A Guide to the Engineering Management Body of Knowledge

5th Edition

Editor: Hiral Shah
Associate Editor: Walter Nowocin

AMERICAN SOCIETY FOR ENGINEERING MANAGEMENT
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PREFACE

We are proud to publish the 5th edition of *A Guide to the Engineering Management Body of Knowledge* (EMBOK). Each new edition of the EMBOK guide demonstrates the growing importance of the field of Engineering Management globally and across a wide range of technical disciplines. We express our thanks to those involved in the original publication which was developed and edited by a subsidiary of the American Society of Mechanical Engineers (ASME) designated as Engineering Management Certification International (EMCI). Starting with the 3rd edition, the copyright moved to ASEM and the EMBOK continues as one of the society's most important publications.

The 5th edition was developed considering the international audience. All domains are updated to include examples or content from a global perspective. The major change is the inclusion of a new domain on Quality Management Systems replacing the domain on Marketing and Sales Management. The important concepts from the Marketing and Sales domain are moved to the domain on Management of Technology, Research, and Development. Overall, there are still 11 domains in the EMBOK Guide. The current content represents the best information available in the field of engineering management based on a role delineation study. New topics such as knowledge management and entrepreneurship have been added. In addition, the existing domains on Project Management and Systems Engineering have been revised.

The 5th edition is the foundation for the ASEM professional certification program available at two levels, Certified Associate in Engineering Management® (CAEM) and Certified Professional in Engineering Management® (CPEM). In addition, this edition serves as a guide for ASEM sanctioned training programs, curriculum development, program certification, and a framework for many such advances in the field.

The EMBOK is the result of the time and efforts of a number of volunteer subject matter experts. They are acknowledged in the various domains of this edition and we thank them for their efforts. ASEM is proud to publish this guide and we hope that it contributes to your knowledge of the field of engineering management and your professional development as a technical manager and leader.

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Introduction to Engineering Management

Domain 1 Champion
Hiral Shah, Ph.D., CEI, CPEM, PMP

Domain 1: Introduction to Engineering Management

Key Words and Concepts

Controlling	A management function of measuring performance and comparing the results with established standards to ensure that the work conforms to requirements and brings the desired outcome.
Engineering Management	An art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component.
Functional Organization	Employees are grouped within functional types and perform a specialized set of tasks and report to one boss.
Matrix Organization	A combination of functional and project-based organizational structure. The organization is grouped by both function and project. An employee may have to report to a functional manager and a project manager in this structure.
Operational Planning	Involves managers at middle and lower levels to break down the company goals into individual tasks that focus on day-to-day operations for easy implementation.
Organizing	Arranging and relating work so that it can be done efficiently by the appropriate people.
Project-Based Organization	Team members report directly to the project manager and the project manager has complete authority over projects.
Strategic Planning	Involves senior management to set the mission, vision, and long-term and short-term goals of the company.
Tactical Planning	An action plan that is focused toward activating the strategy to make it work.

1.1 Introduction

The purpose of *A Guide to the Engineering Management Body of Knowledge Guide (EMBOK Guide)* is to delineate the knowledge and skills that are applicable to the engineering management discipline. It answers the question, "What does it take to be an effective engineering manager?" The *EMBOK Guide* also provides a common vocabulary for the engineering management discipline and outlines the competency areas that should be possessed by professionals working in the field of engineering management (Shah & Nowocin, 2015).

The *EMBOK Guide* serves as a foundation for certification exams, curriculum development, and professional development programs. This guide should be viewed as a foundational reference for the discipline.

1.2 What Is Engineering Management?

The engineering management discipline bridges the gap between engineering and management. The American Society for Engineering Management defines engineering management as "an art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component."

1.2.1 Planning

Planning can be at any of the three levels: (a) strategic, (b) tactical, or (c) operational.

Strategic planning is the highest level and involves senior management to set the mission, vision, and long-term and short-term goals of the company.

Tactical planning is an action plan that is focused toward activating the strategy to make it work. Tactical plans are of a shorter timeframe and involve lower-level units within each division. It is usually a middle-level manager's responsibility to convert strategic plans into actions.

Operational planning involves managers at middle and lower levels. Managers and directors work with supervisors, team leaders, and facilitators to break down the company goals into individual tasks that focus on day-to-day operations for easy implementation.

1.2.2 Organizing

Organizing means arranging and relating work so that it can be done efficiently by the appropriate people (Galbraith, 2014). In other words, organizing is a part of managing that involves establishing an intentional structure of roles for people to fill in an enterprise.

Organizations adopt different types of structures to best accomplish the work. These organizational structures can be categorized broadly under one or more of the following types:

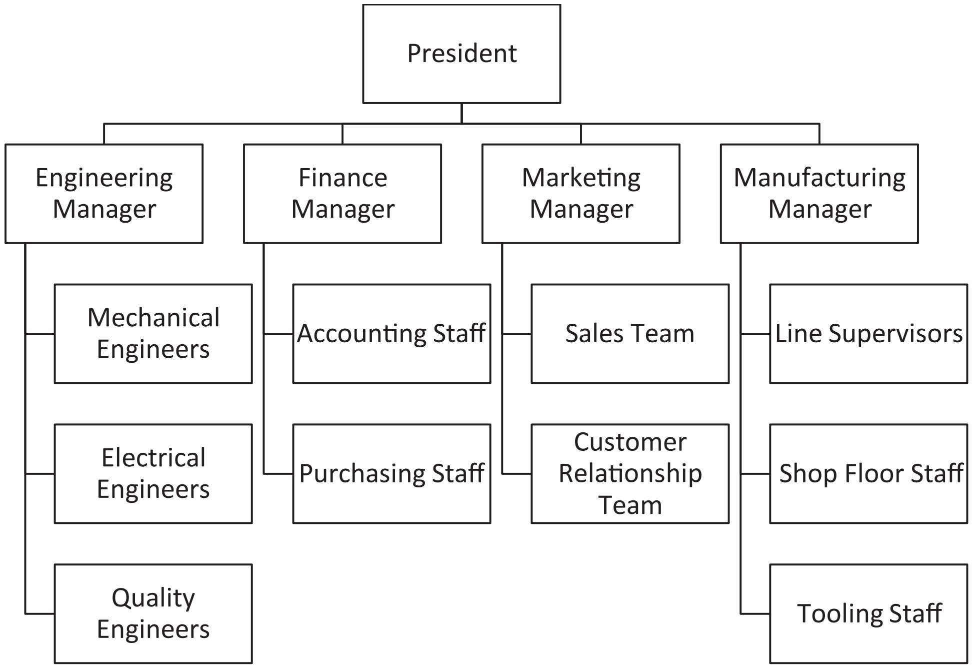
- Functional Organization
- Project-Based Organization
- Matrix Organization

1. Functional Organization

Functional organization (as illustrated in Figure 1-1) is a traditional type of hierarchical structure, wherein employees are grouped within functional types and perform a specialized set of tasks. Moreover, each employee is assigned to report to one boss. The types of companies that adopt this organizational structure include the following:

- Manufacturing operations, process industries, and other organizations with limited product diversity or high relative stability of workflow
- Start-up companies
- Companies with narrow product range, simple marketing pattern, and few production sites

Figure 1-1. Example of a Functional Organization



The advantages of a functional organization include the following:

- Clear line of communication within each functional area
- Well-defined roles in the area of specialty
- Ease of coordination within the functional division
- Enhanced efficiency

However, there are several disadvantages involved:

- Poor integration across functional areas
- Complexity in coordination among different functional areas
- Slow decision-making process
- Limitations to employee growth

2. Project-Based Organization

Project-based organization is more common in firms where projects are the dominant form of business, such as a construction firm or a consulting firm (Chang, 2016). The team members report directly to the project manager and the project manager has complete authority over projects. Figure 1-2 shows an example of a project-based organization.

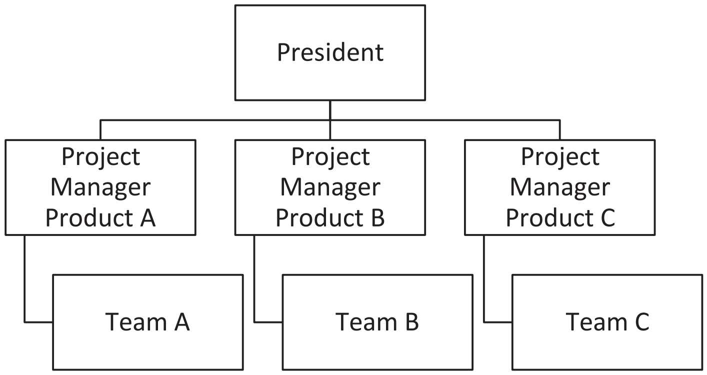
The advantages of the project-based organization include:

- Efficiency in getting projects completed
- Involvement of cross-functional teams
- Complete line of authority to the project manager
- Dedicated teams

The disadvantages include the following:

- High cost of maintaining such structure
- No home for team members once the project is complete
- Difficulty in technical interchange between projects
- Less emphasis on process, maintenance, and development of domain expertise

Figure 1-2. Example of a Project-Based Organization



3. Matrix Organization

Matrix organization is a combination of functional and project-based organizational structures. The organization is grouped by both function and project. An employee may have to report to a functional manager and a project manager in this structure. Therefore, there are two chains of command in the reporting structure. Based on the level of authority assigned to the two types of managers, a matrix organization can be further categorized as a weak matrix, balanced matrix, or strong matrix organization. Figure 1-3 shows an example of a matrix structure.

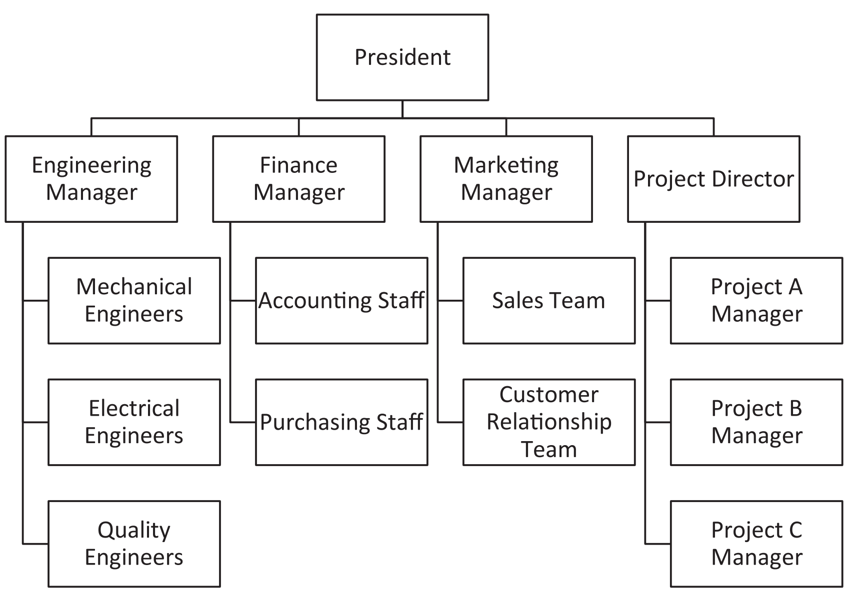
The advantages of a matrix organization structure include the following:

- Optimized use of resources
- Dynamic project team
- Project members have a home after completion of a project

The disadvantages of matrix organization structure are as follows:

- Dual reporting system
- Potential of conflict between functional and project manager in allocation of resources
- Slow decision-making process
- Team members end up doing project work on top of their normal functional duties

Figure 1-3. Example of a Matrix Organization



1.2.3 Allocating Resources

Resources can be in the form of capital, equipment, or people. One of the functions of engineering managers is to assign resources to the task, thereby assigning roles and responsibilities to the individuals they manage. However, resources should be assigned using an economical and balanced approach. The resource-leveling technique can be applied to maximize the use of resources and to balance ones that are overallocated.

Resources should be allocated to the right position and at the right time so that they meet the strategic mission and vision of the organization.

1.2.4 Directing

Directing is the management function of motivating, supervising, and influencing people to achieve the strategic goals of the organization. It is carried out by an engineering manager who is authorized by the organizational policies to make a decision (Larson & Gray, 2014). Depending on the organizational structure, the engineering manager may have varying authority and power in making decisions. It is the role of an engineering manager to ensure that engineering decisions are made in a timely manner. Thus, an engineering manager is involved in both managing and leading people.

Although the term leadership and management are used interchangeably, there are differences between them. Figure 1-4 shows differences between the characteristics of a leader and a manager.

