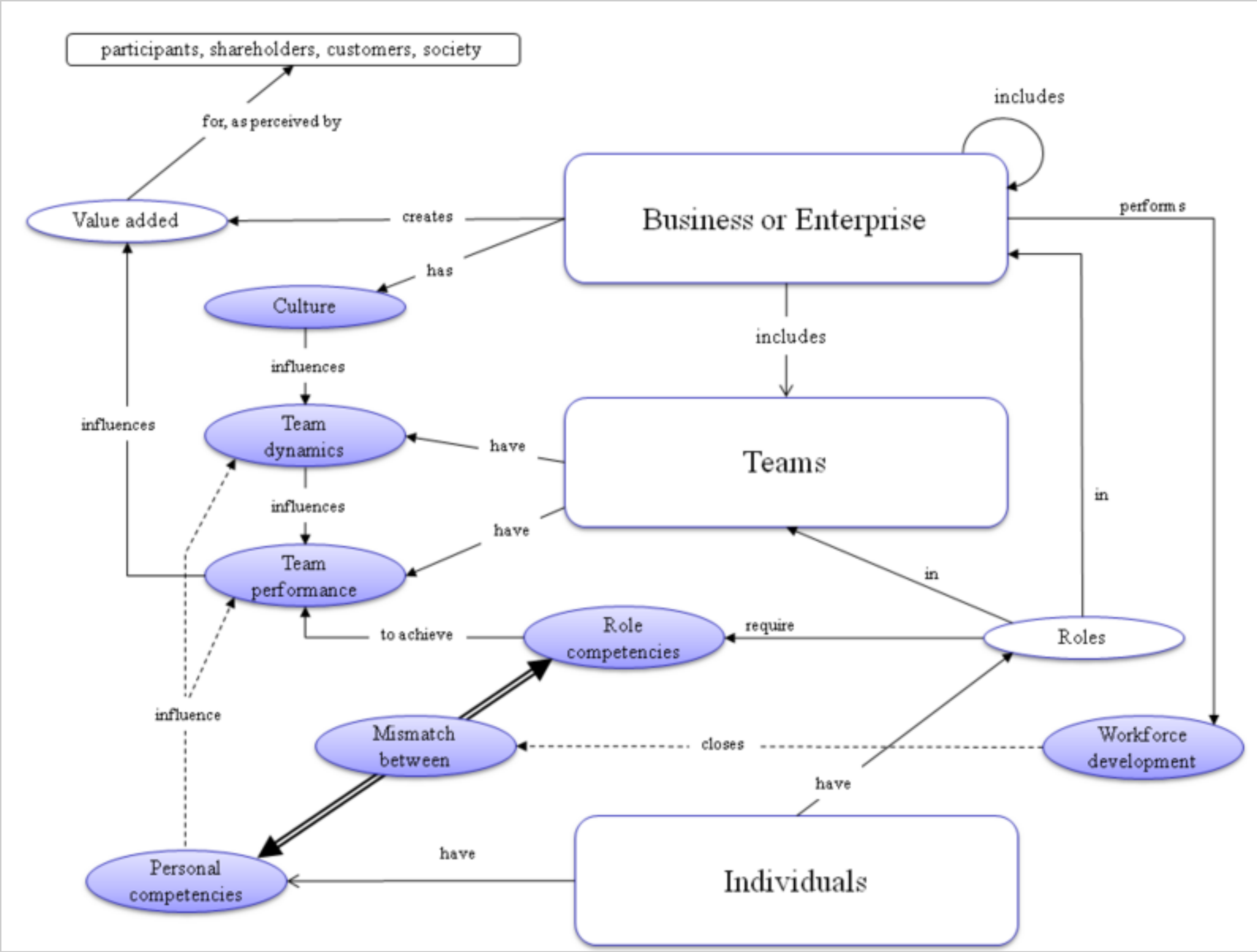

Figure 1. Culture, Competence, Team Performance and Individual Competence (Figure Developed for BKCASE)

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

In any organization where activities and skills are shared, there is always a danger of silos or duplication. One of the purposes of SE is to reduce this risk; for example, consider the 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).

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).

SE can make a very powerful contribution to the organization's quality goals. 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 2011; ISO 2008; see Quality Management).

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.

A business is a system and SE is one of the functions that the system may need to perform. The specific requirements for the SE function can be derived from understanding what the overall system (the organization) needs to do, and from the relationship between SE and other functions within the organization at different levels. Ideally, there would be a tailored solution to an organization's SE requirements based on the unique set of purposes, scope, context, capabilities, and the culture of each organization. Also, organizations change over time (learning, improving, or losing capability). Thus, balancing SE with everything else that it involves is an ever changing process.

Balancing the need for a systematic and standardized approach to SE processes, such as defined in models and handbooks, with the flexibility inherent in systemic thinking is critical. Systems thinking helps the organization understand problem situations, remove organizational barriers and blockers, and make the most of the organization's technical capabilities (see "The Three T's of Systems Engineering" (Beasley 2011)).

Finally, a key ingredient in deciding what SE Capabilities are required is listening to other stakeholders (e.g., program managers and corporate/enterprise leaders) and enlisting their feedback. In fact, the entire SE strategy should flow down from the business strategy and be developed in cooperation and collaboration with members of the entire business leadership team (other engineering disciplines, HR, Finance, Supply Chain, Training, etc.).

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Organizing Business and Enterprises to Perform Systems Engineering

Each organization is unique. The type and scope of the overall organization determines the particular way Systems Engineering (glossary) (SE) is deployed and carried out to suit the purpose of the organization. A standard way of describing the capabilities needed is based on the Toyota (Morgan and Liker 2006) approach of considering people, processes and tools. This division is used to structure this topic, with the addition of some specific issues about SE and the enabling organization.

Components of Business and Enterprise SE Capability

Governance of Systems Engineering

Systems Engineering Governance both impacts and responds to the SE Culture and approach, and defines how and by whom SE decisions are made, monitored, and measured in order to deliver business value.

Definition of Roles

SE organizations typically establish a career structure for people management to address three key issues for business success: how people are recruited, trained, allocated, supervised, promoted, and rewarded; how to optimize use of expertise, across projects and business units; and how to develop SE skills.

(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.

People

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

Knowledge and Information

There are two kinds of knowledge: explicit and tacit. Explicit knowledge can be written down or incorporated in computer codes, and can be treated as an asset. Much knowledge is tacit. Tacit knowledge only exists within the heads of people and in the context of relationships that people form with each other. The ability of a business/enterprise to create value is highly dependent on the people it employs, what they know, how they work together, and how well they are organized and motivated to contribute to the business/enterprise's purpose.

(Fasser and Brettner 2002) discuss knowledge management extensively and emphasize the value of numerous mechanisms for informal knowledge transfer. 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".

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.

Organizations need to manage SE know-how, integration of SE with other organizational processes and activities, and knowledge of their business domain. Typical strategies include internal networks of SE leaders, experts, practitioners, reviewers, trainers, assessors; links from knowledge to organizational training and people development; and IT "Infostructure" to facilitate distributed working and cross-site collaboration. 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 and commercially and nationally sensitive material. Different cultures and personal styles make best use of information presented in different ways and in different orders (i.e. in levels of abstraction, big picture first or detail, principles first or practical examples). (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; and 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 ensure 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. (Elliot et al. 2008) suggests 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.

Managing Organizations in a High-Risk Environment

Many industrial domains are subject to catastrophic events. Special managerial skills are required to manage these organizations and minimize these events. Organizations that possess these skills are called High Reliability Organizations (HROs) (glossary), a term coined by Weick and Sutcliffe (2001, p. 3). HROs are "organizations that operate under trying conditions and have fewer than their fair share of accidents." Example HROs include "power grid dispatching centers, air traffic control systems, nuclear aircraft carriers, nuclear power generation plants, hospital emergency departments, and hostage negotiation teams." Weick and Sutcliffe (Weick and Sutcliffe, 2001, p. 10) identify five hallmarks of HROs:

Preoccupation with Failure

HROs do not ignore errors, large or small. They encourage reporting of errors. They learn from near misses. They avoid complacency. They avoid the temptation to reduce margins of safety.

Reluctance to Simplify Interpretations

HROs simplify less and see more. They position themselves to see as much as possible. They “encourage skepticism towards received wisdom.” They pay attention to the nuances that diverse people detect.

Sensitivity to Operations

HROs pay attention to possible latent conditions, defined by James Reason (1997) to be deficiencies in the system that have not yet resulted in an accident but are waiting to happen. They have well developed situational awareness and make continuous adjustments to keep errors from accumulating and enlarging.

Commitment to Resilience

HROs keep errors small and improvise “workarounds that keep the system functioning.” They have a deep understanding of the technology and constantly create worst case situations to make corrections.

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.

Process

Many SE organizations maintain a set of organizational standard processes, integrated in their quality and business management system, adapted to their business, and with tailoring guidelines to help projects apply the standard processes to their unique circumstances. This may be supported by a process group who develop and maintain the process assets, and support their deployment into business units and projects. 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) (glossary)), concerned with organizational definition and tailoring of the SE lifecycle processes discussed in detail elsewhere in this document; and Organizational Process Focus (OPF) (glossary), concerned with establishing a process culture in an organization.

Organizations may choose to assess and measure performance at the business/enterprise level, in which case, the evaluation may well look to how well SE is truly delivering business value rather than just how well the business/enterprise is executing processes.

CMMI also provides a means to measure performance of systems engineering projects. The Organizational Process Performance (OPP) (glossary) process area provides guidance on managing process performance at an organizational level. Consistent process measurement across the business allows the development and calibration of parametric estimating models that improve the predictability of SE projects. 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 (INCOSE 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.

Tools, Models and "Infostructure"

SE organizations often invest in SE tools and models, developing their own, and/or integrating off-the-shelf tools into their particular business/enterprise processes. Certainly, automation makes executing SE methods and processes easier and more reliable. Conversely, risks with tools include the possibility that they may “lock in” inefficient and counterintuitive processes, fail to manage exceptions properly, and force people to service the tool instead of the tool serving the people. Tools require great attention to culture and training, to developing a consistent “style” of use so that people can understand each others’ work, and configuration manage the information so that people are working on common and correct information.

Tools and facilities to support SE processes may be generic, with no particular tailoring for a specific domain such as telecommunications or finance. Quite often, companies and some niche vendors produce tools tailored to specific domains.

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.

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

- 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 part 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 and systems engineers need appropriate facilities for accessing, sharing and capturing knowledge and for interacting effectively with the whole set of stakeholders. Often a systems engineer will need to “move into their world” to deal effectively with stakeholders. So visiting customer sites, using simulation facilities, etc, are important ways to engage with and understand operational and customer communities. Even such simple things as putting photographs of the operational systems and environment up on the walls can help to establish a common understanding that that leads to effective communication. Warfield (2006) describes collaborative workspaces, and 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:

- 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 environment
- 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, ordnance, etc.
- Training and support infrastructure – training simulators, embedded training, tools and test equipment for operational support and maintenance, etc.

Fitting it All Together

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

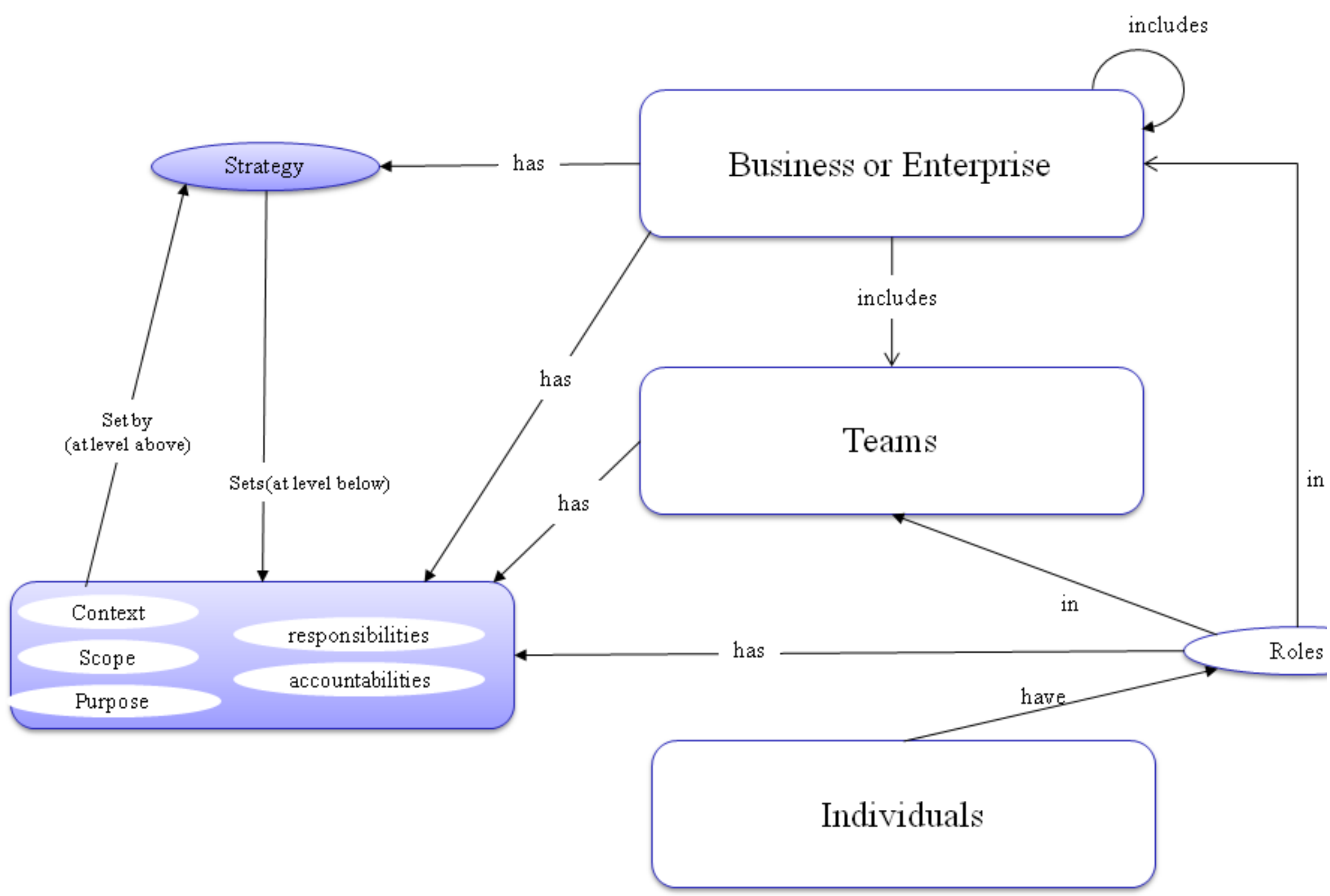

Figure 1. Businesses, Teams, and Individuals in SE (Figure Developed for BKCASE)

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Assessing Systems Engineering Performance of Business and Enterprises

At the project level, systems engineering measurement focuses on indicators of project and system success that are relevant to the project and its stakeholders. At the business and enterprise level there are additional concerns. Systems Engineering Governance should ensure that the performance of systems engineering within the business or enterprise adds value to the organization, is aligned to the organization's purpose, and implements the relevant parts of the organization's strategy. 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 a business and enterprise should cover these dimensions and inform these choices.

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 reliable collect and aggregate data across teams, having a policy that consciously decides how the business/enterprise will address data collection and analysis is valuable.

Relevant Measures

Typical relevant measures for assessing SE performance for a business/enterprise include:

- SE internal process
- Ability to mobilize the right resources at the right time for a new project or new project phase
- Project SE 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
- Deployment and consistent usage of tools and methods

How the Measures Fit in the Governance Process and Improvement Cycle

Since collecting data and analyzing it takes effort - often significant effort - Measurement is best deployed when its purpose is clear and part of an overall strategy. Figure 1 shows one way in which appropriate measures inform business or enterprise level governance and drive an improvement cycle such as the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) model.

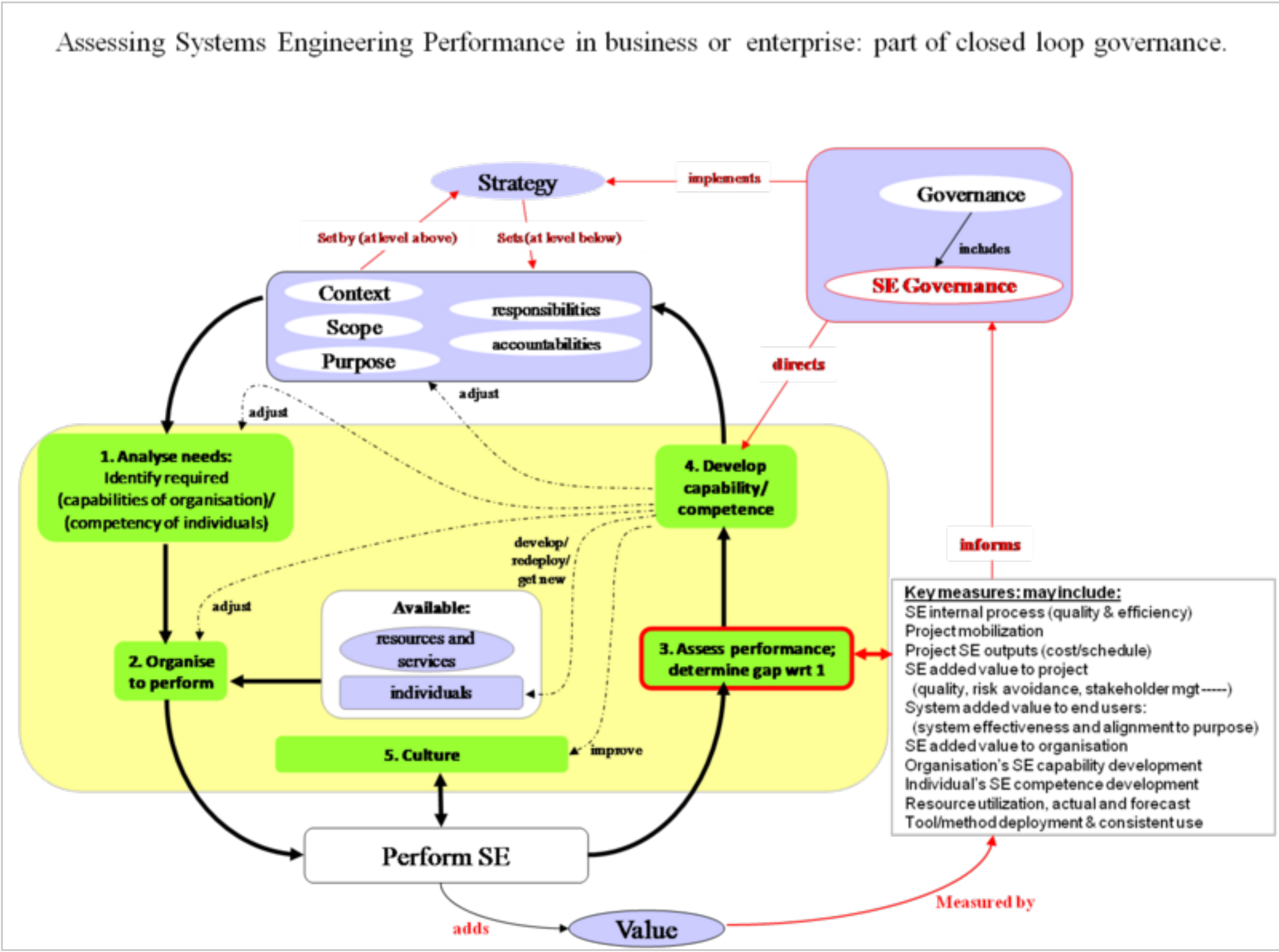

Figure 1.Assessing systems engineering performance in business or enterprise: part of closed loop governance (Figure Developed for BKCASE)

Discussion of Performance Assessment Measures

Assessing SE Internal Process (Quality and Efficiency)

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: CMMI for Development V1.3 Page 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 - 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, and capitalize acquired knowledge and redeploy team members expeditiously as the team winds down - is an organizational capability that has substantial leverage on project and organizational efficiency and effectiveness.

Specialists and experts are used to a review progress, 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. See Systems Engineering Governance.

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.

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 (SE Leading Indicators Guide 2010), contain information that allows residual defect densities to be estimated. (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. (INCOSE UK Chapter Z-3 Guide 2009).

SE Added Value to Project

SE 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 value proposition for systems engineering section.

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.

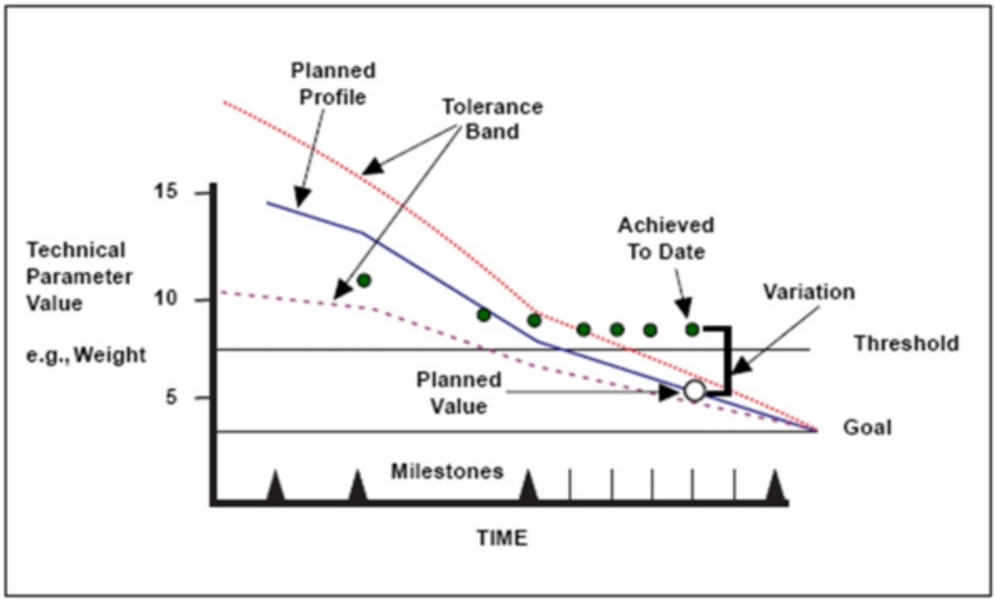

Figure 2. Technical Performance Measure (TPM) Tracking (Roedler et al. 2010 This material is reprinted with permission from the International Council on Systems Engineering (INCOSE).

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

(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

The INCOSE Systems Engineering Leading Indicators Guide (p. 58) offers 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

"To err is human - to really foul things up we need a computer!" (anonymous)

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; storage media and file formats as little as 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. The INCOSE Systems Engineering Leading Indicators Guide (p 73) recommends metrics on "facilities and equipment availability".

Practical Considerations (Pitfalls, Good Practice, etc.)