Figure 1-4. Leader vs. Manager

1. Leader	2. Manager
Has a vision	Buys the vision
Provides direction	Follows direction
Innovates	Administers innovation
Looks outside the organization	Looks inside the organization
Sets the work	Gets the work done
Brings change	Solves complex problems
Sets standards	Effectively uses resources

1.2.5 Controlling

Controlling is a management function of measuring performance and comparing the results with established standards to ensure that the work conforms to requirements and brings the desired outcome. The control process is carried out in the following manner:

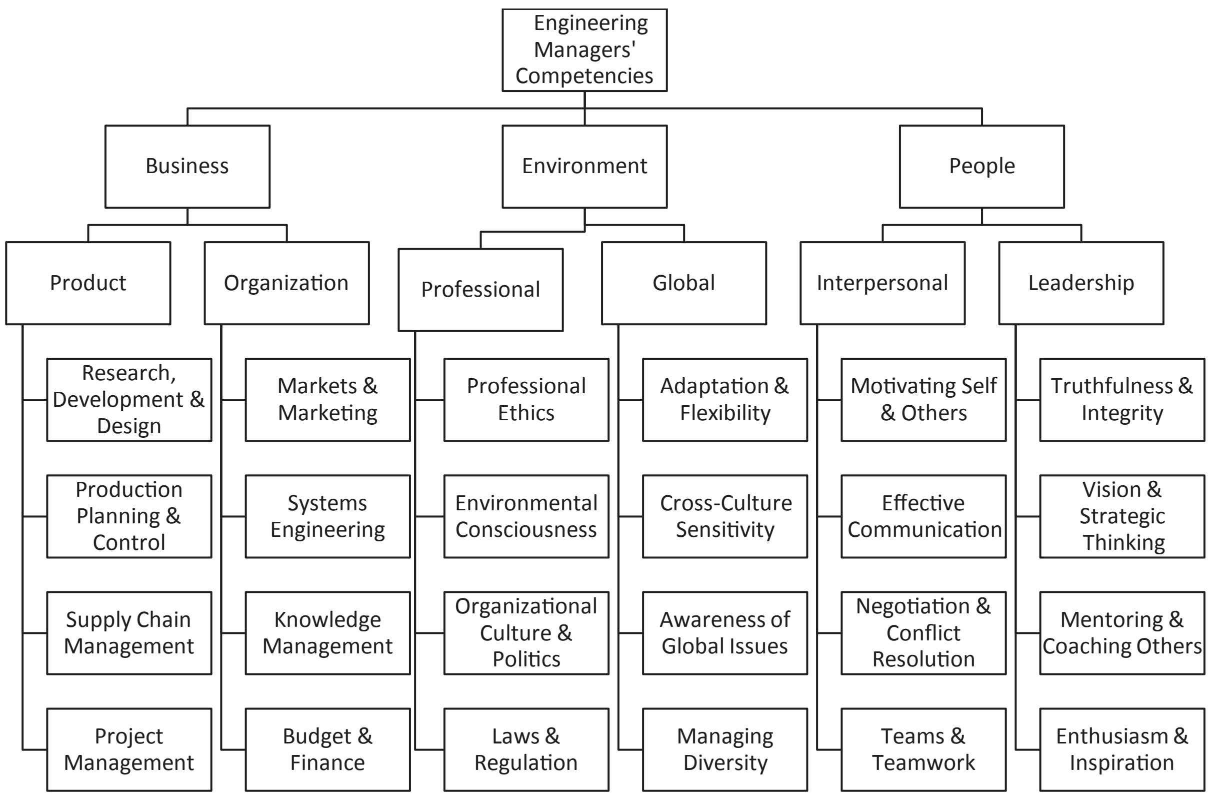
- Setting a baseline standard
- Measuring progress and performance
- Comparing the baseline standard against actual performance
- Taking appropriate corrective action

A baseline standard sets a guideline for an expected performance level. Standards are typically established in the form a number (how many), quality (how good), acceptance level (how well), and time (how soon), as imposed by the company management, customers, or marketplace (Cleland & Kocaoglu, 1981). One of the methods to establish standards is benchmarking. The performance can then be measured using time study, rating scale, control charts, financial, non-financial criteria, or other related performance metrics. Thus, a comparison can be made to evaluate any variation from the baseline standard. Engineering managers can use the performance data to take appropriate corrective action.

1.3 Engineering Management Skills

Engineers come to a decision point, usually between three and seven years after graduating with an engineering degree, to choose between a technical specialty and technical management (Chang, 2016). Further, engineering managers may not exclusively originate within an engineering, science, or business background. Some engineering managers may have moved into an engineering management role from a business management background. Regardless of the background of any given engineering manager, managing in a technological environment involves both technical (hard) and non-technical (soft) skills. Figure 1-5 shows a hierarchical structure of the engineering managers' competency model (El-Baz & El-Sayegh, 2010). This model was derived based on a review of literature related to the EMBOK.

Figure 1-5. Hierarchical Structure of the Engineering Managers' Competency Model (From El-Baz & El-Sayegh, 2010)



1.4 Role of Practicing Engineering Managers

Engineering managers are involved in a variety of technical, managerial, and leadership roles in an organization. They carry out the management functions of planning, organizing, allocating resources, and directing and controlling activities that have a technological component. An engineering manager is suitable for this managerial role because of the technical expertise gained from working in a technological environment.

An engineering manager's role mainly consists of the following:

1. Planning, organizing, and managing the work that is consistent with the organization's goals.
2. Being proactive in preventing problems from occurring and solving them if they occur.
3. Directing engineering activities and demonstrating innovative capabilities.
4. Creating policies and procedures to help employees focus on their goals. Then reviewing and appraising employee performance.
5. Developing technical strategies that align with the organization's mission and vision.
6. Transforming the agreed strategies of the company into tactical action plans.

7. Managing resources and processes efficiently.
8. Focusing on meeting the needs of the customer and providing a quality product or service.
9. Delegating tasks, overseeing engineers and other technical people, and providing technical expertise.
10. Reporting to senior management about the progress of operations and projects.

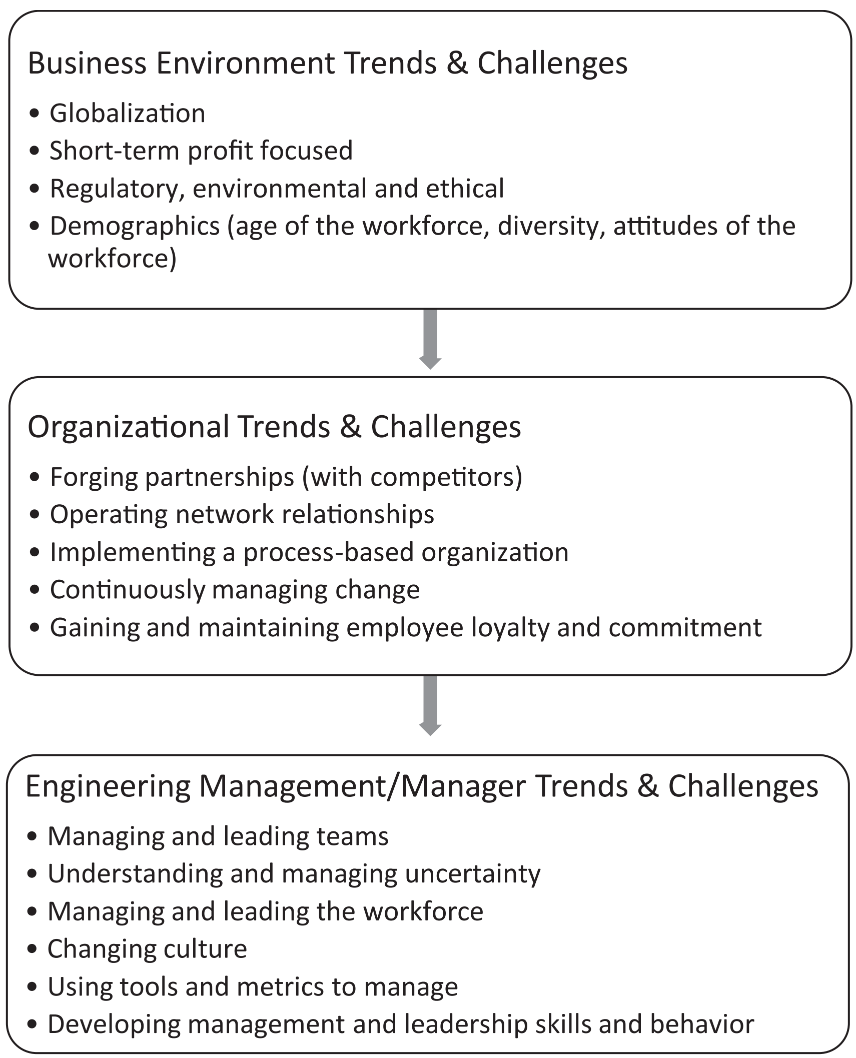
1.5 Future Challenges

Managing technological organizations is becoming challenging in the 21st century. Both internal and external factors make it difficult to manage complex operations. The external factors are related to situations outside of the organization, whereas the internal factors are linked within the organization. Challenges for the technical organization and engineering manager can be categorized into three groups (Farr, Gandhi, & Merino, 2016):

1. Business environment trends and challenges
2. Organizational trends and challenges
3. Engineering management/manager trends and challenges

Figure 1-6 explains the components of these broadly defined challenges.

Figure 1-6. Challenges for the Technical Organization and Engineering Manager. From Farr, Gandhi, & Merino, 2016.



With the rise in technological innovation, an engineering manager is expected to perform with reduced lead time, decreased time to market, and promptness in responding to customer questions, as well as to deliver a consistent and reliable service. Global competition tied in with energy and environmental concerns also leads to challenges in sourcing sustainable resources, hiring technical people, managing knowledge workers, working in a multicultural environment, and keeping the team motivated toward its goal. The trend in outsourcing requires a visibility of supply and logistics operations. Nonetheless, all these services need to be delivered in the least amount of time and cost and at the best level of quality that meets or exceeds customers' expectations.

Review

Upon completing the study of Domain 1: Introduction to Engineering Management, you should be able to answer the following questions:

1. What is engineering management?
2. What is the role of an engineering manager?
3. What are different levels of planning? Explain each level.
4. What are the different types of organizational structures? What are the advantages and disadvantages of each type?
5. What are the challenges an engineering manager can expect to encounter in the 21st century?

For Further Information

The Engineering Management Handbook, by the American Society for Engineering Management, 2016.

A Guide to the Project Management Body of Knowledge, 2017, Newtown Square, PA: Project Management Institute. Consult this ANSI publication for more information about organizational structures.

Managing Engineering and Technology, by L. C. Morse and D. L. Babcock, 2013, Upper Saddle River, NJ: Pearson.

Engineering Management: Meeting the global challenges, by C. M. Chang, 2016, Boca Raton, FL: CRC Press.

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Shah, H., & Nowocin, W. (2015). Yesterday, today, and the future of the engineering management body of knowledge. *Frontiers of Engineering Management Journal, 9*, 60-63.

2

Leadership and Organizational Management

Domain 2 Champions

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Domain 2: Leadership and Organizational Management

Key Words and Concepts

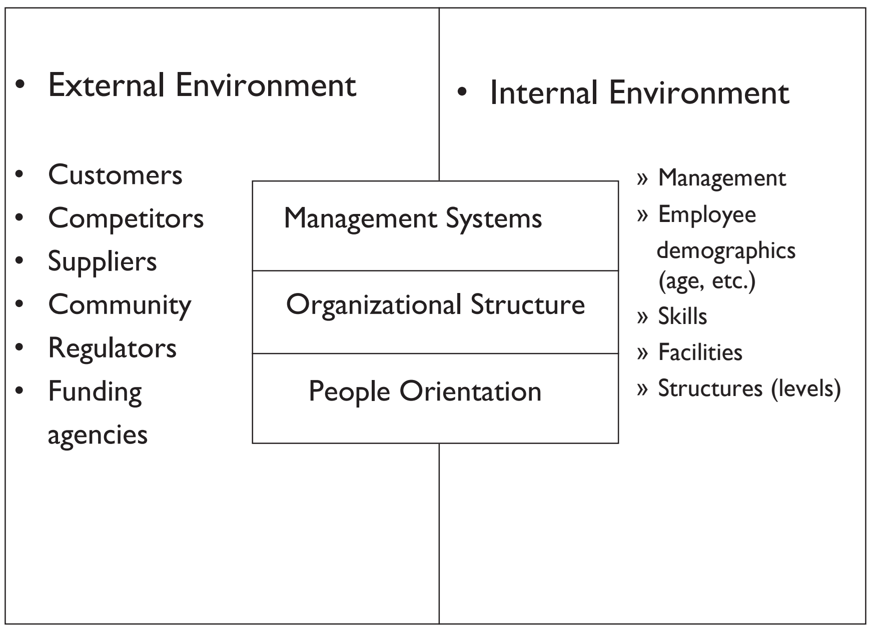
Compensation	Items earned by the employee for the job that he or she does. Examples include salary, benefits packages, bonuses, and rewards.
EEOC Regulations	The regulations set by the U.S. Equal Employment Opportunity Commission to assure fair employment practices are extended to all employees and potential employees, regardless of diversity factors.
Hygienes	Term coined by Frederick Herzberg to describe certain workplace factors that, alone, are unlikely to increase worker satisfaction or productivity. These include company policy, working conditions, peers, supervisors, and pay.
Knowledge Workers	Term coined by Peter Drucker (1959) to describe workers whose primary labor is intellectual, as opposed to manual. This term is particularly applicable to engineers, engineering managers, and many other workers in the Information Age.
Linking Pin	A middle-management function responsible for coordinating, inspiring cooperation, and managing conflict between upper management and direct reports.
Mechanistic Organizational Structure	Organizational structure governed by rigid policies and job descriptions. Frequently used in mass production industries (e.g., automotive manufacture), where decisions are primarily made at the top of the organization.
Motivators	Term coined by Frederick Herzberg to describe certain workplace factors that motivate employees, including knowledge workers. Examples of motivators include recognition, responsibility, the job itself, and opportunity.
Organic Organizational Structure	A flexible organizational structure with few set rules. This type of structure is well-suited to meet the requirements of a rapidly changing technological environment.
Schools of Management Thought	Schema developed by Dr. Harold Koontz to identify six categories of management thought. Some of the schools see management as adherence to well-conceived rules; others see it as the application of economic and mathematical principles, or the application of lessons learned from behavioral science.
Selection	The process of establishing selection criteria, interviewing and hiring the most qualified job applicant.
Strategy	In a systems context, strategy is one way of integrating organizational resources, including people, to meet the needs of forces or players external to the organization. These include customers, society, and suppliers.
Systems Thinking	An approach to organizational thinking outlined by Peter Senge. This approach holds that organizations are composed of interlinking systems and should be managed accordingly.
Teaming	Teams are defined as groups of geographically and organizationally co-located or dispersed knowledge workers brought together for a common organizational purpose.
Recruitment	The process of locating new team members whose knowledge, skills, and abilities fit the needs of the team.
Workforce Diversity	Using inclusion as a means of achieving superior performance by recognizing the unique contributions of each employee toward meeting the company's goals.