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 do not drive perverse behaviors. (INCOSE 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 excessively risk averse behaviour.

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); and 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 per se.

> *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)

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Developing Systems Engineering Capabilities within Businesses and Enterprises

The pursuit of continuous improvement is a constant for many organzations. 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, and capitalize acquired knowledge and redeploy of the 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 business/enterprise provides project teams with the necessary resource, background information, facilities, cash, support services, etc. It also provides a physical, cultural and governance environment in which the projects and teams can be effective. So the key functions of the business/enterprise include generating and maintaining relevant resources, allocating them to projects and teams, providing support and governance functions, maintaining expertise and knowledge (on process, application domain and solution technologies), securing the work in the first place, organizing finance, and maintaining the viability of the organization.

For improvements to persist, they must reside in the business/enterprise rather than just the individuals, so the improvements can endure as personnel leave. This is reflected in the CMMI (SEI 2010) progression from a "hero culture" to a "quantitatively managed and optimizing process" - though this process capability augments and does not replace individual talent.

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

Overview

Figure 1 (also presented in Enabling Businesses and Enterprises to Perform Systems Engineering) shows the "analyze - organize - perform - assess - develop" cycle used to structure this part of the SEBoK. This 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 (SEI 2010) that many organizations find a positive correlation between business performance and CMMI levels.

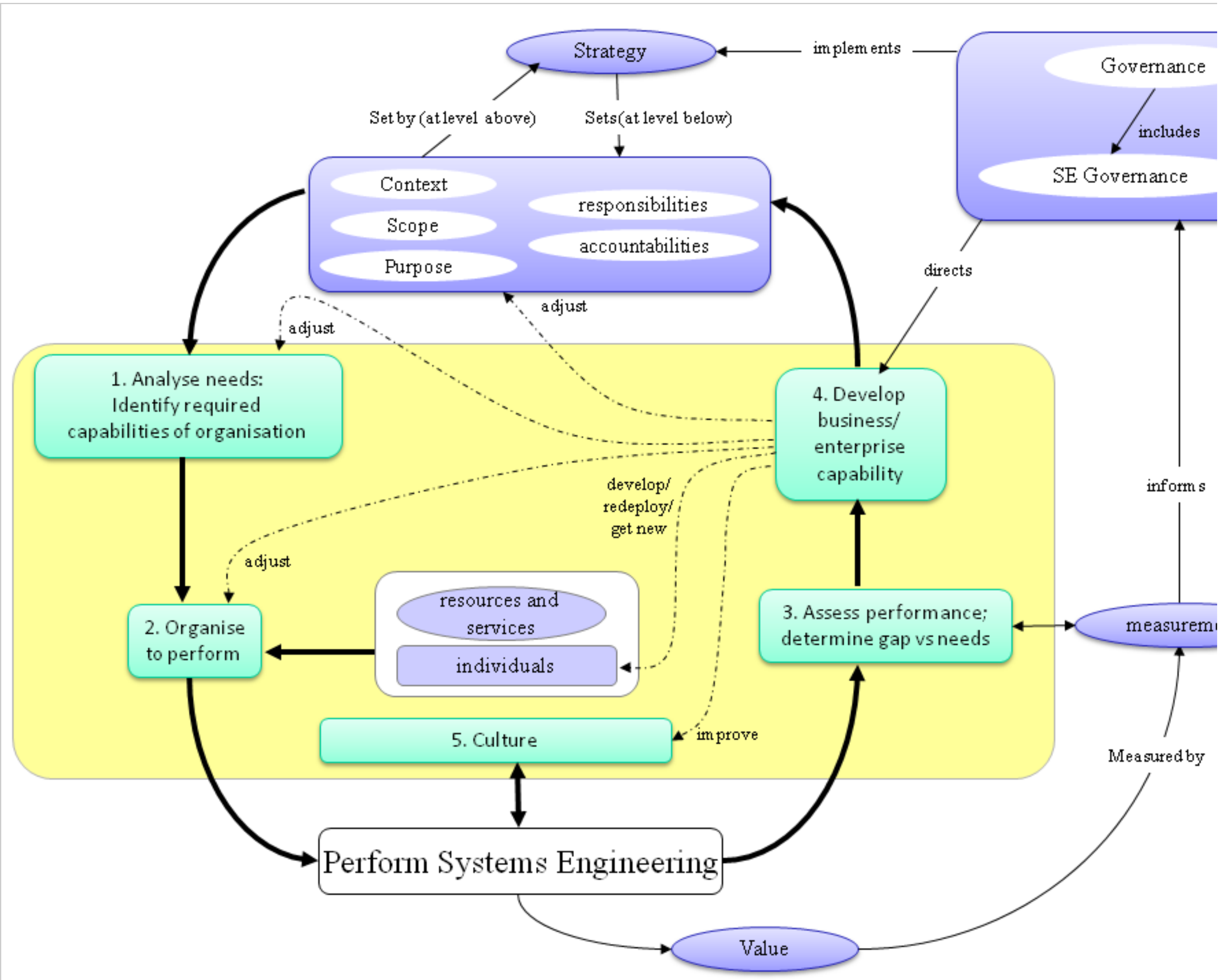

Figure 1. Concept Map for Businesses and Enterprises Topics (Figure Developed for BKCASE)

Change Levers

SE managers have a number of possible change levers they can use to develop SE capabilities. Different change levers have different time constants to take effect.

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. After each rotation of the cycle the need should be re-evaluated 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 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 jeopardize any certifications the organization has earned which demonstrate its process capability or performance.

Develop/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.

Development of individuals is discussed in Enabling Individuals to Perform Systems Engineering.

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. "What gets measured gets done." 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; that 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); e.g., 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 1998, Oppenheim et al. 2010), Six-Sigma (Harry 1997), and CMMI (SEI 2010).

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; or 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 Brian Sauser's **system readiness levels**. (Sauser 2006)

Planned Change: Standing Up or Formalizing SE in an Organization

Planned change may include: introducing SE to a business (Farncombe et al. 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 (SEI 2010) 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 but 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 and benefits.

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; by competitors - current offering becomes less/more competitive, a disruptive innovation may be launched in market; or by 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; strategy change (e.g. new CEO, respond 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): establish a sense of urgency, create a coalition, develop a clear vision, share the vision, empower people to clear obstacles, secure short term wins, consolidate and keep moving, and 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.

A Structured Survey of Improvement and Change Literature Relevant to SE in Businesses and Enterprises

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 (Table Developed for BKCASE)

Area	Primary "Business" references	Primary "SE" references
Doing every day things better	Kaizen; Lean (Womack); 6-Sigma (Harry 1997) 4 competencies of Learning Organisation – absorb, diffuse, generate, exploit (Sprenger and Ten Have 1996) Covey's 7 habits of very effective people (Covey 1989, 2004)	CMMI Forsberg & Mooz, Visualizing project management (Forsberg and Mooz 2005) INCOSE IEWG "Conops for a Systems Engineeriing Educational Community" (Ring et al. 2004) INCOSE Lean Enablers for SE (Oppenhein et al. 2010)
	Mitroff, managing crises before they happen (Mitroff and Anagnos 2005);	Scott Jackson, architecting resilient systems (Jackson 2010)

Dealing with unplanned disruption	Shell, Scenario Planning (Wack 1985; Ringland 1988)	Design principles for ultra-large-scale systems (Sillitto 2010 and 2011)
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 (described in Bungay 2002, page 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 8 phases of change (Kotter 1995), Berenschot's 7 forces (Berenschot 1991) Levers of control (Simon 1995) – tension between control, creativity, initiative and risk taking Chaos model, "complexity theory applied to change processes in organisations"; (Zuiderhoudt et al. 1999) Business Process Re-engineering (Hammer and Champy 1993) Senge's 5th discipline (Senge 1990 and 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 et al. 2009); ▪ Z-7, Systems Thinking (Godfrey et al. 2010)
Understanding peoples' motivation, behaviour	Maslow's hierarchy of needs Myers-Briggs Type Indicator; NLP (Neuro-Linguistic Programming) (See for example: Knight 1995-2009) Socio-technical organisation (Taylor and Felten 1993) Core quadrants, (Offman 1992 and 2001)	INCOSE Intelligent Enterprise Working Group – "enthusiasm", stretch goals (Ring et al. 2004) Sommerville, Socio Technical Systems Engineering, Responsibility Mapping (Sommerville et al. 2009)
Understanding culture	Hofstede, Cultural Dimensions, (Hofstede 1966 - -) Etzioni, Compliance Typology (Etzione 1965)	
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

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Culture

A critical issue in effective organizational deployment of systems engineering is establishing and managing cultures (glossary), values and behaviors. (Fasser & Brettner 2002) A high degree of churn or imposed change can disrupt established cultures that are key to effective systems engineering. A safety or process culture can be damaged by too high a pace of change (see the *Nimrod Crash Report*, Haddon-Cave 2009) or by perceived management imperatives (e.g. Challenger, discussed below). A highly competitive, adversarial or "blame" culture can impede free flow of information and synergistic working. These factors particularly affect the multi-national, multi-business, multi-discipline collaborative projects that are increasingly prevalent in systems engineering. Effective handling of cultural issues is a major factor in the success, or otherwise, of systems engineering endeavours.

Cultural Perspective

The focus of this topic is *Culture (glossary)* within systems engineering. As defined in the Columbia Accident Investigation Report (NASA 2003, p.101), culture is "the basic values, norms, beliefs, and practices that characterize the functioning of a particular institution."

Cultural change to improve systems engineering efficiency and effectiveness is possible through a systems approach as described in Part 2 and by (Lawson 2010) and by learning to think and act in terms of systems, organizations and their enterprises.

A general culture-related perspective is characterized by (Senge et al. 1994), who identify systems thinking as being the "fifth discipline" that promotes a learning organization culture. The four disciplines that are supported by systems thinking are as follows:

- *Personal mastery* such that a person continually clarifies and deepens personal vision, focuses energy upon it, develops patience in seeking it and in this way apparently increasingly views reality in an objective manner.
- *Mental models* aims to train people to appreciate that mental models do indeed occupy their minds and shape their action.
- *Shared vision* refers to shared operating values, a common sense of purpose, and a basic level of mutuality.
- *Team learning* to achieve alignment of people's thoughts so that a common direction creates a feeling that the whole team achieves more than the sum of its team members.

Paradigms

Many authorities, for example, (Jackson 2010), have found that cultural shortfalls can be summarized in a set of negative Paradigms (glossary) that are injurious to a system. Although there are many paradigms, the following two are typical:

- *The Risk Denial Paradigm* - This paradigm holds that many people are reluctant to identify true Risks (glossary). This paradigm is apparent in the Challenger and Columbia described above.
- *The Titanic Effect* - This paradigm holds that the individual believes the system is safe even when it is not. The name of this paradigm comes, of course, from the famous ocean liner catastrophe of 1912.

Approaches

Jackson and Erlick (e.g., 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 an approach founded on the principles of organizational psychology, namely, the Community of Practice (Jackson 2010, 110-112). The pros and cons of various other approaches are also discussed. These include training, the charismatic executive, Socratic teaching, teams, coaching, independent reviews, cost and schedule margins, standard processes, rewards and incentives, and management selection. (Shields 2006) provides a comprehensive list of these and similar approaches.

Many official reports, such as for the Columbia Accident (NASA 2003) and the Triangle fire (NYFIC 1912), call for an improvement in leadership to address the cultural issues. However, this approach is usually accompanied by a more objective approach of auditing, such as the Independent Technical Authority. This authority has the following features:

- Independent means that the authority is separate from the program organization. It may be from another business/enterprise with an objective view of the program in question. In short, the authority cannot report to the program manager of the program in question.
- Technical means that the authority will address only technical as opposed to managerial issues.
- Authority means that that the board has the authority to take action to avoid failure including preventing launch decisions.

In addition to the specific safety related cultural issues, there are many management and leadership experts that have identified various means for leading cultural organizational change. For example, the usage of creative thinking promoted by, amongst others, (Gordon 1961) in his work on the productive use of analogical reasoning called Synectics (glossary). Another example, (Kotter 1995), identifies needed steps in transforming an organization.

Other Cultural Factors

Cultures evolve over generations in response to the community's environment (physical, social, religious). However, as the environment changes, cultural beliefs, values and customs change more slowly. There are many definitions of culture, but one cited by the Columbia

Accident Investigation Board, above, is representative. (NASA 2003)

It is now generally considered that there are three main sources of cultural influence:

- National (or ethnic) culture,
- Professional culture, and
- Organizational culture.

These sources of culture, their effects on aviation safety, and suggested implications on safety cultures in other domains such as medicine, are described in (Helmreich and Merritt 2000) and other writings by these authors.

National (or ethnic) culture

National culture is a product of factors such as heritage, history, religion, language, climate, population density, availability of resources and politics. National culture is picked up at a formative age, and, once acquired, is difficult to change. National culture affects attitudes and behavior, and has a significant effect on interactions with others, for example:

- Communication styles (direct and specific vs. indirect and non-specific),
- Leadership styles (hierarchical vs. consultative),
- Superior – inferior relationships (accepting vs. questioning decisions),
- Attitudes to rules and regulations,
- Attitudes to uncertainty, and
- Displaying emotional reactions

Professional culture

Medical doctors, airline pilots, the military, teachers and many others possess particular professional cultures that overlay their ethnic or national cultures. Professional culture is usually manifested in its members by a sense of community and by the bonds of a common identity (Helmreich and Merritt 2001). Features associated with professional culture typically include some or all of the following:

- Selectivity, competition and training in order to gain entry to the profession
- Member-specific expertise
- A shared professional jargon
- Prestige and status with badges or defining uniform
- Binding norms for behaviour and common ethical values
- Professional and gender stereotyping
- Self-regulation
- Institutional and individual resistance to change

Professional culture overlays a person's national culture. If there are conflicts between the two cultures, in particular in threat situations, the professional culture may dominate, or the earlier-acquired national culture may rise to the fore. Elements of professional culture that are of particular importance (e.g. to safety or survivability) need to be inculcated by extensive training programs, and reinforced at appropriate intervals.

Organizational culture

Organizational culture arises out of the history of an organization, including its leadership, products and services. Although there will be a common layer across the organization, significant differences will emerge in organizations with a high level of multinational integration due to differing national cultures. These will appear as differing leadership styles, manager-subordinate relationships, etc. Organizations have a formal hierarchy of responsibility and authority; therefore organizational culture is more amenable to carefully-planned change than are either professional or national cultures. Organizational culture channels the effects of the other two cultures into standard working practices; therefore changes to it that are sympathetic to national culture (rather than a culture in the distant group head office) can bring significant performance benefits.

Organizational culture is also unique; what works in one organization is unlikely to work in another. Some of the factors thought to influence or engender organizational culture include:

- Strong corporate identity,
- Effective leadership,
- High morale and trust,
- Cohesive team working and cooperation,
- Job security,
- Development & training,
- Confidence, e.g. in quality and safety practices, management communication and feedback, and

- High degree of empowerment.

Culture and Safety

Reason (1997, 191-220) identifies four components of a culture with a focus on safety:

- A reporting culture encourages individuals to report errors and near misses including their own errors and near misses.
- A just culture is "an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety related information." (Reason 1997)
- A flexible culture abandons the traditional hierarchical reporting structure in favor of more direct means of team-to-team communications.
- A learning culture is the willingness to draw the right conclusions from information and to implement reforms when necessary.

In addition, the Nuclear Regulatory Agency (2011) has issued its final report on safety culture. This report focuses mainly on leadership and individual authority.

Historical Safety Related Cases

Culture has been cited as a key factor in the success or failure of many systems. In all of the following cases, culture was cited in official reports or by authoritative experts as a factor in the success or failure of the systems involved.

Table 1. Examples of Culture Discussion in Safety Critical Incidents. (Figure Developed for BKCASE)

Example	Cultural Discussion
Apollo	According to Feynman (1988), Apollo was a successful program because it was a culture of "common interest." Then over the next 20 years there was "loss of common interest." This loss is the "cause of the deterioration in cooperation, which . . . produced a calamity."
Challenger	Vaughn (1997) captured what she called "normalization of deviance." She states that rather than taking risks seriously, NASA simply ignored them by calling them normal. She summarizes this idea by saying 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 broke out in the borough of Manhattan in New York City in which 145 people died mostly women. (NYFIC 1912) The New York State Commission castigated the property owners for their lack of understanding of the "human factors" in the case. The report called for the establishment of standards to address this deficiency.
Nimrod	On 2 September 2006 a Nimrod British military aircraft caught fire and crashed killing its entire crew of 14. The Haddon-Cave report (Haddon-Cave 2009) focused on the cultural aspect. This report specifically references the Columbia Accident Investigation Report and the conclusions in it. A system of detailed audits is recommended.

Implications for Systems Engineering

As systems engineering increasingly seeks to work across national, ethnic, and organizational boundaries, systems engineers need to be aware of cultural issues and how these affect expectations and behavior in collaborative working environments. Different cultures and personal styles make best use of information presented in different ways and in different orders (levels of abstraction, big picture first or detail, principles first or practical examples). Sensitivity to cultural issues will make a difference to the success of systems engineering endeavors; e.g., (Siemeniuch and Sinclair 2006).

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Enabling Teams to Perform Systems Engineering

Engineering activities are sometimes accomplished by individuals but are more often accomplished by teams (glossary) that perform systems engineering (glossary) (SE), develop or otherwise obtain components, develop the system, and provide specialty engineering capabilities.

One of the primary roles of those who perform SE is often to ensure that all elements of a project contribute to an optimal solution within the technical and managerial constraints imposed on the project. Not all who perform SE are labeled "systems engineer." Thus, electrical, mechanical, and software engineers, as well as enterprise architects in IT organizations and service providers may lead or be members of teams that perform SE tasks. Those individuals are referred to as systems engineers in this article, regardless of their job titles within their organizations.

Systems engineers contribute to development and sustainment of products, enterprise systems, and the delivery of services. Systems engineers also coordinate the technical aspects of multiple projects that comprise a program. These activities require teams of individuals who share a common vision and work in a cooperative manner to achieve shared objectives. Not all groups of individuals who work together perform as teams; thus, teams must be enabled to perform SE in an efficient and effective manner.

Topics

The topics contained within this knowledge area include:

- Determining Needed Systems Engineering Capabilities in Teams
- Organizing Teams to Perform Systems Engineering
- Assessing Systems Engineering Performance of Teams
- Developing Systems Engineering Capabilities within Teams
- Team Dynamics

References

Works Cited

None.

Primary References

No primary references have been identified for version 0.75. Please provide any recommendations on primary references in your review.

Additional References

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Determining Needed Systems Engineering Capabilities in Teams

The capability (glossary) to perform Systems Engineering (glossary) includes factors such as having competent personnel, adequate time, sufficient resources and equipment, and appropriate policies and procedures. Team capability requires both competency and capacity to perform the team's collective job functions. Team competency requires the collective aptitudes, intelligence, and skills among team members be used to perform their assigned duties. Capacity requires sufficient numbers of team members and sufficient time within their schedules to perform their duties. A team's capability to perform SE is also dependent on morale and attitudes, at both the individual and team level.

Overview

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 factors 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

Determining needed team competencies

This article describes ways in which the SE competencies needed by a team to perform its SE duties can be determined for projects and programs that are conducted to develop a new product, a new enterprise endeavor, or a new service; or to develop a significant enhancement to an existing product, enterprise endeavor, or service. The competencies needed and the competencies that are available influence the ways in which a SE team (glossary), project (glossary), or program (glossary) is organized and enabled.

Individual competencies

As noted in Enabling Individuals to Perform Systems Engineering, 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 systems engineering 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, V&V). The article on Roles and Competencies includes a summary of systems engineering 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 team. It is not often that a single individual will fulfill the full list of competencies given in these models.

Collective competencies

In addition to individual competencies to perform systems engineering roles, the collective competencies needed by a systems engineering team for a product, enterprise, or service 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 SE team. For example, SE competencies needed to develop an IT enterprise architecture are quite different from those needed to support a mission-critical product at multiple sites. In the former case, the SE team might be organized to play the leadership role in working with senior managers, business process analysts, and other stakeholders at the organizational level, with participation of solution implementers (who may be internal or external to the organization), solution maintainers, and one or more vendors. In the latter case (supporting a mission-critical product at multiple sites), the SE team may consist of a centrally located lead systems engineer with a team of SE members, each deployed to one of the geographically dispersed sites.

One way to determine the collective set of competencies needed by a SE team to conduct a project or program is:

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; see Organizing Teams to Perform Systems Engineering.

As indicated, the set of competencies needed to accomplish SE for a product, enterprise, or service are established by first determining the scope of effort, the responsibilities and authority of the SE team and the roles to be played by systems engineers. Competency models and skills inventories, such as (INCOSE 2010), can be used as a checklist to assist in determining the needed competencies and competency levels for a product, enterprise, or service; see Roles and Competencies.

Accommodating team constraints

Having determined the needed competencies, competency levels, and capacities, one of two situations will arise: in the optimal case, the number of systems engineers who have the needed competencies and competency levels to fill the identified roles will be available and can be mapped into one of the organizational models presented in Organizing Teams to Perform Systems Engineering.

However, it is sometimes the case that some of the needed competencies, in sufficient quantities, are either 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. Some 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.

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Organizing Teams to Perform Systems Engineering

This topic addresses the ways in which teams are organized to facilitate Systems Engineering (glossary) (SE), considerations that influence the internal organization of teams that perform SE, and inhibitors to effective organization of teams. The internal structure of a team that perform SE, and the structure of a project or program that incorporates a SE team are influenced by the roles, responsibilities and authority of the team in relationship to managers, customers, component specialists, affiliated projects, subcontractors, and vendors; and those considerations, in turn, influence the ways in which stakeholders organize their relationships to software engineering teams. In this article, those who perform systems engineering tasks are referred to as systems engineers regardless of their titles within specific organizations.

Introduction

Systems engineers and SE teams may play the roles of technical leads, consultants, or advisors; 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. For additional information on organizational options see Deciding on Desired Systems Engineering Capabilities within 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 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.

Staffing relationships

At the project level, a 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. For additional information see Systems Engineering and Project Management.