2.1 Introduction: The Integrated Management Model

When engineers are promoted into management positions without first having had formal management training or much management experience, they likely lack a thorough understanding of key management principles. This is unfortunate, as such principles provide managers—both new and seasoned—the guidance they need to navigate day-to-day management challenges, especially those involving the management of people.

Domain 2 examines a number of these management principles, focusing in particular on the management styles and organizational structures that are most conducive to managing professionals—including engineers—whose primary labor is intellectual. Dr. Jerry Westbrook's five-element Integrated Management Model (Figure 2-1) is used as the basis of this examination (2011).

Figure 2-1. Westbrook's Integrated Management Model (from Westbrook, 2011)



Integrated Management Model

The Integrated Management Model holds that management consists of three key elements: management systems, an organization's structure, and management's orientation toward its people. When combined, these interrelated building blocks determine how the manager and the organization will interact with and be impacted by the model's other two elements: the internal and external business environments (Westbrook, 2011).

Domain 2 is organized around each of the five elements of the integrated management model. After a brief, context-setting survey of the six key schools of management thought, each of the model's five elements is examined in depth. Each discussion focuses on how the element—alone and in concert with the other elements—can be optimized to enhance the productivity of engineers and other knowledge workers.

The domain concludes with an examination of key human-resources-management concepts and practices. These include the recruiting, selecting, and compensating of employees; guidelines for managing a diverse workforce; techniques for resolving conflict; and tips for managing labor relations.

1. The External Environment

Each element of the external environment exists outside the organization but has a direct impact upon it. Typical elements comprising the external environment are:

- Customers
- Competitors

- Suppliers
- Community
- Regulators
- Funding agencies

An effective manager must understand and be prepared to deal with each of these strategically. For example, a strong customer may become vertically integrated and become a competitor. A supplier may give competitors better prices. Competitors' research and development programs may yield a better, cheaper product. The community may support a local organization, or may attempt to put unfavorable regulations in place. For all of these reasons and more, a manager must be sensitive to the external environment, and remain keenly aware of the threats and opportunities it provides.

2.The Internal Environment

An organization's internal environment is the set of internal resources that enable the organization's successful operation. Effective managers must determine if the available resources are adequate to the challenges faced by that organization.

An organization's internal environment includes the following:

- The skill base of its workforce
- Key employee demographics
- Age and condition of its facilities
- Management style and organization culture

A strategic analysis of the internal environment yields its key strengths and weaknesses. The resources available to an organization also determine priorities for decision-making.

3. Management Systems

Systems are the way processes are organized to get things done. There are many types of systems: everything from accounting, purchasing, and production to strategic efforts to coordinate workflow. It is the latter that is of most interest. Many powerful and useful systems have been implemented in the past 20 years. Further back, one of the first management systems was management by objectives. Then Zero Defects, Total Quality Management, and Business Process Re-engineering became popular. Each had a half-life of approximately two years and was gone. They were good systems that didn't last. Why? Many were never implemented very well. Middle management gave lip service to some but never really supported them. Upper-management members felt like the systems were for workers, not them. The structures of some organizations were too complex to support the system. The reasons were systemic. The whole organization failed to adopt and use the new system.

Lean Enterprise and Six Sigma are the management systems currently in use. How long these management systems survive depends largely on how effectively organizations implement them. The model suggests ways that good systems can be effectively implemented and maintained.

4. Organizational Structure

An organization's structure is the way an organization arranges its components to carry out its mission. Organizational structure is not well understood, and, as a result, many organizations find themselves constantly "reorganizing." Organization structure is therefore the silent force behind the organization's success or failure.

Structure can be defined in several ways:

- Complexity – The number of organizational levels that communication must travel between and among
- Control systems – The number of employees reporting to one manager, also referred to as "span of control"

- Culture – How members of the organization relate to each other – formally or informally, vertically or omni-directionally

The more sophisticated the organization's technologies, the faster the communication within the organization must be. Similarly, a sophisticated technological organization benefits from a relatively flat structure. Complex, tall structures do not suit rapidly changing business environments.

5. People Orientation

Much of a knowledge-worker-based organization's success depends on how the organization relates to its employees. Most organizations proclaim that their employees are their most valued asset but still make decisions that take them for granted (e.g., massive outsourcing to other countries). Acting in a manner that generates trust allows a knowledge-worker-based organization to succeed. Failure to do so is the reason so many of the systems mentioned earlier failed.

6.The Integrated Management Model

Together, all of the elements discussed earlier form an integrated management model where each element works in relation to all the others. For example, systems fail when all of the elements do not act in a coordinated manner. The internal environment must have appropriate resources. Analysis of the internal environment yields an organization's strengths and weaknesses. The external environment must be mined for opportunities and potential threats. Appropriate systems must be used, and the structure must support those systems. Knowledge workers must work in a culture that challenges and appreciates their contributions.

The remainder of Domain 2 presents each element of the integrated management in detail:

- A context-setting survey of the key schools of management thought is delivered in Section 2.2: Schools of Management Thought.
- Concepts for managing and motivating knowledge workers both individually and as a team are presented in Section 2.3.
- Approaches to assessing the effectiveness of an organization's structure are presented in Section 2.4: Organizational Structure.
- Methods of integrating organizational systems are discussed in Section 2.5.
- A systems view of leadership is the subject of Section 2.6.
- Making management systems function through effective human resource management is discussed in Section 2.7.
- Traditional and virtual team structures are discussed in Section 2.8.
- Managing and retaining key technologies is presented as part of Knowledge Management in Section 2.9.

Students of engineering management are expected to understand that there are different approaches to management. Knowledge workers are typically at the heart of a technology-driven organization, and their efforts are to be encouraged and appreciated. Engineering managers must deal with a changing external environment and be ready to develop the internal resources needed to meet that challenge.

There are a wide range of management styles, philosophies, and practices. The purpose of this section is to review that range and demonstrate how various elements of each are of use by the modern-day engineering manager. The review will also form a foundation for the Integrated Management Model that is the centerpiece of this domain.

2.2 Schools of Management Thought

2.2.1 The Management Process School

In their article "The Management Theory Jungle," Koontz and O'Donnell (1961) condensed the range of contemporary management practices into six major "Schools of Management Thought":

- The Management Process School
- The Empirical School

- The Social Systems School
- The Human Behavioral School
- The Mathematical School
- The Decision Theory School

1. The Management Process School

The Management Process School maintains that management is a process that can be defined, taught, learned, and applied. This school also holds that management consists of the following activities: planning, organizing, staffing, leading, communicating, and controlling. By focusing on these activities, the individual manager improves both his or her management skills and the productivity of the overall organization. This is in opposition to the argument that management is an innate quality with which one must be born.

Typical management principles within the Management Process School include the following:

- *Chain of command:* Communication is primarily vertical, guided by direct reporting relationships.
- *Division of labor:* Work is divided into relatively small tasks so that less-skilled workers can be trained to do these tasks repetitively. This concept was developed during the Industrial Revolution, when employees were predominantly untrained and uneducated women and children. It is now being applied to a better trained and educated workforce, with mixed results.
- *Narrow span of control:* This is the number of direct reports per manager. Span of control depends on many factors, including the skill level of the workforce and the number of tasks that the manager supervises. Narrow spans of control add supervisors and overhead to the organization. Division of labor tends to reduce that ratio of supervisors to workers.
- *Unity of command:* One worker has one supervisor to minimize any confusion regarding from whom to take orders.

Research by Mintzberg (1971) indicates that the Management Process School's list of management activities does not adequately describe the management function. It fails to include the important communication role that managers play within an organization (i.e., the manager as communication center, a disseminator of information, and a spokesperson for the organization, etc.). Managers also influence work, allocate resources, and handle disturbances. Despite its limitations, however, the management process's list of functions does provide us with a useful conceptual framework for describing managerial activities.

2. The Empirical School

The Empirical School, as promoted by the Harvard Business School, uses case studies of real-world management scenarios to train and educate future managers and organizational leaders. Principles of management are based on actual business cases or the study of real situations. The case-study approach allows students to learn from managers' successes and failures and to begin forming their own principles of management.

2.2.2 Behavioral Schools

1.The Social Systems School

This school-of-management thought examines how workers perform in groups or teams. The Hawthorne Experiments were the catalyst for this school's core concepts. They demonstrated that both external conditions (e.g., lighting, work rules, etc.) *and* a team's relationship to organizational goals affect productivity. Many researchers have put forth management theories on the role of group processes in achieving organizational success, including Blake and Mouton (*The Managerial Grid*), Likert (*The Four Systems*), and Katzenbach and Smith (*The Wisdom of Teams*). (For additional information about the Social Systems School, see Blake & Mouton, 1964; Likert, 1975; Katzenbach & Smith, 2003.)

2. The Human Behavioral School

This school holds that management should recognize employees as organizational assets who want to get work done, as opposed to workers merely responding to supervisory dictates. This behavioral approach is especially important in the management of knowledge workers, as the way they feel about their job has a significant impact on their effectiveness. Individual theories within this school include Herzberg's "Motivators and Hygienes," Maslow's "Hierarchy of Human Needs," McGregor's "Theory X and Theory Y," and McClelland's "That Urge to Achieve." (For additional information about the Human Behavioral School, see Herzberg, 1968; Maslow, 1943; McClelland, 1966; McGregor, 1957.)

2.2.3 Mathematical Schools

1. The Mathematical School

This school models an organization's systems using mathematical techniques, such as linear or non-linear programming. The goal of the modeling exercise is to optimize each system in an effort to maximize that organization's productivity. Modeling an organization's functions is, of course, a formidable task. Nevertheless, proponents of this school forge ahead. Several university engineering management programs focus on this management approach.

2. The Decision Theory School

Decision Theory identifies a situation and its range of possible outcomes, then formulates the strategies an organization could use to respond to each. Decision rules are applied to determine which strategy would yield the best result for the broadest array of possible outcomes. The probability of each outcome is estimated and entered into the decision process.

Take, for example, a university trying to determine how it will fund research in an election year. If a Democratic candidate should win, environmental research may be funded at a higher level. If the Republican candidate should win, new weapons systems may receive additional funding. Any proposed research programs that have elements of both areas may get a more serious look. For instance, if a crop-sensing satellite program is proposed, it could also be used to check the growth of drug fields in Afghanistan. This has elements of environment, culture, and defense and might receive a higher priority. Otherwise, researchers would be encouraged to submit environmental research projects that a Democratic administration would be more likely to fund.

3. Scientific Management

The next major development in management theory was Taylor's Scientific Management (1911). Taylor was one of the founders of the field of Industrial Engineering. He worked at several major companies, primarily in the steel industry, and his work led to large improvements in productivity. He developed four management principles that led to these production improvements:

1. Develop a large collection of knowledge about the process under study. Use this knowledge to determine the one best way to perform the work.
2. Scientifically select workers who are most able to perform the work by the specified method.
3. Train the workers to do the work using the "one best way." Provide incentives for using the correct method.
4. Let management and workers collaborate on decisions so that the unique knowledge each has can be used when solving organizational problems.