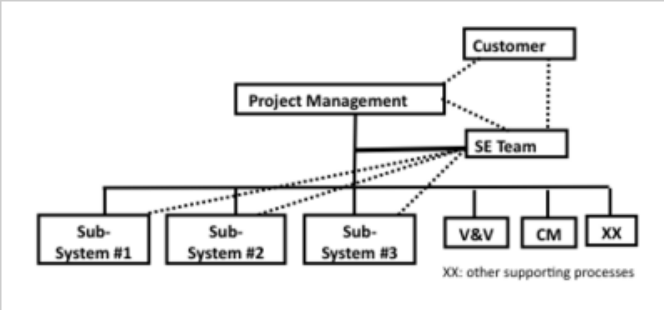

Figure 1. SE Team Subordinate to Project Management(Figure Developed for BKCASE)

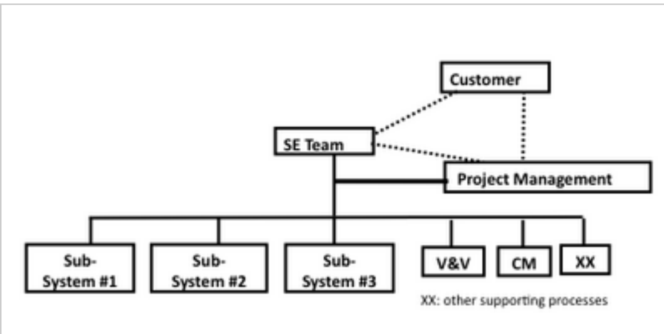

Figure 2. Project Management Subordinate to Systems Engineering (Figure Developed for BKCASE)

Scaling up and scaling down

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, 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.

Influence of the organizational strategy

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 unit. In Product Centered Organizations, for example, an Integrated Product Team 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 systems engineering and integration team (SEIT). The purpose of the Systems Engineering and Integration Team (SEIT) 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); they are created at various levels of the SBS as needed.

Additional information on organizational structures, including the roles played in IPTs is in Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises.

Communication and coordination

Organizing communication and coordination among a group of systems engineers should follow the 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).

Organizational Considerations

Organizing for sustainment services

Systems engineers may also provide a variety of sustainment services, including chairing and coordinating one or more change control boards, ensuring that upgrades are made, supporting users and other stakeholders, and coordinating system functionality and interfaces with affiliated projects and programs.

One consideration for sustainment efforts is the distinction between low-level, on-going sustainment activities and projects that are formed to develop a significant upgrade or enhancement to a product, enterprise endeavor, or service facility. Some organizations use guidelines to determine the level of a sustainment effort that should be designated as a project that has allocated requirements, schedule, budget, and resources. A guideline might state, for example, that a sustainment effort requiring more than one person-month of effort (one person, one month; two people, two weeks) should be planned, organized, and conducted as an enhancement project.

Organizing teams to perform enterprise systems engineering

In the commercial sector, enterprises exist to provide products and services to society, to provide jobs, and to create wealth. Non-profit and governmental enterprises exist to preserve and enhance the general welfare of society. Commercial, non-profit, and governmental enterprises may be local, national, or international in scope.

Responsibilities of systems engineers within enterprises vary widely. In some instances, systems engineers may have primary responsibility for planning, coordinating, and overseeing all aspects of workflow and information management for the enterprise. In other cases, systems engineers may participate as members of a business process-engineering group that includes senior executives, financial analysts, and human resource and information technology specialists.

Systems engineers and engineering teams may be specialized by domain. For example, within the domain of information technology, a systems engineering team might be responsible for all aspects of information flow for a global enterprise. Work activities might include specifying and designing an enterprise-wide network for information flow that includes both technological and manual processes, with special attention to issues of privacy and security; developing an enterprise-level information architecture; and working with solution developers to ensure that processes, infrastructure, and applications satisfy the constraints imposed by the enterprise architecture. In the health care domain, a systems engineering team might work with a health care provider to plan, coordinate, and enhance the overall technical, social, legal, and human aspects of health care delivery to patients.

Considerations for organizing teams to perform enterprise systems engineering do not differ in significant ways from the considerations presented above.

Organizing teams to perform systems engineering of services

Service organizations take many forms including those that provide a service to a specific population, such as the United Service Organizations (USO) that provides morale and recreational services to members of the U.S. armed forces; fraternal organizations, both religious and secular, that provide opportunities for those who share common interests to affiliate; and service organizations that provide services such as repair and maintenance of other organizations' computers or that provide billing services for small medical offices. Other forms of service organizations, in addition to independent service organizations, are those that provide of services internal to a larger organization; for example food services or IT services.

For independent organizations, SE of services is typically concerned with analysis and design of all aspects of service delivery, including the mission and vision of the organization, the clients and other stakeholders, staffing requirements, physical facilities, information processing hardware and software, training of service providers; and coordination of services with other organizations or enterprises.

The roles of SE for services within an organization are typically determined by the various organizational entities. IT service delivery,for example, is concerned with all aspects of maintaining the IT infrastructure and providing methods, tools, and techniques to support IT users who include all personnel from senior executives to IT technicians to help desk and help phone personnel; or, SE may be usefully applied to the emergency room operations of a hospital; those involved may not think of their job as SE even though they perform (or should perform) many SE tasks.

Organizing for SE of services can take any of the forms described above, depending on the nature of the service, ranging from an in-house SE group to and independent SE company that is hired to analyze and provide recommendations to a service facility. Considerations for organizing teams to perform SE for services do not differ in significant ways from the considerations presented above.

Inhibitors

There are many possible inhibitors to organizing teams to perform systems engineering activities in an efficient and effective manner. They include (DeMarco and Lister 1999):

- Inadequate skills and experience levels
- Incorrect skill mixes
- Inadequate numbers of personnel
- Unclear responsibilities
- Poor communication channels
- Geographic separation of team members
- Inappropriate process models

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Assessing Systems Engineering Performance of Teams

Part of Enabling Teams to Perform Systems Engineering is assessing the performance of Teams (glossary) in order to improve performance. Systems Engineering (glossary) is most often performed by teams of individuals, and it is a team is usually required to perform the full list of needed SE roles. In order to understand performance of the systems engineering workforce, it is important to understand the systems engineering performance of teams. The performance of a team is not just an aggregation of the performance of the individuals, since social dynamics such as Team Dynamics and power relationships play a role.

Competency, Capability, Capacity, and Performance

The performance of a SE team is a function of competency, capability, and capacity. SE competency, capability, and capacity are complex topics. The human aspect of competency may be considered a subset of capability, which includes not just human capital, but processes, machines, tools, and equipment as well. Even if an individual has an outstanding level of competency, being able to perform within a limited timeframe might stunt the results. Capacity accounts for this. Since performance incorporates the other enabling concepts, team performance is a more useful focus for assessment than competency or capability. In the end, it is the actual performance of the team that matters.

Methods to Assess Team Performance

Performance evaluation is most often conducted for individuals. (Robbins 1998, 576) states that the historic belief is that individuals are the core building blocks around which organizations are built. However, when developing Engineered Systems (glossary), business (glossary) and enterprise (glossary) normally structure themselves around teams. Robbins offers four suggestions for designing a system that supports and improves the performance of teams:

1. Tie the 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
4. Train the team to create its own measures.

For SE in particular, it is a team of individuals who perform the full range of SE tasks. See the section on Systems Engineering Roles and Competencies for more information on SE tasks. To understand how well the SE tasks are being accomplished, it is the team performance which must be assessed. Elaborating on the applicability of Robbins' four steps as they apply to SE:

First, the team's results should be tied to the organization's goals. Find 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 team should not be only the SE products themselves. For more information on general SE assessment, see Systems Engineering Assessment and Control.

Second, consider the team's customers and more broadly their key stakeholder (glossary) and the work process that the team follows to satisfy customer needs. Customers and stakeholders can be internal or external. The final product received by the customers from the team can be evaluated in terms of the customer's needs and requirements. Transactions can be evaluated for on-time delivery and quality. The process steps can be evaluated for waste and cycle time; i.e., efficiency and effectiveness.

Third, assess both individual and team performance. Define the roles of each team member in terms of the tasks that must be accomplished to support the team's work product. For more information on individual assessment, see Assessing Individuals.

Finally, having the team define its own measures helps all members of the team to understand their roles, while also building team cohesion.

Example

As an example, NASA's Academy of Program/Project and Engineering Leadership (APPEL) provides a service where team performance is assessed, then 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

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Developing Systems Engineering Capabilities within Teams

Continuous development and improvement of Systems Engineering (glossary) capabilities can be practiced all levels: individuals, teams (glossary), and businesses (glossary)/enterprises (glossary). The capability to perform SE includes factors such as having competent personnel, adequate time, sufficient resources and equipment, and appropriate policies and procedures. Team Capability (glossary) to perform SE is also dependent on morale and attitudes, at both the individual and team levels. This article addresses developing and improving team capability to perform SE and identifies those who perform SE activities as systems engineers regardless of their official organizational title. Developing and improving SE capabilities of individuals is covered in Enabling Individuals to Perform Systems Engineering, and at the business/enterprise level in Enabling Businesses and Enterprises to Perform Systems Engineering.

Introduction

Ideally, a team that performs SE tasks is a group of individuals who cooperatively perform those tasks based on a shared vision and a common set of engineering objectives. Not all groups that work together are effective teams. DeMarco and Lister discuss "teamicide" by which management, perhaps unintentionally, practices "sure fire techniques to kill teams." (DeMarco and Lister 1999). 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, studying and participating in post-mortem analyses, and preparation and examination of lessons learned.

Building Cohesive Systems Engineering Teams

Members of a cohesive SE 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 are (Fairley 2009, 411):

- Clear understanding of roles and responsibilities
- Shared ownership of work products
- Willingness to help one another
- Good communication channels
- Enjoyment of working together

Negations of these indicators are key indicators of a dysfunctional team:

- Confusion of roles and responsibilities
- Protective ownership of work products
- Unwillingness to help one another
- Absence of good communications
- Dislike of other team members

Techniques for building and maintaining cohesive SE teams include:

- An appropriate number of team members
- A correct mix of competencies
- Celebration of project milestones
- Team participation in off-site events
- Social events that include family members

Each of these techniques is discussed below.

Appropriate number of team members

Having too few team members will result in too many tasks for each member. Overtime is the typical way in which having too many tasks to perform is handled. Excessive overtime leads to fatigue and loss of morale which then results in poor performance. The stress created by excessive overtime also limits the time available for learning new skills and decreases receptivity for new approaches. Having too many team members can also create problems. As Fred Brooks observed, in his seminal book The Mythical Man-Month (Brooks 1995, 25):

> *Adding manpower to a late software project makes it later.*

Although Brooks admits that he is oversimplifying outrageously, this quotation became know as **Brooks Law**. His point is that having too many people on a software (or a systems) project creates increased complexity in partitioning of the work and the resulting complexity of communication and coordination. An old folk saying is "too many cooks spoil the stew." A cohesive team has the correct number of team members -- not to many and not too few.

Correct mix of competencies

A competent team has the correct mix of skills and abilities, at the necessary competency levels, to fulfill the roles that need to be played to accomplish the SE tasks. Competencies are developed and enhanced by education, training, and experience. Team members can increase the breadth of their competencies by engaging in a variety of tasks rather than becoming "stuck" in a particular job specialty. Balancing specialization with generalization is a challenging, but effective, way to develop and enhance team capabilities.

Celebration of project milestones

Celebration of project milestones need not be gala events. An extended coffee break with pastries or a Friday afternoon get-together may suffice. Important milestones to be celebrated may include successful reviews, integration and demonstration of component increments, completion of end-item verification and/or validation, and project completion. Celebrating project milestones are important rituals that can enhance team cohesion, which creates synergy and increases team performance. Other rituals may include participatory morning and afternoon coffee/tea breaks and short, weekly stand-up status meetings.

Team participation in off-site events

Off-site events may include planning and review meetings, training classes, and preparation of status reports and proposals. The purpose of being off-site is to minimize interruptions and other distractions (no cell phones or email, please) and to provide opportunities for informal socializing. In some cases, extended lunches and breaks are planned to allow time for team members to become better acquainted and to discuss common work issues. In other cases, off-site meetings allow members of different teams and cross-functional groups to interact. Some teams have reported that the most important aspect of off-site meetings is the opportunity to engage in informal interactions, rather than the officially stated purpose of the meeting.

Social events that include family members

Social events such as picnics, sporting events, and performances provide an opportunity for team members to interact in a different social setting and to thus become better acquainted, which can increase team cohesion and synergy. Not everyone wants to belong to family-oriented bowling leagues or a ball team but these kinds of social networks sometimes form spontaneously. While generally regarded as positive situations, care must be taken that exclusionary cliques do not develop within SE teams.

Dealing with asocial team members

Some members of SE teams, by virtue of their personalities and preferences, may not desire to be, or are not suited to be members of cohesive teams. In rare cases, these team members may be asocial or anti-social. It is sometimes possible that these individuals can be assigned tasks that do not require close interactions with other team members. These team members may have to reassigned to other duties that do not disrupt and destroy team cohesion.

Other Techniques

Other techniques for developing SE capabilities within teams include conducting pilot projects, preparing of post-mortem analyses, and participation in, and study of 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 pilot projects are the time required and diversion of personnel resources.

Post-mortem analysis

The purpose of a post-mortem analysis is to identify areas for improvement 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 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 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 post-mortem analysis well include using a third party facilitator, brainstorming, Strength-Weakness-Opportunity-Threat analysis, fishbone (Ishikawa) diagrams, and mind mapping.

Lessons learned

Lessons learned 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 results in improved capabilities for the remainder of the present project and for future projects. Inputs for developing and documenting 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 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.

Forming the team

Before a team that performs systems engineering tasks 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) demonstrate that a team needs time to form, for the members to get to know and understand each other as well as the task 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 allow team members to satisfy their individual goals (Fraser 2010).

The cost of this start-up period may be significant, and will tend to increase the “time to value” and reduce the return on investment for a project.

The “cost and time to value” can be minimized by good selection and management of the 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 teams, more time must be allowed for team formation. (Fraser 2010) explains that teams are more effective if attention is given to ensuring that the members' work can satisfy their individual goals as well as the team and organizational objectives.

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Team Dynamics

A Team (glossary) is a special type of group. According to Forsyth, a team is “an organized, task-focused group" (Forsyth 2010, 352) and groups are “two or more individuals who are connected by and within social relationships" (Forsyth 2010, 3).

Application of the practical considerations of group dynamics is essential to enabling teams to successfully perform SE. 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 this information is crucial to facilitate teams performing work and accomplishing their goals.

The study of group dynamics was initially within the province of psychology and later within sociology. The importance of group dynamics for successful teams has led other disciplines such as business management to study 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 as shown by the number of journals related to organizational psychology and group behavior that can be found at http://www.socialpsychology.org/journals.htm and http://www.socialpsychology.org/io.htm#journals.

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 Systems Engineering (glossary). 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) as shown in Figure 1.

Figure 1. Circumplex Model of Group Tasks (McGrath 1984, pg. 61) The source information for this image is unavailable.

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." (Forsyth 2010, 8) Interdependence can be categorized in five types (1) mutual, reciprocal; (2) unilateral; (3) reciprocal, unequal; (4) serial; and (5) multi-level as shown in Figure 2. (Forsyth 2010, 8)

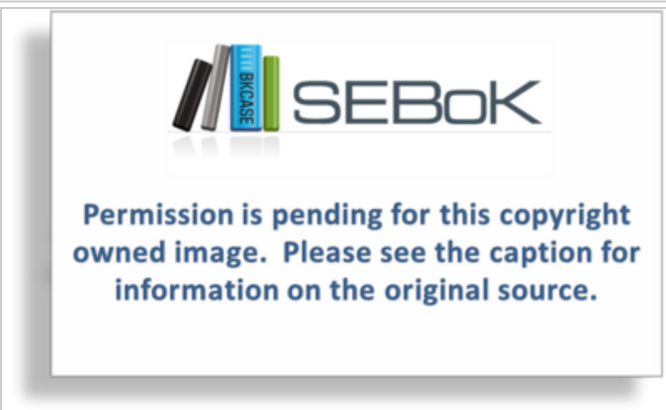

Figure 2. Interdependence Examples (Forsyth 2010, pg.8) Source is available at http://www.cengage.com/maintenance/help_welcome.html

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 & 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 as shown in Figure 3 (Forsyth 2010, 20, Modified Figure 1.5).

Figure 3. Stages of Group Development (Forsyth 2010, pg. 20) Source is available at http://www.cengage.com/maintenance/help_welcome.html

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.

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Enabling Individuals to Perform Systems Engineering

Ultimately, individuals perform systems engineering (glossary) (SE) tasks within a team (glossary) or business (glossary)/enterprise (glossary). This knowledge area addresses the the roles of individuals in the systems engineering profession, how individuals are developed for and assessed in these roles, and what ethical behavior is expected of them.

Topics

The topics contained within this knowledge area include:

- Roles and Competencies
- Assessing Individuals
- Developing Individuals
- Ethical Behavior

In the Roles and Competencies article, the allocation of SE roles and the corresponding SE Competencies (glossary) are discussed. Existing competency models are provided. The article on Assessing Individuals discusses how to determine the level of individual proficiency and quality of performance. Needed SE competencies should be developed in the individuals as discussed in Developing Individuals. Individuals are responsible for acting in an ethical manner as explored in Ethical Behavior.

Context

Individuals, Teams, Businesses, and Enterprises

The ability to perform SE resides in individuals, teams, and businesses/enterprises. Existing literature provides lists of systems engineering

Roles and Competencies. An expert systems engineer would possess many competencies at a high level of proficiency. No one would be highly proficient in all possible competencies, but the team and the business/enterprise might collectively have the capability to perform all needed competencies at a high level of proficiency. A team/business/enterprise performs the full range of SE roles, with individuals within the team/business/enterprise being responsible for performing in one or more specific roles. A business may have dedicated functions to perform specific SE roles. An enterprise may have a purposeful strategy for combining individual, team, and business abilities to execute SE on a complex project.

Competency, Capability, Capacity, and Performance

The discussion of SE competency, capability, capacity, and performance is complex. The human aspect of competency may be considered a subset of capability. Capability includes not just human capital, but processes, machines, tools, and equipment as well. Even if an individual has an outstanding level of competency, being able to perform within a limited timeframe might stunt the results. Capacity accounts for this. The final execution and performance of SE is a function of competency, capability, and capacity. This knowledge area focuses on individual competency.

Systems Engineering Competency

Competency is built from knowledge, skills, abilities, and attitudes (KSAA). Certain aspects are inherent in individuals, but are subsequently developed through education, training, and experience. Traditionally, SE competencies have been developed primarily through experience. Recently, education and training has taken on a much greater role in the development of SE competencies. SE competency must be viewed through its relationship to the systems life cycle, the SE discipline, and the domain where the engineer practices SE. Competency models for SE typically include KSAAs that are both technical and "soft" (such as leadership and communications), as well as around the domains in which the SE will be practiced. A competency model typically includes a set of applicable competencies along with a scale for assessing the level of proficiency an individual possesses in each competency of the model. Those proficiency levels are often subjective and not easily measured.

Competency Model Purposes

Individual competency models are typically used for three purposes:

- Recruitment and Selection – Competencies define categories for behavioral-event interviewing, 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.

Competency Models

No consensus on SE competencies and competency models has emerged in the community. Many of the competency models available were developed for specific contexts or for specific organizations, and these models are useful within these contexts. Large organizations that employ many systems engineers often have their own competency models tailored to their specific needs. Model users should be aware of the development method and context for the competency model they use, since some of the primary competencies for one organization might be different than some of those needed for another organization.

The list of competencies in existing models are not always intended to be fulfilled by one individual, but by groups of individuals. Team competency is not a direct summation of the competency of the individuals on the team, since team dynamics and interpersonal issues complicate the combination of individual competencies at the team level. Enabling Teams to Perform Systems Engineering and Enabling Businesses and Enterprises to Perform Systems Engineering address groupings of individuals to fulfill the elements of the SE competency models.

The Nature and Role of Systems Engineering Standards

A major role of a profession is to standardize the terminology, measurement methods, and process methods used in national and international practice of the profession. The goal is to enable professionals, educators, and organizations to communicate internationally, and to improve the effectiveness and efficiency of professional practice. Systems Engineering Standards provides a description of standards that are related to the practice of SE. As the SE profession evolves, the corresponding competencies required to support the discipline also evolve.

References

This article relies on limited sources. Reviewers are requested to identify additional sources.

Works Cited

None.

Primary References

No primary references have been identified for version 0.75. Please provide any recommendations on additional references in your review.

Additional References

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Roles and Competencies

Enabling individuals to perform systems engineering (glossary) (SE) requires understanding SE roles and competencies. Within a business (glossary) or enterprise (glossary), SE responsibilities are allocated to individuals through the definition of SE roles. For an individual, a set of competencies enables the fulfillment of the assigned SE role.

SE competency (glossary) is built from knowledge, skills, abilities, and attitudes (KSAA). These are developed through education, training, and experience. Traditionally, SE competencies have been developed primarily through experience. Recently, education and training have taken on a greater role in the development of SE competencies. SE competency must be viewed through the relationship to the system life cycle, the SE discipline, and the domain in which the engineer practices SE.

SE Competency Models

Individual competency models are typically used for one three purposes:

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

Application

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

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 competency is not a direct summation of the competency of the individuals on the organization, since organizational dynamics play an important role that can either raise or lower overall proficiency and performance. Enabling Teams to Perform Systems Engineering and Enabling Businesses and Enterprises to Perform Systems Engineering explore this.

Existing SE Competency Models

Though many organizations have proprietary SE competency models, there are several published SE competency models which can be used for reference. These include:

- The International Council on Systems Engineering (INCOSE) UK Advisory Board model (Cowper and et al. 2005; INCOSE 2010b)
- The MITRE SE Competency model (MITRE 2007, 1-12)
- The SPRDE-SE/PSE model (DAU 2010); and
- The Academy of Program/Project & Engineering Leadership (APPEL) model (Menrad and Lawson 2008).

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. SE competencies can also be inferred from standards such as ISO-15288 (ISO/IEC/IEEE 15288) and from sources such as the INCOSE *Systems Engineering Handbook* (INCOSE 2010a), the INCOSE Systems Engineering Certification Program, and CMMI criteria (SEI 2007). Table 1 lists information about several SE competency models. 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 Existing Competency Models (Figure Developed for BKCASE)

Summary of Existing Competency Models

Competency Model Individual Level	Date	Author(s)	Purpose	Development Method	Competency Model
INCOSE UK WG	2010	INCOSE	Identify the competencies required to conduct good systems engineering.	INCOSE Working Group	INCOSE (2010, January)
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)
SPRDE-SE/PSE Competency Model	2010	DAU	Assess U.S. DoD civilian acquisition workforce capabilities.	DoD and DAU internal development.	DAU (2010a), DAU (2010b)
APPEL Competency Model	2009	NASA	To improve project management and systems engineering at NASA.	NASA internal development.	APPEL (2009)
Competency Model Organizational Level	**Date**	**Author(s)**	**Purpose**	**Development Method**	**Competency Model**
CMMI for Development	2006	SEI	Process improvement maturity model for the development of products and services.	SEI Internal Development	SEI (2006)

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.

Commonality and Domain Expertise

SE competency models generally agree that systems thinking (glossary), 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.

However, a few domain- and industry-specific models have been created, such as the Aerospace Industry Competency Model (ETA 2010), published in draft form October 15, 2008 and now available online, developed by the Employment and Training Administration (ETA) in collaboration with the Aerospace Industries Association (AIA) and the National Defense Industrial Association (NDIA). This model for the aerospace industry is designed to evolve along with changing skill requirements. The ETA also provides numerous competency models for other industries through the ETA web sites (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 2006).