The overriding assumption in these four principles is that management divides the work (i.e., creates a division of labor) and makes decisions affecting the way work is done. Taylor believed that if any task is studied sufficiently, management can determine the one best way for doing it and, thus, optimize productivity. Further, he believed that the variation introduced by the workers could be reduced to insignificance through training and incentives. Workers and machines were seen as only slightly different.

Summary
The field of engineering management is dominated by knowledge workers, professionals, and talented technical personnel. As Argyris (1957) pointed out, classical management concepts were developed for unskilled workers in an environment controlled by upper management. The question now becomes one of balance between the management concepts and their appropriate relationship to each other, as well as their applicability to the field of engineering management.

2.3 Managing and Motivating Knowledge Workers

People Orientation
The focus of this section is the "People Orientation" block of the Management Model shown in Figure 2-1. The people component of an organization undergirds all other components of the model. An organization's human resources, for example, interact with both the internal and external environments. Similarly, an organization's structure and systems can only function with motivated and productive knowledge workers.

Knowledge workers is a concept first coined by Peter Drucker in 1959. He used the term to define the class of workers that drive today's information economy. The class includes inventors, innovators, process developers, and process improvers, to name a few examples.

Knowledge workers present a unique challenge to management. Unlike with physical labor, you cannot assess a knowledge worker's productivity or effectiveness by observation. With mental labor, the value of work being done may not be known for a significant period of time. If the knowledge worker doesn't feel as if he or she is being treated fairly, rewarded adequately, or supported appropriately, the worker may decide to slow the work or stop working altogether, without being detected.

Because job satisfaction is vital to a knowledge worker's productivity, it is more important than ever to understand the behavioral dimension of management. The knowledge worker wants to be a part of the organization, not just to occupy a "slot" on the organizational chart, and an effective manager has to understand how to address that desire.

The management model introduced earlier will continue to guide the thought process throughout this domain. In this section, we will focus on people management, as it is the least known and practiced of the model's concepts.

Background on Behavioral Approaches
The first years of the twentieth century saw the development of multiple management concepts. The French engineer Henri Fayol (2013), for example, developed the first recorded management principles. Taylor (2014) developed Scientific Management to increase productivity. Frank and Lillian Gilbreath (1973) developed methods analysis, and Henry Gantt (1913) developed the Gantt chart for scheduling large-scale projects.

The idea that management practice could improve productivity encouraged many organizations to actively experiment with new management techniques in the hopes of giving themselves a competitive advantage. Western Electric, for example, conducted a wide range of experiments with management practice at its Hawthorne works. The company experimented with lighting, work breaks, incentive systems, organizational communication, and other concepts. The general conclusion was that the attitude of workers had much to do with organizational productivity. The company did not, however, reach firm conclusions on how to develop those positive attitudes. Effective theories on workforce motivation required another 35 years to develop.

Argyris (1957) performed a seminal study of management approaches and concluded that modern management tended to treat workers as children while expecting them to behave as adults. Following Argyris's conclusion, faculty in an engineering-management program must be very careful about what is taught as acceptable practice.

After World War II, many behavioral theories were developed. The ill-fated "human relations" movement spawned much research that proved beneficial, although still short of being the total answer.

The major behavioral concepts applicable to knowledge workers by engineering managers include concepts developed by McGregor, Maslow, Herzberg, and McClelland. Each is discussed next.

2.3.1 The Impact of Assumptions

1. McGregor's Theory X and Theory Y

Douglas McGregor, a Harvard professor and business consultant, studied the assumptions management makes about its workers and the impact these assumptions have on worker productivity. He distilled the range of managerial assumptions as follows (1957):

- Theory X – workers must be coerced to work. They are lazy and want security above all else.
- Theory Y – workers are dedicated to organizational objectives and will exercise self-control in order to achieve them. They are responsible and frequently innovative in their approach to solving organizational problems.

McGregor observed that, in most cases, Theory X becomes a self-fulfilling prophecy. When management crafts work rules as if the workers need close supervision or cannot be trusted, workers are likely to act as if they need to be told exactly what to do. In fact, the opposite is usually true: workers frequently know exactly what needs to be done, many times better than management. If, on the other hand, management assumes that its workforce strongly supports the organization, workers are more likely to value the relationship with management and respond to them and their responsibilities positively.

2.3.2 Identifying and Meeting Employee Needs

1. Maslow's Hierarchy of Human Needs

Maslow (1943) theorized a five-level hierarchy of human needs; the highest level is listed first:

- Self-actualization
- Esteem (public and self)
- Membership
- Safety and security
- Physiological

According to Maslow, individuals seek to satisfy the needs associated with each of these levels in a sequential fashion. Once the basic Level 1 physiological needs have been met, an individual would then attempt to satisfy the needs associated with safety and security. After satisfying safety and security needs, the individual then seeks membership in a formal or informal organization. This is followed by a search for esteem—both public esteem and self-esteem—which is then followed by the search for self-actualization. Note that the individual in Maslow's schema is not motivated to move onto the next level until he or she has substantially (i.e., 85%) met the needs of his or her current level.

Maslow's hierarchy is a useful concept for management and its understanding of worker motivation and productivity. As individuals, workers are motivated to advance through the levels of the hierarchy. Management must recognize this and initiate programs to assist in the advancement. The organization as a whole benefits when its members are making these kinds of strides.

It is important that managers be sensitive to an individual's location within the hierarchy. While a manager might be dedicated to the organization at the self-actualization level, many employees might be seeking to satisfy the needs associated with membership. To best assist the employee, the manager must recognize where employees are in the hierarchy and then help them develop a course of action to advance to the next level.

2.3.3 Motivator-Hygiene Concept

Herzberg (1968) did research on job satisfaction, initially using accountants and engineers to perform his study. He asked participants to think of a time they were satisfied with their jobs and then identify what they considered the causes of that satisfaction. He then asked for them to think of a time they were dissatisfied and list the causes associated with that. He and his researchers recorded the responses and grouped them according to similarities or “thought units.” The satisfiers, or motivators, follow:

- Recognition
- Achievement
- Possibility of growth
- Advancement
- Responsibility
- The job itself

The dissatisfiers, or hygienes, follow:

- Working conditions
- Company policies
- Relations with the supervisor
- Relations with peers
- Pay

Herzberg observed that management frequently attempts to use hygienes to motivate the workforce, but an increase in hygienes (e.g., pay) only increases the anticipation of further increases. Costs rise, but motivation and productivity do not. While more difficult for management to apply, motivators are less expensive than hygienes and more likely to promote job satisfaction and productivity. He further observed that while hygienes must be maintained at an appropriate level to prevent dissatisfaction (i.e., maintain neutrality), they alone cannot motivate.

The study has been replicated many times with similar results for subjects in a variety of professions, countries, and cultures. A study of blue-collar workers showed similar overall results, although hygienes were of more importance and motivators of slightly less importance than in studies of white-collar workers.

2.3.4 Achievement-Affiliation Concepts

1. McClelland’s Need to Achieve

McClelland (1966) studied workers involved in a plant shutdown in Erie, Pennsylvania. A few of those laid off immediately set about finding jobs in nearby towns, frequently using their connections. Most people in this group found work within six weeks. He labeled this group nAchievers (nAch) because of their need to achieve.

The majority of laid-off employees, however, checked with their union several times, inquired if another company would buy and reopen the factory, and read the local want ads. They gathered in small groups to discuss the situation to see if anyone knew of available jobs. The majority of this group was still unemployed after six months. McClelland labeled this group as nAffiliators (nAff) for their need to affiliate.

McClelland discovered that organizations tend to take on the characteristics of their workers. Some are achievement-oriented while others are more affiliation-oriented. Management needs to examine its recent recruits to determine what kind of employees it is attracting. Productivity and success are products of its workforce but might not be achievable if the organization has the wrong mix of employees—that is, a preponderance of nAffiliators with few nAchievers.

It should also be noted that McClelland has had success in training company workforces to become nAchievers, suggesting that people can be trained to achieve.

2.3.5 Intrinsic, Extrinsic Factors in Motivation

Pink’s (2009) writing and research have the advantage of being among the later theories. His research and writing have been done with the basic works of Maslow, McGregor, Herzberg, McClelland, and others being known. Most of the earlier theorists operated independently of each other.

Pink uses Intrinsic (I) and Extrinsic (E) factors similar to Herzberg’s motivators and hygienes. Many managers still assume that the E factors, such as money, are primarily what motivates us. Research done in many cultures and countries shows that not only is money not a motivator, but also it can have the opposite effect. His conclusions are that if a task is primarily manual with a premium on dexterity, incentives work as they are intended. The more the pay, the more is accomplished. However, if there is only a modicum of mental effort required, then the higher the pay, the poorer the performance. Pink explains that when cognitive, creative work is about pay, not accomplishment, there is a negative impact on performance. Is this relationship responsible, at least in part, for the poor performance of CEOs with huge compensation packages that are not related to organizational accomplishment?

According to Pink, the factors that actually motivate us are Autonomy, Mastery, and Purpose. Autonomy means that the knowledge workers have the opportunity to work on ideas and projects that could have potential benefit to the organization. Many organizations incorporate this into company policy. Perhaps the best known is 3M, which allows knowledge workers to use 14% of their own time in pursuit of their own ideas. Post-it Notes were developed under this policy.

Mastery refers to the opportunity to improve skills and knowledge. Rapidly developing technologies in a world economy demand that the human resource be continually developed. This development is done according to both the organization's and individuals' interests.

Purpose means that those making significant contributions understand that the organization is providing goods and/or services that contribute to the greater good. The individual wants to contribute to the organization that is making the world a better place in some significant way. The job is not just about pay, fringe benefits, challenges and opportunities; it is about making things better.

2. Skinner's Operant Conditioning Theory

Skinner won the Noble Prize for science in 1963 for his work on behavioral research. He termed the results of his research the Operant Conditioning Theory (1953).

His theory was as follows:

- Behavior that is rewarded tends to be repeated.
- Behavior that is ignored tends to be extinguished.
- Behavior that is punished generates a negative, fragmented response.

According to Skinner's theory, if a manager sees a behavior that is favorable to the organization, the behavior should be rewarded. The reward may be financial but might also be a favorable comment, a write-up in the company newsletter, or a mention before employees in the same department. By ignoring the positive accomplishment, the manager runs the risk of "extinguishing" it.

Negative behaviors may be ignored and thereby discouraged as long as positive behaviors are rewarded. This does not mean ignoring an employee's violation of rules or failure to follow prescribed processes. They should be dealt with according to policy. It is assumed that many negative comments and attitudes are an attempt to get attention. If the attention is not given, then the behavior is likely to be "extinguished."

When punishing offensive behavior, the manager must make sure that the offense merits the punishment. If punishment is dealt that is in excess of the offense, a backlash is likely to occur, perhaps not immediately, but eventually.

Summary

Maslow's Hierarchy of Human Needs, McGregor's Theory X and Theory Y, Herzberg's Motivators and Hygienes, and McClelland's Achievers might at first glance seem to be independent concepts but are actually highly complementary.

For example, Maslow's self-actualization and esteem needs are closely related to Herzberg's motivators. Theory Y is a natural way of thinking about employees who tend to be affiliators.

Those having membership and security needs tend to focus on hygienes, to be affiliators, and are accurately described by Theory X.

Figure 2-2. Motivation Diagram

Maslow	McGregor	Herzberg	McClelland
Self-Actualization Esteem	Theory Y	Motivators	nAchievers
Membership Security	Theory X	Hygienes	nAffiliators

In order to motivate knowledge workers, Theory Y must be assumed, self-actualization must be encouraged with opportunities, and there must be a focus on motivators and achievement.

In order to limit dissatisfaction, membership activities should be facilitated, Theory X assumptions must be avoided and hygienes should be provided at as high a level as can be reasonably afforded.

2.3.6 Management Styles and Group Processes

Relationship Between Classical Management Theory and Productivity in Technical Organizations

The focus of this section is managing knowledge workers in groups or teams. The background for this section is a meta-study by Argyris. He reviewed hundreds of management studies that linked management practices with human behavior (1957).

Most organizations use some version of the standard management practices described in the Management Process School of Management Thought described in Section 2.2.1. This school espouses the chain of command, unity of command, division of labor, vertical communication channels, authority in accordance with responsibility, and so forth. Argyris critiqued these management principles. First, he researched the common characteristics of personality development, in which each individual...

1. Develops from a passive infant to an increasingly active adult.
2. Goes from a state of dependence to independence.
3. Changes from simple behavior to complex with maturity.
4. From shallow interests, develops deep commitments.
5. Goes from short time frames to long time frames—more affected by the past than the future.
6. Develops from family subordinate to peer or leader.
7. Goes from a lack of awareness of self to the development of self-control.

Argyris further identified four common classical organizational concepts and compared the result of using them with the traits of normal personality development listed earlier.

- Division of labor – The individual sells skills rather than total abilities.
- Chain of command – This tends to make individuals dependent and passive.
- Unity of direction – This is leader-oriented, not a function of workers.
- Span of control (usually four to eight) – Adds levels to the organization; thus, increases dependence.