To provide specific examples for illustration, three SE competency model examples follow.

INCOSE SE Competency Model

The INCOSE model was developed by a working group in the UK (Cowper and 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 2010b).

Table 2. INCOSE UK Working Group Competency (UK Chapter 2010, pg. 503) This information has been published with the kind permission of INCOSE UK Ltd and remains the copyright of INCOSE UK Ltd - ©INCOSE UK LTD 2010. All rights reserved.

INCOSE UK Working Group Competency Framework

Systems Thinking:	System Concepts	
	Super System Capability Issues	
	Enterprise and Technology Environment	
Holistic 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 Integration & Verification	
	Validation	
	Transition to Operation	
Systems Engineering Management:	Concurrent Engineering	
	Enterprise Integration	
	Integration of Specialties	
	Lifecycle Process Definition	

United States DoD SE Competency Model

The model for US Department of Defense (DoD) SE acquisition professionals (SPRDE/SE-PSE) includes 29 competency areas, as shown in Table 3 (DAU 2010). Each is grouped according to a "Unit of Competence" as listed in the left-hand column. For this model, the three top-level groupings are analytical, technical management, and professional. The life cycle view used in the INCOSE model is evident in the SPRDE/SE-PSE analytical grouping, but is not cited explicitly. Technical management (TM) is the equivalent of the INCOSE SE management, but additional competencies are added, including software engineering competencies. Some general professional skills have been added to meet the needs for strong leadership required of the systems engineers and program managers who use this model.

Table 3. SPRDE/SE-PSE Competency Model (DAU 2010) Released by Defense Acquisition University (DAU)/U.S. Department of Defense (DoD)

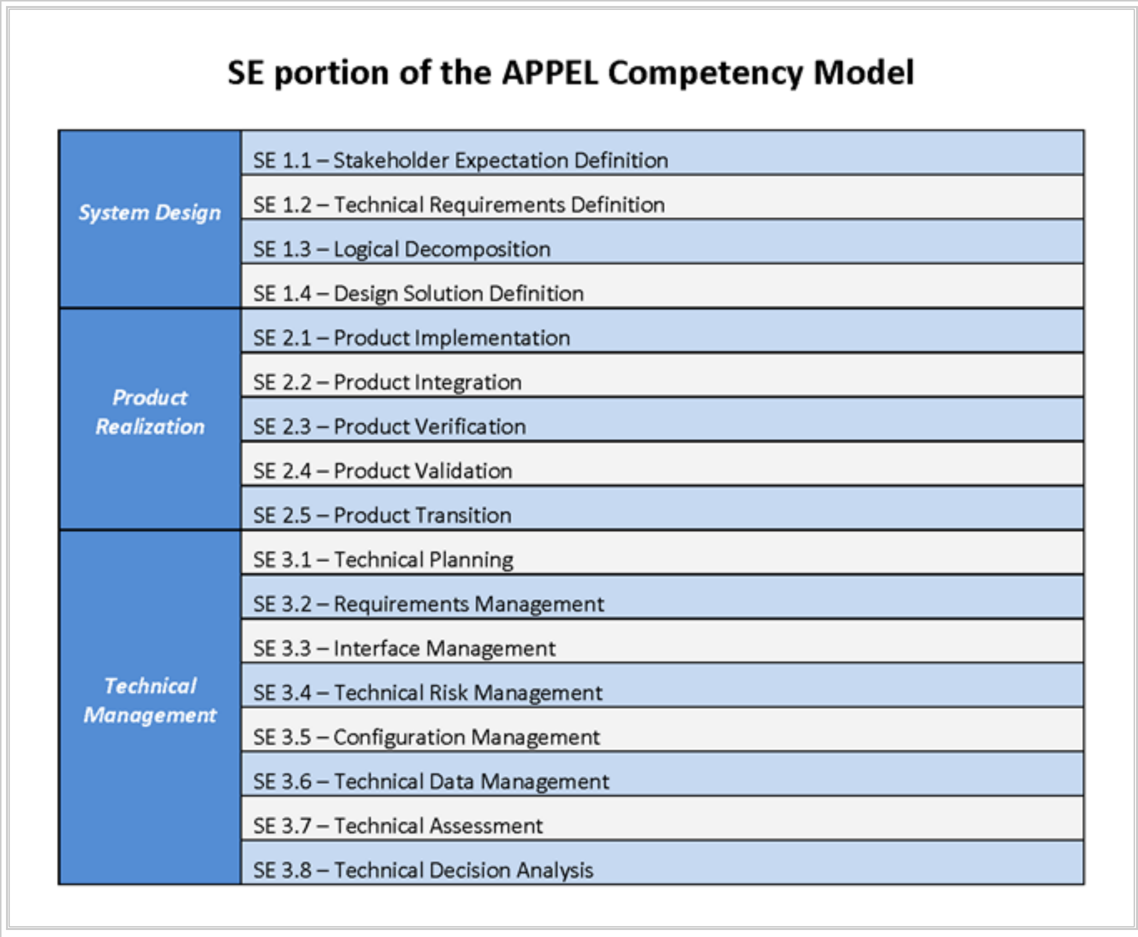
SPRDE/SE-PSE Competency Model

Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance
	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12 System Assurance
	13. Reliability, Availability, and Maintainability (RAM)
Technical Management (12)	14. Decision Analysis
	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk Management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. Systems Engineering Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

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, Larson, and Sauser 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 (NASA APPEL 2010) Released by NASA APPEL.



SE portion of the APPEL Competency Model

System Design	SE 1.1 – Stakeholder Expectation Definition
	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, 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:

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

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.

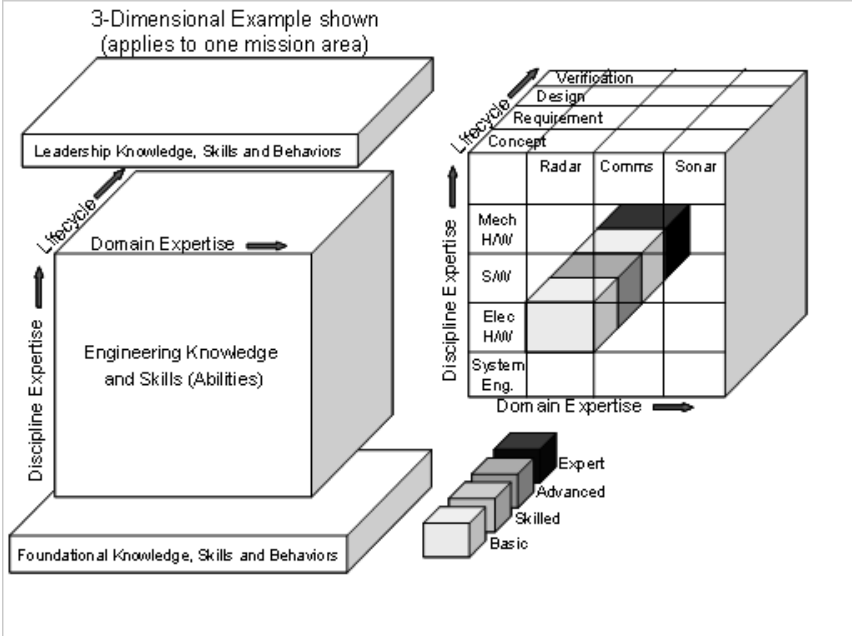


Figure 1. Layered and Multi-dimensional in the Engineering Layer (IEEE)Reprinted with permission of © Copyright IEEE – All rights reserved.

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.

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Assessing Individuals

A critical aspect of Enabling Individuals to Perform Systems Engineering is the ability to fairly assess individuals. This article describes how to assess systems engineering (glossary) (SE) competencies needed by, actual SE competencies of, and SE performance of individuals.

Assessing Competency Needs

If an organization wants to their own customized competency model, an initial decision is “make versus 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.

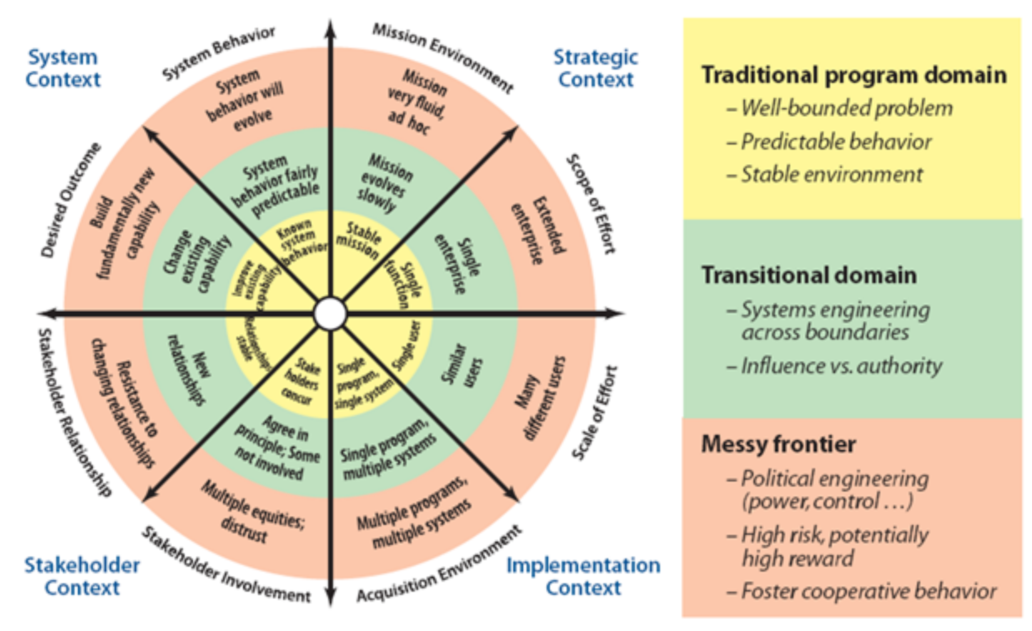

Figure 1. MITRE Enterprise Systems Engineering Framework (MITRE 2007) Reprinted with permission of © 2011. The MITRE Corporation. All Rights Reserved.

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 which specific SE roles are needed and how those roles will be allocated to teams and individuals. In order to be able to assess the performance of individuals, it is essential to explicitly state the roles and competencies required for that individual. The references from the section on SE Roles and Competencies provide guides to existing SE standards and SE competency models which can be leveraged.

Assessing Individual SE Competency

In order to enable improvement or fulfill of the required SE competencies identified by the organization, it must be possible to assess the existing level of competency for individuals. This assessment informs the interventions needed to further develop individual SE competency. Listed 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

One approach to competency assessment is the use of proficiency levels. Proficiency levels are frameworks to describe the level of skill or ability of an individual on a specific task. One popular proficiency framework is based on the "levels of cognition" in Bloom's taxonomy (Bloom 1984), presented below in order from least complex to most complex.

- **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.

Other 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.

Situational Complexity

Competency levels can also be situationally based. The levels for the U.S. Department of Defense (DoD) Systems Planning Research, Development, and Engineering (SPRDE) competency model are based on the complexity of the situation to which the person can appropriately apply the competency (DAU 2010):

- No exposure to or awareness of this competency.
- Awareness: Applies the competency in the simplest situations.
- Basic: Applies the competency in somewhat complex situations.
- Intermediate: Applies the competency in complex situations.
- Advanced: Applies the competency in considerably complex situations.
- Expert: Applies the competency in exceptionally complex situations.

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 if an individual possesses exemplary proficiency in an SE competency, the specific context in which the individual is embedded may preclude exemplary performance of that competency. For example, a highly proficient individual in risk management may be embedded in a team which does not use that talent or in an organization with flawed procedural policies which do not fully utilize this individual's proficiency. Developing individual competencies is not enough to ensure exemplary SE performance. The final execution and performance of systems engineering is a function of competency, capability, and capacity. The sections on Enabling Teams to Perform Systems Engineering and Enabling Businesses and Enterprises to Perform Systems Engineering address this context. If the SE roles are clearly defined, performance assessment can be an objective evaluation of the individual's performance. However, it is most often a team of individuals tasked with accomplishing the SE tasks on a project, and it is the team's performance which might be assessed. (See Assessing Systems Engineering Performance of Teams).

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Developing Individuals

A key aspect of Enabling Individuals to Perform Systems Engineering is to deliberately develop each individual's systems engineering (SE) competencies (glossary). This article describes strategies to close SE competency gaps.

Strategies to Close Competency Gaps

Once a list of required competencies is developed and the competencies of individual systems engineers have been assessed (please see the discussion in Assessing Individuals), the next step is to develop a way ahead for closing any gaps. The table below provides an outline of several methods that organizations use to develop SE competency and close any competency gaps (Davidz and Martin 2011).

The primary goal in all SE activities is to deliver excellent systems to fulfill customer needs. In order to do this, an organization must develop the capability to deliver systems that will fulfill customer needs, which is a secondary goal. It should be noted, however, that just because an organization has developed the capability to deliver excellent systems, it may still not consistently deliver them. Table 1, below, provides a reference for methods which may be used to close competency gaps.

Table 1. SE Competency Development Framework (Table Developed for BKCASE)

System Delivery

To enhance their ability to deliver excellent systems that fulfill customer needs, some organizations focus directly on successful system delivery with specific initiatives directed at enhancing the delivery of the end goal. Some organizations focus on the performance of the project team. One method to accomplish this is to offer coaching of the project team for performance enhancement. The U.S. National Aeronautics and Space Administration (NASA) Academy of Program/Project & Engineering Leadership (APPEL) has a performance enhancement service which assesses team performance and then offers developmental team interventions with coaching (NASA 2010).

Develop Competency

SE Competency Development Framework

Goal	Objective	Method
PRIMARY GOAL= Delivery of excellent system to fulfill customer needs	Focus on successful performance outcome	Corporate initiatives
	Focus on performance of project team	Team coaching of project team for performance enhancement
SECONDARY GOAL= Competency to deliver excellent system 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
		Standardize systems policies and procedures for consistency
		Systems engineering web portal
		Systems knowledge management repository
		On-call organizational experts
		Rotating professor who works at company 1/2-year and is at university 1/2-year
	Alter organizational design to support competency	Create organizational home and support for particular competency
	Shorten product lifecycle to build competency	Build new system every two years to maintain system competency

To develop the competency to deliver excellent systems, organizations choose multiple paths, from developing the competency of individuals to developing the capability of the organization through processes (Davidz and Maier 2007). Additionally, to ensure that competency development is indeed enhancing system delivery, adequate measures should be put in place to confirm the efficacy of the selected methods.

Individual Competency

Methods used to develop individual competency include training courses, job rotation, mentoring, hands-on experience, selecting individuals for key projects or university degree programs, customized educational programs, combination programs, and certificate programs.

Classroom training courses are traditionally used by organizations 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.

Another approach used to develop individual capability is job rotation. Here, a participant works in a series of rotational work assignments that cut across different aspects of the organization to gain broad experience in a relatively short amount of time.

Mentoring is when a more experienced individual is paired with a protégé in a developmental relationship. Many organizations utilize mentoring to varying levels of success. As with training, the impact and effectiveness of mentoring varies considerably. There must be a tenable pairing of individuals and adequate time must be spent on the mentoring.

Organizations may choose to develop systems competency in individuals by getting more hands-on experience for their engineers. 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.

Another method to develop individual competency is to select individuals who appear to have high potential and focus on their development. Hand-selection may or may not be accompanied by the other identified methods. Individual competency can also be developed through formal education, such as a university degree program. A growing number of SE degree programs are offered worldwide.

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.

An organization may choose a combination of methods to develop individual systems competency. A combination program might include education, training, job rotation, mentoring, and hands-on experience. Many companies offer these types of combination programs. Though many of these programs are not 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. Example combination programs include General Electric's Edison Engineering Development Program (GE 2010) and Lockheed Martin's Leadership Development Programs (Lockheed Martin 2010).

Individual Certification

Organizations may try to ensure individuals' systems competency through a certification program. These types of certification can be a combination of work experience, educational background, and training classes. Organizations may encourage employees to seek out certifications from local, national, or international professional bodies. In SE, an organization may encourage its employees to seek certification from the International Council on Systems Engineering (INCOSE) (INCOSE 2011) or may use this type of certification as a filter (see section on Filtering, below). In addition, many companies have developed their own internal certification measures. One example is that of the Aerospace Corporation has an Aerospace Systems Architecting and Engineering Certificate Program (ASAECP). (Aerospace 2007)

Filters

Another approach to developing individual competency is to use certain individual characteristics as a filter for selecting employees for systems roles. Before an organization utilizes a list of individual characteristics as a filter, however, it is important to (1) critically examine how the list of individual characteristics was determined and (2) critically examine how the individual characteristics identified enable the performance of a systems job. Individual characteristics should (a) enable one to perform a systems job, (b) be viewed as important to perform a systems job, or (c) be needed and necessary to perform a systems job. The idea is that a characteristic that is necessary is much stronger than one that is enabling, and before filtering for certain traits, it is important to understand if the characteristic is an enabler or a necessity. Understanding the extent to which findings are generally applicable is very important, 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 inclue:

- 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

Another approach is to ensure organizational competency through certification. An example is ISO certification (ISO 2010). Before this approach is used, it is important to verify that the capabilities required by the certification are indeed the systems capabilities sought by the organization (please see Deciding on Desired Systems Engineering Capabilities within Businesses and Enterprises for additional information on determining appropriate organizational capabilities).

Shorten Product Life Cycle

An organization may also choose to reposition its product life cycle philosophy to maintain system competency. Since the systems competencies of individuals are primarily developed through experiential learning, providing experiential learning opportunities is critical. An example is the NASA APPEL program (APPEL 2009).

Maintenance of Competency Plans

Once an organization has developed an SE competency plan, maintenance should be considered. Since global contexts change, business strategies change, and the SEBoK develops, the organization should define how and how often the competency plan will be re-examined and updated. The process for assessing competencies and taking actions to improve them must be part of the normal operations of the organization and should occur periodically.

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Additional References

No additional references have been identified for version 0.75. Please provide any recommendations on additional references in your review.

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Ethical Behavior

A systems engineer's knowledge and skills provide necessary competency (glossary). Acting ethically, within a moral framework of right and wrong, is clearly an additional obligation of the professional systems engineer. This section outlines and discusses some of the elements of such conduct.

Common definitions of ethics (glossary) include:

1. A system of moral principles. (Dictionary.com)
2. The rules of conduct recognized in respect to a particular class of human actions or a particular group, culture, etc.: e.g. medical ethics; Christian ethics; [engineering ethics]. (Dictionary.com)
3. Moral principles, as of an individual: e.g. His ethics forbade betrayal of a confidence. (Dictionary.com)
4. The discipline dealing with what is good and bad and with moral duty and obligation. (Merriam Webster Dictionary)

The word moral (glossary), in turn, is commonly defined as (Merriam Webster Dictionary):

1. Of or relating to principles of right and wrong in behavior.
2. Conforming to a standard of right behavior.

Ethics and Morals in Engineering

The difference between ethics and morals can seem somewhat obscure, and most books on ethics start by clarifying the differences between these; e.g., (Whitbeck 2007). *Morals* are defined by personal character, the result of upbringing, family influence and other environmental influences. *Ethics* stress the application of those morals with a social system. In other words, ethics point to standards or codes of behavior expected by the group to which an individual belongs. This may be framed as professional, company, social, or even family ethics. While a person's moral code is usually considered to be unchanging, the ethics he or she practices can be more broadly-based and be dependent on one's profession or role in life.

Behaving ethically can involve tensions between what an engineer's responsibility is to his or her society, customer, employer, or even family. This tension, then, may be an important aspect of the environment within which and individual's morals affect his or her choices.

There is no shortage of discussion on ethics or ethical codes, which are promulgated by various organizations and professions. *Professions* here refer to occupations that require learning and advanced knowledge and which safeguard or promote the wellbeing of others and of society as a whole. Systems engineers (glossary) have two additional ethical responsibilities that differ from those of most other engineering professions:

1. Like other engineers, systems engineers generally apply their professional skills to the realization of customer desires. However, because systems engineering (SE) deals significantly with determining customers' desires or needs through the definition and management of requirements for the work, there is an added level of obligation to ensure that the problem or program definition phase is governed by the needs of the customer or user and that the interests of the systems engineer or his firm are not allowed to influence the nature of the problem definition. This element of integrity is not found to the same degree in other engineering fields.
2. More than is the case in most other engineering disciplines, systems engineers are typically charged with the integration and oversight of the work of others whose field of knowledge is different from the SEs. The obligation to widen one's understanding and to seek competent advice from other professionals is more acute in the SE profession.

Caroline Whitbeck's *Ethics in Engineering Practice and Research* provides a useful discussion of the numerous aspects of ethical behavior for engineering professionals. Some specific issues of concern in the engineering of modern systems are outlined in the sections below.

Data Confidentiality and Security, Surveillance, and Privacy

Issues related to privacy, confidentiality, and the security of individual information place special responsibility on the systems engineers who develop products that deal with such issues.

Contracts and Liability, Intellectual Property, Freedom of Information

Systems are typically developed in a society that has laws concerning contracts, intellectual property (copyrights, trademarks, and patents), freedom of information, and employment. Systems engineers must be aware of such laws, will be governed in their practice by the requirements and restraints of those laws, and must consider the implications of those laws in their partnerships. Typically, system requirements include legal and regulatory requirements that may not be stated in the system requirements document or provided by the customer. It is the systems engineer's responsibility to know and apply these laws and regulations, recognizing the proprietary interests of others by safeguarding trade secrets, patents, trademarks, and copyrights that belong to them. Engineers also have a responsibility to give credit for work performed or innovations made to the individual(s) who deserves that credit.

Cultural Issues

Since systems engineers develop and maintain products used by humans, 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 Enginering Method

There is clearly a need for integrating SE ethics as a natural consideration in SE approaches to meeting needs.

Codes of Ethics and Professional Conduct

The International Council on Systems Engineering (INCOSE) *Code of Ethics* (INCOSE 2006) addresses fundamental principles in ethics, such as honesty, impartiality, integrity, keeping abreast of knowledge, striving to increase competence, and supporting educational and professional organizations. From these principles, a set of fundamental duties to society and the public are drawn for systems engineers, namely to (INCOSE 2006):

- 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 granted by a whole system viewpoint and the understanding of systemic interfaces.
- Promote the understanding, implementation, and acceptance of prudent SE measures.

Rules of practice then stem from these duties. The full INCOSE *Code* is available at (INCOSE 2006). In addition, the National Society of Professional Engineers (NSPE) also has a code of ethics which is of interest as well; this URL may also be found below. (NPSE 2007)

Responsibilities to Society

All engineers who create products and services for use in society have an obligation to serve the public good. Because of the criticality and scope of many systems, systems engineers have special responsibility. Poorly designed systems or services can have calamitous effects on society. The INCOSE *Code of Ethics* notes 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)

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