Argyris hypothesized three results of using classical organizational concepts:

1. There is a lack of congruence between normal personality development and classical organizational concepts.
2. This lack of congruence generates frustration, short-term perspective, and conflict.
3. The result will be inter-subordinate hostility and rivalries and a focus on parts of the organization rather than on the whole.

2.3.7 Defined Management Systems

1. Likert – An Integrating Principle

Likert (1961) was an international management consultant, theorist, and author. He worked with organizations all over the world and used his experiences to develop management theories, three of which will be discussed in this section:

- Principle of Supporting Management
- Team Management
- Four Systems

He documented the concepts used by the most successful organizations and continuously compared them with those of less successful organizations. He concluded that high-producing organizations and their managers managed differently than managers of low-producing organizations. In general, managers using classical management theories were less successful than those managers who managed in a way that will be discussed below.

2. Characteristics of High-Producing Organizations

- There are favorable attitudes of members of an organization toward superiors, toward the work, toward the organization. There is mutual confidence and trust throughout the organization.
- There is a high sense of involvement in the achievement of high goals, and there is a sense of dissatisfaction if goals are not met.
- The organization effectively harnesses all of the major motivational concepts, including the following:
    - Ego motives
    - Security motives
    - Creativity and curiosity
    - Economic motives
- The organization consists of a tightly knit, effectively functioning social system. Employees want to work together, solve problems, and make the organization successful.
- The system is made up of interlocking groups with a high degree of group loyalty and with favorable attitudes and trust between subordinates and superiors.
- Measurements of organizational performance are primarily used for self-guidance rather than for superimposed control. This is more of a Theory Y approach within an nAchiever workforce.

3. Characteristics of Low-Producing Organizations

- Motivation is achieved by the exercise of control through authority—that is, traditional management.
- Jobs are organized, methods are prescribed, standards are set, and performance goals and budgets are set by management. (Remember worker dependence and the result?)
- Compliance is sought through the use of hierarchical and economic pressure. It is a Theory X assumption that this is the only way to get workers to produce.

In short, those managers who demand success don't get it. Those managers who allow employees to be successful are more likely to be in a successful organization.

4. High-Producing Managers

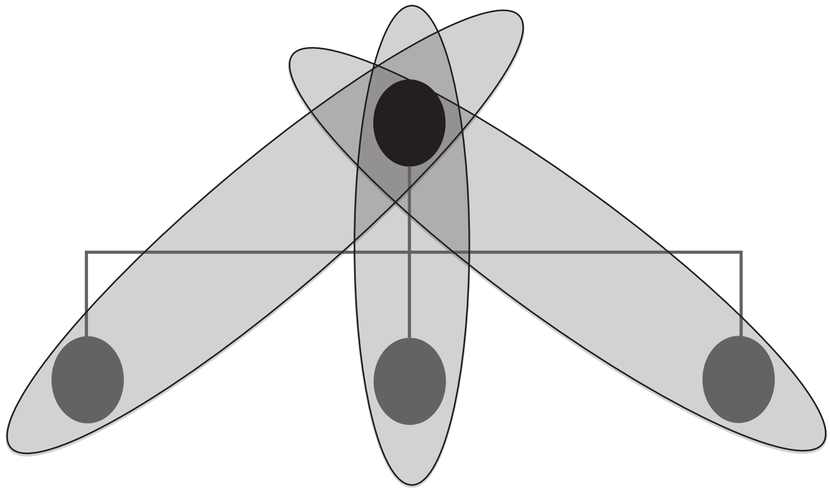
Below are the perceptions employees in productive organizations have toward their superior:

- Supportive, friendly, helpful, not hostile
- Displays confidence in subordinate's integrity and ability
- Has high expectations of subordinates
- Coaches and assists employees whose performance is below expectations

This type of manager is with his or her employees, rather than just being above them. This manager is heavily involved with both the work and the employees.

5. Traditional Organization

Figure 2-3. Traditional Organization Structure



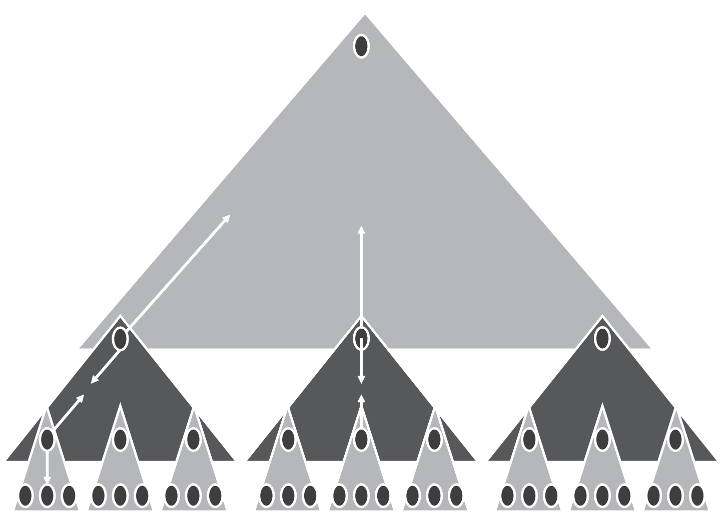
In a traditional organization structure (Figure 2-3), the following occurs:

- The boss has a one-on-one relationship with each subordinate. Each subordinate attempts to use whatever means available to extract more resources from the boss than other subordinates receive.
- Communication from subordinate to boss is highly filtered. The boss hears only what the subordinate wants the boss to know in order to receive favor for his or her unit.
- There is mistrust between subordinates who each consider that other subordinates are better treated.
- The good of the organization as a whole receives little consideration. Decisions are made in a vacuum with each unit competing for resources.
- Each unit staffs for the maximum contingency. There is little sharing of resources between units.

This is the way unenlightened managers deal with their employees. This is frequently true organization-wide. They know no other way of supervising.

6. The Team-Based Organization

Figure 2-4. The Team-Based Organization



The team-based organization structure (Figure 2-4) is an alternative to the traditional organization structure. It is characterized by the following qualities:

- The good of the organization as a whole is easy to relate to.
- Communications are with the whole group; filtering is not possible.
- Vigorous debate focused on the issues generates better decisions.
- Sharing of resources is looked upon with favor as it allows unnecessary unit cost to be reduced by loaning employees to units in greater temporary need.
- Decisions are better supported. Even those whose recommendations are not followed had input and know the other positions and can generally support the decision.

The *linking pin* is a leader to a group who is also a member of the team at the next highest level.

The organization is "linked" together by these "linking pins." This is in contrast to the typical top-down approach that does not value upward or lateral communication patterns. The linking pins improve total organizational communication.

Communication loss from the top level down within a traditional organization is represented in Figure 2-5.

Figure 2-5. Message Loss in Top-Down Communications

Communication From	To	% Message Surviving
Top Management	Middle Management	67%
Top Management	General Manager	50%
Top Management	Supervisor	33%
Top Management	Worker	20%

This indicates that those at the base of the traditional organization receive very little accurate information emanating from the top. The real question is, "What are the similar percentages going from the bottom to the top level?" As this generally does not happen, it is zero. Likert's "linking pins" facilitate this upward communication and in this sense is better than the limited uni-directional communication available within a traditional organization.

2.3.8 Likert's System IV

Likert (1961) carefully observed and analyzed a wide array of organizations in order to develop his schema of management styles. The schema consists of four management systems, each of which is described below. Of the four, he concluded that only System IV achieves normal productivity goals consistently.

Likert's Four Systems

- System I: Exploitive-Authoritative
- System II: Benevolent-Authoritative (We have your best interest at heart.)
- System III: Consultative-Democratic
- System IV: Participative-Democratic

Likert evaluated each system according to the following criteria:

1. **Leadership Processes:** The extent to which superiors have confidence and trust in subordinates.
2. **Character of Motivational Forces:** The forces used to motivate employees. Can include the promise of physical security and fulfillment of economic needs to achievement of satisfaction derived from teamwork.
3. **Character of Communication Process:** The amount and direction of communication aimed at achieving organizational objectives.

Figure 2-6. Likert's Four Systems Compared

AREAS OF DIFFERENTIATION	SYSTEM I Exploitive-Authoritative	SYSTEM II Benevolent-Authoritative	SYSTEM III Consultative-Democratic	SYSTEM IV Participative-Democratic
Motivational Forces	Taps fear, need for money, and status. Ignores other motives that cancel out those tapped. Attitudes are hostile, subservient upward, contemptuous downward. Mistrust prevalent. Little feeling of responsibility except at high levels. Dissatisfaction with job, peers, supervisor, and organization.	Taps need for money, ego motives, such as desire for status and for power, sometimes fear. Untapped motives often cancel out those tapped, sometimes reinforce them. Attitudes are sometimes hostile, sometimes favorable toward organization, subservient upward, condescending downward, competitively hostile toward peers. Managers usually feel responsible for attaining goals, but rank and file do not. Dissatisfaction to moderate satisfaction with job, peers, supervisor, and organization.	Taps need for money, ego motives and other major motives within the individual. Motivational forces usually reinforce each other. Attitudes usually favorable. Most persons feel responsible. Moderately high satisfaction with job, peers, supervisor, and organization	Taps all major motives except fear, including motivational forces coming from group processes. Motivational forces reinforce one another. Attitudes quite favorable. Trust prevalent. Persons at all levels feel quite responsible. Relatively high satisfaction throughout.
Interaction-Influence Process	No cooperative teamwork, little mutual influence. Little upward influence. Only moderate downward influence, usually overestimated.	Very little cooperative teamwork, little upward influence except by informal means. Moderate downward influence.	Moderate amount of cooperative teamwork. Moderate upward influence. Moderate to substantial downward influence.	A great deal of cooperative teamwork. Substantial real influence upward, downward, and laterally.
Goal-Setting Process	Orders issued. Overt acceptance. Covert resistance.	Orders issued, perhaps with some chance to comment. Overt acceptance, but often covert resistance.	Goals are set or orders issued after discussion with subordinates. Usually acceptance both overtly and covertly, but some occasional covert resistance.	Goals established by group participation, except in emergencies. Full goal acceptance, both overtly and covertly.
Communication Pattern	Little upward communication. Little lateral communication. Some downward communication, viewed with suspicion by subordinates. Much distortion and deception.	Little upward communication. Little lateral communication. Great deal of downward communication, viewed with mixed feelings by subordinates. Some distortion and filtering.	Upward and downward communication is usually good. Lateral communication is fair to good. Slight tendency to filter or distort.	Information flows freely and accurately in all directions. Practically no forces to distort or filter.
Decision-Making Process	Decision made at top, based upon partial and inaccurate information. Contributes little motivational value. Made on person-to-person basis, discouraging teamwork.	Policy decided at top, some implementation decisions made at lower levels, based on moderately accurate and adequate information. Contributes little motivational value. Made largely on person-to-person basis, discouraging teamwork.	Broad policy decided at top, more specific decisions made at lower levels, based upon reasonably accurate and adequate information. Some contribution to motivation. Some group-based decision-making.	Decision-making done throughout the organization, linked by overlapping groups, and based upon full and accurate information. Made largely on a group basis, encouraging teamwork.
Control Process	Control at top only. Control data often distorted and falsified. Informal organization exists, which works counter to formal, reducing real control.	Control largely at top. Control data often incomplete and inaccurate. Informal organization usually exists, working counter to the formal, partially reducing real control.	Control primarily at the top, but some delegation to lower levels. Informal organization may exist and partially resist formal organization, partially reducing real control.	Widespread real and felt responsibility for control function. Informal and formal organizations are identical, with no reduction in real control.

4. **Character of Interaction Influence Process:** How different levels of an organization work together to solve problems and achieve objectives.
5. **Character of Decision-Making Process:** At what level in the organization are decisions made?
6. **Character of Goal Setting:** Where are goals established and from what level do orders normally come?

The findings are listed in Figure 2-6.

No one has surveyed the population of contemporary organizations to determine the current distribution of these management systems, but it is widely believed that most organizations are System II. A few organizations are System III, and System IV organizations are rare.

Likert believed that in determining the value of an organization, the value of the human asset must be assessed. Human-asset value consists of the following:

- Recruiting costs
- Training costs
- Familiarization costs
- Capability costs
- Development costs

A layoff is a liquidation of valuable assets just as surely as selling equipment, land, facilities, or inventories. All of the costs listed earlier are lost when human resources are liquidated.

Many of these costs will have to be paid again, at a higher rate, without the guarantee that the work will be done as well.

Likert's general conclusion was that attitudes and skill generate productivity. He observed that an organization's management system drives a worker's attitudes and attitudes generate productivity and profits. In other words, management systems have a significant impact on productivity and profits.

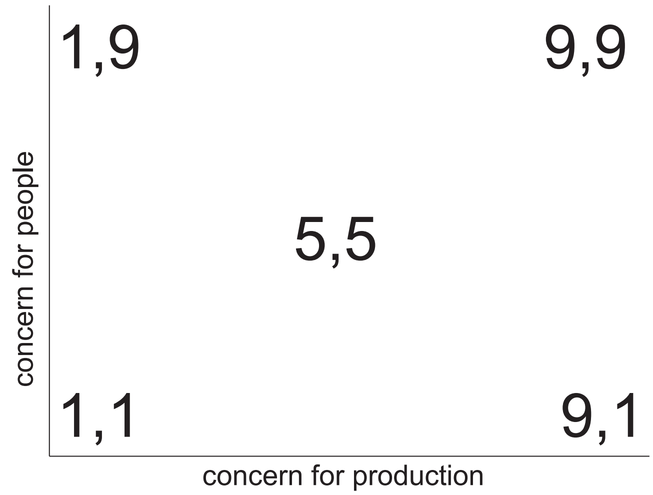
System IV has much in common with Theory Y, Self-Actualization, and Motivators, all of which are discussed earlier.

2.3.9 Blake and Mouton's Managerial Grid

In the late 1960s, Dr. Robert Blake of the University of Texas studied the management of a major corporation at its corporate headquarters. The commonly accepted theory of the day was that management style could be categorized on a continuum from autocratic to participative. Blake and Mouton (1964) sought to either validate this theory or to develop a new one. They observed that some managers were very successful and managed productive units. They were observed to have similar management styles. Other managers that were in charge of less successful units also had similar management styles. Neither management style fit into the autocratic-participative continuum. Further observations were made of some successful managers who were transferred to units with productivity problems. These units improved over time to be similar to the unit the successful managers had left.

The Managerial Grid (Figure 2-7) is the theory Blake and Mouton developed to describe the results of their study.

Figure 2-7. The Managerial Grid



Definitions of the Positions on the Managerial Grid

Five positions on the grid are adequate to demonstrate the array of common management styles:

- **1,1.** These managers avoid decisions and use "policies" instead of positions. They hide behind policies and avoid confrontation. They are not oriented toward production either. They stay in their offices frequently. Their approach to conflict resolution is to ignore the conflict.
- **1,9.** Sometimes referred to as country-club management style, these managers make decisions to make their employees happy as opposed to addressing issues and solving problems. They hope that production will take care of itself if employees are content. They attempt to meet goals by manipulating employees. Conflict resolution is to simply ignore that there is a problem.
- **9,1.** This is an autocrat management style. These types of managers solve problems by edict. Production is their first priority. People are hired to get the work done. Their approach to conflict resolution is to do it my way or leave.
- **5,5.** This type of manager views people and production equally but is not particularly strong on either. This is a bureaucratic, status-quo position. There are more managers in this position than all others according to standardized tests. They tend to solve problems by compromise.
- **9,9.** This is the team-manager position. These managers use employees as teams to gather and share information and to identify and solve productivity problems. There is a natural balance between people and production. These managers' teams solve problems by confronting them.

Results

Only managers with strong concerns for both people and work were in high-productivity units. These managers completed the following actions:

- Used teams extensively
- Confronted issues to resolve conflict
- Received extensive input from employees
- Developed employee capabilities

Summary

All of the studies discussed earlier reach similar conclusions (Figure 2-8). Argyris showed that traditional management does not work very well. Efforts to get high productivity under classical principles are not successful. Likert's System IV had similar constructs and results as Blake and Mouton's Managerial Grid 9, 9 position.

Managers making a Theory Y assumption and a focus on motivators will likely use Likert's System IV and have a 9-9 management style on the Managerial Grid.

Figure 2-8. Comparing the Results of Key Management Studies

How is all this related?

		Intrinsic Factors
Organic		
Theory Y	Self Act	Motivators nAch
System IV	Self Esteem	9, 9
		Extrinsic Factors
Mechanistic		
Theory X	Public Esteem	Hygienes nAff
	Safety	
System I, II	Security	1-9, 1-1, 9-1

2.4 Organizational Structure

This section concerns the "Organizational Structure" block at the center of the management model depicted in Figure 2-1. In order for an organization to restructure successfully, its managers must understand the characteristics of potential structural alternatives. That understanding is the purpose of this section.

Structure is the mechanism that an organization uses to carry out its mission. If the structure and the mission are not compatible, problems will surface in communication and coordination. This has to do with how the structure functions, in an organic or mechanistic way.

2.4.1 Organic vs. Mechanistic Structures

1. Burns and Stalker Study

The first major research study of organizational structure was by Burns and Stalker (1961) in England. In their study, the environment was divided into three classes: stable, changing, and innovative. The study establishes the relationship between stability of the environment and the organization's structure and operation.

A stable environment is characterized by the following characteristics:

- Stable demand
- Unchanging competitive landscape
- Low level of product change or innovation

The resulting organizational structure and operation consist of the following:

- Centralized decision-making
- Production controls
- Functions rigidly adhere to job descriptions
- Emphasis on chain of command, rules
- Geared for efficiency and cost minimization

A changing environment is characterized by the following:

- Fluctuating demand but within limits—somewhat predictable
- Changing competitive landscape
- Changing product or service
- Government regulations change but can be anticipated

The resulting organizational structure and operation follow:
- Jobs are not rigidly defined; they are more general, flexible
- Communication outside the chain of command is tolerated
- Coordination is aided by committees
- Emphasis on response to customer need

An innovative environment is characterized by the following characteristics:
- Demand is volatile; change happens suddenly and without notice
- Competitive landscape changes quickly and dramatically
- Rapid rate of change in products or services
- Organization is dependent on research and development
- Government policies are evolving and end position is unclear

The resulting organizational structure and operation follow:
- A structure where employees are driven by goals as opposed to specific tasks
- Employees are flexible with regard to roles and responsibilities—The main focus is a project or organizational goal, not a specific, pre-defined set of tasks
- Communications are frequent to allow quick response to environmental change
- There are few pre-established organizational "rules"

2. Mechanistic vs. Organic

Burns and Stalker (1961) further observed two classes of organizational behavior that were linked to structure. They termed the two classes organic and mechanistic. These terms are defined as follows:
- Mechanistic: Mass-producing organizations that experience a low rate of change
- Organic: Technologically sophisticated organizations that experience high rates of change

The following lists provide some insight into the characteristics of each of these organization types. In mechanistic organizations, the following takes place:
- There is close adherence to a chain of command.
- There is a functional division of work, through which the organization's problems are broken down and managed.
- Each task is of a highly specialized nature; work is coordinated via a formal hierarchy.
- Detailed job descriptions provide a precise definition of rights, obligations, and technical methods for each job.
- Employee interactions tend to be vertical, between a superior and a subordinate.
- Operations and working behavior are governed by the instructions and decisions issued by superiors.

In organic organizations, the following takes place:
- There is little adherence to a chain of command, characterized by a more flexible, divisional type of work.
- Each person's responsibility is understood as being broader than a limited set of rights, obligations, and techniques—no more "that's not my job."
- Jobs are not clearly defined in advance but instead are continually adjusted and redefined as the situation demands.
- Communication occurs laterally, or via a network or matrix structure, rather than vertically.
- Consultation is emphasized over commands; communication generally consists of information and advice rather than instructions and decisions.
- Employees are motivated by a pervasive commitment to the organization's goals, as opposed to the system of rewards and punishment that define a mechanistic organization.

2.4.2 Typical Structure Types (Departmentation)

Dessler (1986) defined departmentation as "the process through which [an organization's] activities are grouped logically and assigned to managers. It results in departments—logical groupings of activities—which also often go by the name of divisions, branches, units or sections."

There are three basic types of departmentation:

- Functional (process)
- Divisional (product, geographical, industry)
- Matrix

It should be noted that most organizations are some mixture of these departmentation types. Large organizations—those with over 1,000 employees—tend to be the exception; they are almost always functional.

Each of the departmentation types is discussed in detail below.

1. Functional

Small organizations usually start with a functional departmentation structure. Most departments contain similarly trained personnel, e.g., departments of accountants, engineers, purchasing specialists, manufacturing personnel, etc. The focus of the organization is efficiency.

This structure is based on a division of labor with a strong chain of command and managers with spans of control limited to one or a few of the organization's functions. Both communication and coordination are difficult in large organizations because there is only one common manager—the one at the top. This structure works best in a low-technology environment. It uses strong rules and procedures for coordination. Training is easy because all like employees are in the same group. The primary feature is centralized executive control.

In these organizations, environmental changes can overwhelm the top executive, as he or she has a narrow scope of functional experience. Succession of the top executive is also difficult to plan for, as few people within such organizations have insight into all of the key functions.

2. Divisional

Divisions are copies of the original parent organization. Each division has its own support staff, suppliers, and customers. The division is tied financially, in some manner, to the parent. If additional resources are needed, the first source is usually the parent. If the parent does not supply the needs, it has the option to abandon the project or to seek external sources of funding. Each division can succeed or fail, depending on its own efforts.

Large division organizations, such as those of major auto companies, do not behave like true divisions. They are so large that they act as if they are functionally organized. Johnson and Johnson, with its 200-plus divisions, is the example most cited as a true divisional organization. It tries to grow by forming new divisions that are successful while shutting down those that do not make a profit.

The following are characteristics of product divisions:

- Decentralized decisions
- Easier evaluation, based on accomplishment
- Organization focuses on products or services, not individual departments
    - Produces general managers
    - Responds more quickly to changes in the environment
    - Requires duplication of resources

In general, it is appropriate to use functional organization in the following situations:

- When efficiency is more important than responsiveness
- With narrow groups of unchanging products and customers
- With stable environment, low technology, small organization

There is always a part of an organization that is functional. It is not a handicap in the lower levels or in small organizations.

Use a divisional structure in the following situations:

- New products or services are likely to be added to the organization
- Flexibility is required for decision makers
- Profitability depends on the development of new products or services

Following are some implications for coordination (for divisions or functional organizations):

- For routine, predictable tasks, use rules.
- The more interdependent organizational units are, the more difficult coordination is to achieve.
- The more diverse the goals of the organizational units, the more difficult coordination is to achieve.
- The more there are unexpected problems, the less reliance should be placed on rules for coordination.

3. Matrix

This is the project-based structure. Project managers manage projects, including project finances, project personnel, and project customer relations. Functional managers provide the projects with manpower from their specialized departments. They also are responsible for the professional development of their employees, as well as personnel-related matters such as evaluations. Each project employee is responsible both to the project manager and the functional manager. Each employee may work on several projects simultaneously.

The matrix organization violates some of the classical management concepts:

- *Authority should be equal with responsibility.* The project manager has all of the responsibility for a project but frequently does not have the authority to take appropriate action. The functional manager exerts control through personnel assignment to projects.
- *Unity of command.* Everyone in a matrix team has at least two bosses—the project manager and the functional manager.
- *Division of labor.* The functional departments tend to dominate project teams and division of labor remains intact.

Typical problem areas within the matrix structure follow:

- *The functional organization does not understand its proper role in the matrix.* Because of the functional organization's project-related obligations, it frequently must neglect its knowledge-base responsibilities (e.g., maintaining the knowledge base, deciding what skills will be needed in five to ten years, deciding what skills to develop in its employees and which to obtain through hiring from the outside, etc.). The functional manager does not adequately fulfill the responsibilities of his or her role.
- *Evaluation of employees.* Who does this, project manager or functional manager? It should be a team effort, but the functional manager frequently does it in a vacuum.
- *Who picks team members?* The functional manager might assign employees to projects based on that manager's priorities, not based on the employee's suitability for the specific project. In other words, staffing frequently optimizes the needs of the functional department, not the needs of the project.
- *Leadership style of the project managers.* Inadequate training of the project manager is the norm. He or she is frequently expected to perform without being given proper tools, education, or resources.
- *Support systems.* In order to make adequate decisions, the project manager must know how much has been charged to his or her project in terms of time and money. The organization frequently does not provide the project manager the support needed to track these charges.
- *Inadequate follow-up.* The question "What did we learn from past projects that we can apply to future projects?" is often difficult to answer in a matrix structure, making it hard for the organization to learn from past mistakes. The reason the question doesn't get asked or answered has a lot to do with the frequent coming and going of employees on a given project: that is, few employees who start the project are there at its end.

- *The larger the organization, the more difficult it is to run the matrix.* Successes tend to be in smaller organizations. Many organizations attempt to put many layers of bureaucracy on top of a matrix. This is a particularly deadly combination.

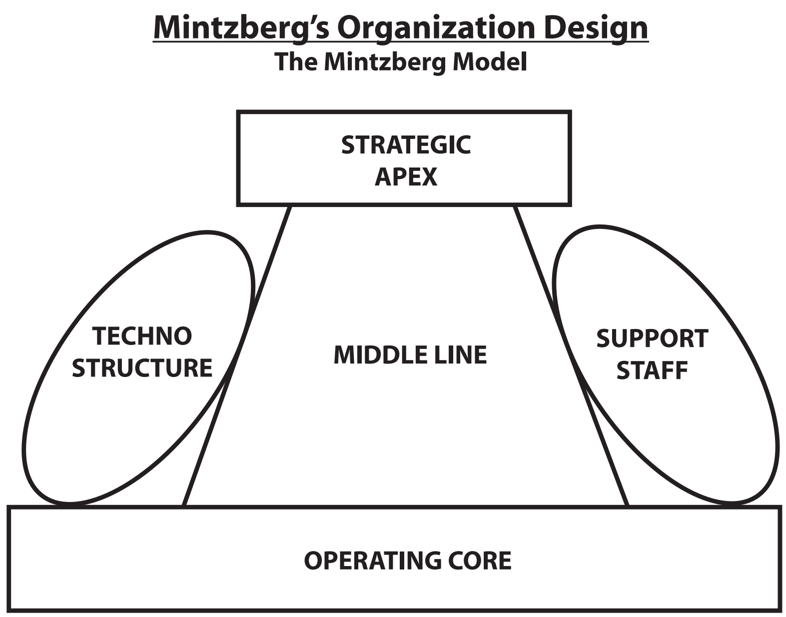
2.4.3 Models of Structures

Mintzberg's Organization Design

Mintzberg (1979) proposed a different model for organization structure. His model contained five common elements that have different sizes and functions depending on the structure's purpose. He observed that structures for professional offices, for instance, are different from those of mass manufacturers.

The basic elements of Mintzberg's model are shown in Figure 2-9.

Figure 2-9. The Mintzberg Model. From *Structures in Fives: Designing Effective Organizations*, by Henry Mintzberg, 1983, Englewood Cliffs, NJ: Prentice Hall.



The five elements follow:

- Strategic Apex
- Middle Line
- Operating Core
- Technostructure
- Support Staff

Each element is described below.

The *Strategic Apex* includes the following:

- The board of directors
- The president or CEO
- The president's staff
- Board committees

The *Middle Line* links upper management with the Operating Core. It includes the following:

- Vice president for operations
- Vice president for marketing
- Plant managers
- Regional sales managers

Technostructure is comprised of the staff groups that support the Operating Core. A large Technostructure is required to standardize work processes, increase efficiency, implement automation, and issue reports on cost and competitive position. Training is included here as an effort to increase productivity.

Support Staff offer services to the organization as a whole:

- Legal counsel
- Public relations
- Human resources
- Payroll, purchasing
- Mail
- Cafeteria

The *Operating Core* is composed of those who are doing the work that meets the primary goals of the organization. They are getting the job done and provide the value added for the organization. They provide the basic service of the organization. In an engineering firm, engineers form the operating core, as do accountants in an accounting firm, and so forth.

Mintzberg's five basic elements are found in all organizations. The relative size and significance of each element can be used to characterize and/or recognize the particular type of structure. There are five basic types of configurations, which are described below.

Five Basic Configurations

1. Simple Structure

The *Simple Structure* has a top and bottom without a Middle Line. This is how many organizations begin. The owners do everything. There is no need for additional people until it is justified by growth. Growth comes easily in this streamlined structure. Communication throughout the organization is natural.

2. Machine Bureaucracy (MB)

The *Machine Bureaucracy* (MB) is characterized by a large Middle Line and Technostructure. Control and efficiency through standardization are emphasized. Communication is typically through top-down channels and comes from either higher management or powerful staff groups. Organizations that have mass production of standard products are most likely to use this structure. Tasks are highly specialized, routine, and controlled by procedures, rules, and policies. The Middle Line ensures that procedures are carried out, handles disturbances from workers, and acts as liaison between the Technostructure staff groups and workers in the Operating Core.

The emphasis is on efficiency; changes in product, environment and innovation are slow in evolving. If the environment changes rapidly—such as when a competitor introduces a revolutionary new product—the machine bureaucracy responds slowly. It is more likely to lower prices to keep customers from buying the new product. Developing a competing product will take a relatively long time.

3. The Professional Bureaucracy (PB)

The *Professional Bureaucracy* (PB) organization is dominated by the skills and abilities of the Operating Core. Medical organizations, legal firms, accounting firms, and universities have been described as Professional Bureaucracies. The Technostructure is small because most of the organization's skills are in the Operating Core. The Support Staff is large in order to give the Operating Core enough support to be effective. The Strategic Apex is small compared to other structures. It has less real power due to the expert power residing in the Operating Core.

The environment is both complex and stable. Changes are usually accommodated by hiring those with the necessary skill sets. Internal change is slow, and communication is fragmented along specialized skill lines. Generally, organization-wide communication is lacking.

4. Divisionalized Form (DF)

The *Divsionalized Form* (DF) is used in companies with self-contained divisions that are similar in nature to the parent corporation. A classic example is a company like GM, where both the parent and its divisions are Machine Bureaucracies. Companies like Johnson and Johnson have many (160) small, organic divisions. The parent has a small Technostructure and large support staff, while the divisions have a Technostructure that is very different from the parent and is unlikely to have a corporate support group. The divisions are normally similar to each other, but may or may not be similar to the parent.

There are two types of Divisionalized Forms: large bureaucratic parents with large bureaucratic divisions, and organic parents with similar, smaller, more organic divisions.

5. The Adhocracy

Burns and Stalker (1961) identified the need for a flexible organic structure. This is the Adhocracy, which is an organization that is composed of cross-functional teams that change with the needs of the organization. The nature of the Adhocracy is for employee roles to continually change with specific projects. Thus, it is a continually innovating structure. WL Gore and Associates is an example of an Adhocracy. Teams work on product development with team members doing the tasks needed by the project. Connection to upper management is more consultative than by mandate.

The matrix structure was intended to be adhocratic; however, it did not work out that way.

The Operating Adhocracy

Multi-disciplined teams innovate and solve problems directly on behalf of clients. The Operating Adhocracy engages in creative effort to find novel solutions to client problems. Administrative and operating work tends to blend into a single effort. The organization employs experts who are available to project teams as needed.

The Administrative Adhocracy

The Operating Core is separated from the Strategic Apex and Middle Line. Projects are managed by the Adhocracy, but the Operating Core is contracted or outsourced. This allows the organization to contract with the best organization for a particular project.

Management in an Adhocracy

Managers exercise little supervision. They are more consultants than supervisors. They are available to assist project teams individually or in combinations.

Many organizations attempt to form adhocratic teams when problems are complex or the solution direction is unknown. Most of the time, management tries to regain control somewhere along the way. Successful teams identify a problem, are separated from conventional management, and are allowed to pursue solutions independently. This is the definition of a true team.

Summary

Organizational structure, though not well understood, is a critical part of successful management. It is the middle element of the management model and touches every other element. Structure does not operate in a vacuum and must be responsive to the environment in which it exists and operates. The structure must serve the mission of the organization.

If the organization's environment is marked by speed and rapid change, then an organic structure is needed. It requires that management treat employees as if they were responsible and productive (Theory

Y), as well as incorporate a system such as Likert's System IV or a 9-9 approach on the Managerial Grid. nAchievers should be hired, promoted, and encouraged, and motivators deliberately provided. Hygienes should be maintained at a high level.

If, on the other hand, the environment is slower-paced without an emphasis on technology production, other more mechanistic structures may work adequately. Heavy manufacturing, for example, may use a Machine Bureaucracy with its emphasis on cost control and efficiency.

2.5 Management Systems and Systems Thinking

"Systems," the first of the middle elements in the Integrated Management Model, is narrowly defined as an organization's efforts to align its operational elements with a particular management philosophy. This includes such systems as Total Quality Management, Lean Enterprise, Six Sigma, and others. All such systems are undergirded by a fundamentally sound philosophy, yet most of those implemented in the past 20 years have failed, lasting only one or two years each. This section provides some answers for why those systems failed despite the soundness of their undergirding principles. Much of the material here is derived from the book *The Fifth Discipline* by Peter Senge (1994).

A famous quote from Machiavelli (2008) seems appropriate:

> *It must be remembered that there is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new system. For the initiator has the enmity of all who would profit from the preservation of the old institutions and merely lukewarm defenders in those who would gain by the new ones.*

Improving existing systems, as well as implementing new ones, generates organizational friction that the organization must overcome. Sources of improvements in systems frequently involve technology application and/or improved communication. *The Fifth Discipline* deals primarily with communication and ways to use it to increase the commonality of goals and the use of conceptual thinking.

2.5.1 Systems Thinking

Metanoia—A Shift of Mind

According to Senge (1994), Systems Thinking requires a new way of thinking about an organization. He uses the Greek term *metanoia* to describe this approach. Metanoia, often used in a religious context, means a fundamental change in the way we look at things. In the context of organizational change, it means seeing all of an organization's functioning systems as being linked together.

Each system in an organization affects others, frequently in unexpected ways. Goldratt (1992) wrote his best-selling, instructional novel *The Goal* to illustrate this principle. He demonstrated that an organization produces only as fast as its slowest process. This impedes the productivity of those processes that are capable of producing more quickly. His remedy is to continue to improve the limiting processes. This rationale is an example of taking a systems view.

Senge points out that the Douglas DC-3 airplane effectively integrated five systems that had never been combined on a single airplane. Except for the engine system, all modern aircraft have these technologies in use. The combination of technologies has the potential to produce innovative products. This is possible, even encouraged, by systems thinking.

Systems Thinking Disciplines

To view an organization in terms of its functioning systems, Senge employed five disciplines:

- Systems Thinking – learning to view connected events as a system
- Personal Mastery – the continuous individual improvement necessary to improve the organization
- Building Shared Vision – identifying what the organization is capable of becoming and having everyone understand and agree on that direction; a shared vision guides managerial decisions
- Team Learning – the organization's intelligence is directly related to its members' ability to act in consort. That ability must increase faster than it does at major competitors.

- Mental Models – positive, accurate views of the organization and its direction must become ingrained in order for it to be successful.

Systems Thinking is the fifth discipline. It binds all others together. It is the ability to view connected events as a part of a functioning system. Failure to see the interconnectedness of systems frequently leads to a system's failure. Prison systems, for example, do not always reform their inmates. Once released, many offend again and return to prison. The welfare system is frequently accused of making its recipients dependent on its benefits. The recipients tend to stay in the system for generations rather than becoming self-sufficient. Both systems are intended to be short-term solutions, but neither effectively achieves that goal. The failure is related to the inability to see the system's complexity and its interconnectedness to other systems. To be effective, systems must be examined and developed in a way that identifies their complex elements and their interconnectedness. It is also vital that actions taken within the system are in line with the shared vision of that system's development.

2.5.2 Organizational Learning Disabilities

Many managers fail to see their organizations as being composed of systems. In fact, most managers are not aware that systems exist. Senge identified this lack of awareness as an "organizational learning disability." The disabilities are as follows:

1. *I am my position.* Isolating positions confounds the formation of a system. Japanese auto manufacturers, for example, use the same-sized bolts in engines. U.S. auto manufacturers, on the other hand, use a different sized bolt for each stress. The latter requires inventories of many fasteners of different sizes, unnecessarily complicating the production process.
2. *The enemy is out there.* This is the assumption that it is always someone else's fault. Assessing blame on some other group frees us from responsibility and the willingness to improve. There is a general failure to see the system.
3. *The illusion of taking charge.* This is a proactive strategy in which you plow ahead in the absence of information. You assume action must be taken, even if this is not the case. Before acting, it is important to first see the problem systematically and then decide if or what action might be necessary.
4. *The fixation on events.* Focusing on events clouds your focus on the evolutionary changes that are impacting the system.
5. *The parable of the boiled frog.* Drop a frog in boiling water and it will jump out. Put a frog in tepid water and turn up the heat, and it will stay until boiled. Most problems get gradually worse, and the organization adjusts without ever addressing or fixing the base problem. We react to sudden changes but are generally less capable of addressing slower changes because of our failure to see the system at work.
6. *The delusion of learning from experience.* Many decisions have effects that are evident only years later. We do not experience these effects, and thus we do not learn from them.
7. *The myth of the management team.* Management teams are used mostly to solve routine problems. They tend to break down under pressure. They tend to focus on compliance rather than focusing on problems in the current system.
8. *Disabilities and disciplines.* This is failure to see the effect of policies and act in the organization's best interest.

The Beer Game

When placed in the same system, people, different people tend to make the same kind of mistakes. It is only by analyzing one's place within a system that problems are identified and proper solutions implemented.

This problem is aptly demonstrated by the "Beer Game," a well-known game developed by MIT's Sloan School of Management and played by business-administration students and seminar attendees all over the world. It is described in detail in *The Fifth Discipline*. The premise of the game is as follows:

A song in a new movie popular with young adults and college students mentioned Lover's Beer, a beer made by a small brewery. The few shops that sold this brand of beer noticed an increase in sales shortly after the movie opened. One shop normally maintained 12 cases of Lover's Beer with weekly sales of four cases. The shop's usual order with the distributor was four cases each week. The order would be turned in with the delivery of the new cases of this beer and then processed by the distributor. The delivery of the new order was made four weeks after the order. In light of the beer's newfound popularity, the shop ordered eight cases of Lover's Beer, double the usual amount.

The second week after the movie opened, the shop sold eight cases of Lover's Beer, leaving only eight on hand. The next week, the usual four cases came in and eight cases were sold. The shop had only four cases on hand, and only four cases were coming in next week. They would be out of the beer the next week. Realizing that the movie had a greater impact than first realized, the shop owner ordered 16 cases that week.

Because all of its shops were increasing the size of their orders, the distributor doubled its order with the brewery. The orders for Lover's Beer kept increasing, so the distributor doubled its order once again. The brewery could double the capacity without new equipment. So in a month, it was making twice as much beer as it had previously.

In four months, the brewery, the distributor and the retailer each had more beer than it could sell. Sales went up four cases per week. When the store ran out, it kept doubling its order. The excess inventory stemmed from the fact that no one in the system talked with each other. Instead, order forms did the talking. When the system was disturbed, the disturbance could not be handled and the system broke down.

There are a number of lessons to be gleaned from the Beer Game:

- Structure influences behavior.
  - Systems cause their own crises; they are not produced by external forces.
  - Three sequential players—the retailer, the wholesaler, and the brewery—ordering a consumable product with a long time delay between order and receipt of the product.
  - Structure causes all players to exaggerate demand.
  - All forces responsible for the disturbance were internal. Demand, an external force, was stable.
- Structure in human systems is subtle.
  - Perceptions lead to decisions or to policies that inform decisions.
  - Lack of delivery had greater impact on order than demand.
- Leverage comes from new ways of thinking.
  - Leverage is a potential that is frequently not exercised.
  - Instabilities could be eliminated, but players fail to recognize the system, only their "job."

Learning Disabilities in the Beer Game

Each of the players in this scenario only played his or her position; no one saw the system of interactions or understood how his or her actions affected other players.

- All of the players blamed each other. This precluded them from learning from the experience as it unfolded.
- Each player's attempt at proactivity—that is, ordering more beer—only made matters worse.
- Over-ordering and time delays in delivery worsened the problem, gradually making it difficult for the players to see the problem until it was too late. A sudden jump in inventory would have provoked questions.

In summary, if we understand structure and how it is intended to work, we can alter behavior in a way that generates desirable system outputs.

System structure → Patterns of behavior → Events

Laws of the Fifth Discipline

Senge observed that the actions organizations take to solve problems usually make matters worse. He catalogued many such efforts and called them "Laws of the Fifth Discipline."

1. Today's problems come from yesterday's solutions.
   - Last month's rebate program generated early sales. Now, current sales are off.
   - A retailer cuts back inventory to lower overall costs. Customers are upset because they cannot get products when they need them. As a result, they take their business to other retailers.

2. The harder you push, the harder the system pushes back.
   - Success in getting the job done attracts more work and creates higher expectations.
   - Low-income housing and job training for inner-city inhabitants attract more people to the city. Additional resources are not available to serve the enlarged population, so the program fails to meet goals.
   - Food for developing countries reduces deaths but also results in a larger population. This brings more malnutrition. Local farmers and markets are destroyed by additional UN giveaway programs, making them more dependent on aid.
3. Behavior grows better before it grows worse.
   - A low-leverage intervention produces a natural, short-term benefit followed by a delay and then by disaster.
   - The problem: Symptoms are being dealt with, not the root cause of the problem.
   - When sales are down, for example, some companies cut back on research and development. Cutting R&D means cutting the creation of new products, new products that might have generated additional income.
4. The easy way out usually leads back in.
   - We use familiar solutions—what we know best—regardless of the nature of the problem or the system in which it exists.
   - If a sports team does not have good-enough athletes, fire the coach.
   - If goals are not met, blame someone else (e.g., employees, the Japanese, old equipment, U.S. workers, etc.).
   - The net result: The problem has not been solved, and the time that could have been used for generating and implementing a real solution has been wasted.
5. The cure can be worse than the disease.
   - The long-term, most insidious consequence of applying non-systemic solutions is increased need for more and more of the solution. Short-term solutions lead to long-term dependency. Relief agencies help a host institution, only to leave the system fundamentally weaker than before. Do we give people food or teach them how to produce food? The short-term solution is much easier and quicker than the longer-term fundamental solution.
6. Faster is slower.
   - Every system has an optimal rate of change. Trying to go faster is a tremendous drain on resources and has little impact.
   - Everyone tried Total Quality Management and abandoned it.
   - It takes two years to begin to change an organization. Most CEOs cannot wait that long, or they do not last that long.
7. Cause and effect are not closely related in time and space.
   - The effects of many actions may not be immediately detectable.
   - The challenge of a new competitor, for example, is not felt quickly. It will take years before the impact is significant. Likewise, an effective response to a problem may not be effective immediately.
8. Small changes can produce big results—but the areas of highest leverage are usually the least obvious.
   - Small, well-focused actions can produce significant, enduring improvements. This is the principle of “leverage.”
   - For example, at a time when personal savings were at an all-time low, personal debt was soaring, and the national debt was rising rapidly, there was great concern that there were not sufficient resources to finance needed business expansion. IRA and then 401K tax shelters were created. They increased available capital, reduced consumption and taxes slightly, stalled inflation and allowed the economy to stabilize without crashing.
   - The focus on customer service or product reliability is also leverage.
9. You can have your cake and eat it, too, but not at once.
   - You can have a product that is low cost and high quality, but time and effort are required. To figure how to have both, you must be able to see your organization as a set of systems and processes. Taking a snapshot view of each function independently will not be adequate.

   - It takes time, but by eliminating scrap and rework, reducing inspection, increasing Just-in-Time manufacturing, and creating better designs and material, you can achieve lower production costs, lower warranty costs, increased customer loyalty, reduced sales promotion needs, and so forth.
   - Leverage is improving both—cost and production quality—over time.
   - Most organizations have twice the number of managers than required, and that causes problems. Also, managers frequently come from a finance background and subsequently tend toward isolated snapshot thoughts, not process thinking.
   - Leverage: Reduce management as fast as the system can assimilate the change.
10. Dividing an elephant in half does not produce two small elephants.
    - All of the organization is needed. Parts cannot be separated and still have a functioning enterprise. Challenging managerial issues requires viewing the system as a whole, not focusing on its isolated parts. Similarly, organizational change must be guided by systems thinking, not through a series of fragmented actions on isolated parts of that system.
    - For example, when a firm acquires a new business and abandons old ones it usually delays the firm's problems rather than solving them. While replacing old parts of the system might have short-term positive effects, it typically causes problems downstream. The problem here is the organization's failure to see itself as a complex system, and instead, as a set of isolated businesses.
11. There is no blame.
    - Most systems' problems are internal. The cure lies in assessing and acting on the relationships among the system's internal parts. Most organizations, both industry and government, rush to attribute blame when a problem occurs. This takes the focus away from where it should be, which is looking at the system as a whole to identify and resolve its problems.
    - If an organization's systems are not performing as desired, they can be improved by increasing the personal mastery of those who are managing and operating the systems. Positive changes also require changing mental models to adjust expectations. Team learning must be increased to identify and solve problems. Shared vision must be established to give teams accurate goals, and systems thinking must be employed to see how systems interact. In other words, all of the disciplines are required for successful development and implementation of better systems.

A Shift of Mind

There are two types of complexity: detail complexity and dynamic complexity:

- Detail complexity is the complexity of many interrelated variables.
- Dynamic complexity is the complexity of cause and effect, where the effects of interventions, over time, are not obvious.

The real leverage in management situations lies in understanding dynamic complexity, not detail complexity. To effectively manage, it must be understood that any given action might have dramatically different effects in the short and long terms. To understand and intervene in a dynamically complex system, a manager must use intuitive observations, carefully integrate resources, and identify trends. It also requires seeing change as a process involving complex interrelationships rather than just a linear cause-and-effect chain. It means remembering that implementing the seemingly obvious solution to a problem does not always produce an obvious or desirable result.

One electrical equipment manufacturer had a small plant in a town of 50,000 people. Corporate headquarters staff members were not satisfied with the labor costs there. They did a cursory study and learned that labor costs in Puerto Rico were less than half that in the existing plant. They had a new plant built there and moved the entire facility. As soon as production started, a substantial number of complaints came in. The products were not built according to specifications. The written plans and prints were followed carefully. It was discovered that employees of the former plant made changes that customers requested but never wrote down the changes. The company had to fly several former employees to Puerto Rico for six months to get the products up to date.

The company lost some customers, had unexpected costs, and failed to meet profit goals for several years. It did not take into account the knowledge of the employees and their relationship with customers. Headquarters staff looked at the plan as detail complexity. Employee knowledge and customer relations introduced dynamic complexity that was not anticipated.

2.5.3 The Five Core Disciplines

- Personal Mastery
- Mental Models
- Shared Vision
- Team Learning
- Systems Thinking

1. Personal Mastery

The Spirit of the Learning Organization

The first revelation follows: The Fifth Discipline is almost a religion.

An organization learns through its people; they are the organization's change agents. For an organization to improve, its employees must grow and improve. Personal Mastery recognizes the tie between organizational and personal improvement.

Our traditional hierarchical organizations are not designed to provide for employees' higher-order needs—self-respect and self-actualization. "Managers must redefine their jobs, must give up planning, organizing and controlling. They must realize the almost sacredness of their responsibility for the lives of so many people" (Senge, 1994, Ch. 9). Yet, massive layoffs are destroying the fabric of society. Pension plans are being looted. People are being laid off just prior to retirement to forego pension payouts. Such actions show little appreciation of the contribution of employees.

Mastery and Proficiency

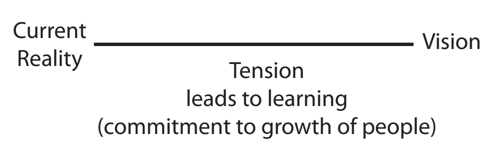
Personal Mastery involves approaching life creatively, not reactively. Consider two movements:

1. Continually clarifying what is important to us.
2. Continually learning how to see current reality more clearly.

People with a high level of mastery share several basic characteristics:

- They are motivated by a special purpose that lies beyond their own vision and goals.
- They experience their vision as a calling rather than just a good idea.
- They assume that current reality is an ally, not the enemy.
- They work with forces of change rather than resisting them.
- They are committed to continually seeing reality more accurately.
- They have the capacity for delayed gratification.

Figure 2-10. Personal Mastery Model



Personal Mastery is the discipline of continually defining the vision and institutionalizing learning so as to facilitate the realization of that vision for yourself and your organization.

Personal Vision

"The ability to focus on ultimate intrinsic goals, not only on secondary goals, is a cornerstone of personal mastery" (Senge, 1994). The organization must create an environment where its employees can meet their intrinsic needs through their work. It is that kind of employee that makes the organization productive and competitive. In this way, the organization's vision provides for employees meeting theirs. It is more than simply focusing on what you want to get rid of (negative vision) or how you might alleviate the symptoms associated with current problems (diminished vision).

Vision is also intrinsic, not merely relative. It is about continually achieving excellence, not only striving to be better than your competitors. It is about aiming for the highest level of customer service, for example, not just being Number One.

All management decisions should be guided by this vision. The vision sets the culture for employees to flourish. If management decisions appear to contradict the organization's vision, then the impact ripples negatively throughout the entire organization.

Leveraging Creative Tension

The gap between current reality and vision is called creative tension. It is the central principle of personal mastery, integrating all elements of the management discipline. A wide difference between current reality and vision is an indication of how much work needs to be done, how much learning will be necessary—learning increases personal mastery, may impact mental models, may make you reevaluate the vision, and challenge its value.

Leveraging creative tension requires that an individual or management be honest with himself or herself and with the firm about what the vision is, to achieve it, and where he or she or the organization currently stands in relation to it. It is also vital that the decisions made are well aligned with the vision and are borne out of an accurate understanding of current reality. Remember that an accurate understanding of the current situation is equally as important as the vision itself.

For example, a project engineer was expecting a positive customer review of a large project in the middle of the design cycle. The customer was dissatisfied. The customer wanted reliability emphasized where the engineer minimized cost. There was a misunderstanding on the vision. Once that was clarified, the project proceeded to a successful conclusion. The engineer had a clear but erroneous view of current reality. That is why there are mid-course reviews. Both current reality and vision are re-evaluated.

Successful leveraging of creative tension requires regular, frank communication with the organization. The communication should clearly telegraph what the organization's vision is, where the firm currently is in relation to it, and the steps that are necessary to achieve it. Communication of this kind encourages individuals within the organization to accept the vision and drives them toward achieving it.

When current reality is perceived as growing further from the vision, emotional tension increases within the organization, as does the pressure to reduce the goals associated with that vision. Personal mastery means resisting this pressure and working to understand and implement the actions necessary to bring current reality in line with the vision.

Using the Subconscious, or You Don't Really Need to Figure It All Out

Complexity is best dealt with using the right side of the brain. Most solutions to organizational problems are not arrived at by standard analytical approaches. Students, for example, cannot sit down and write a term project immediately after all data is collected; the subconscious first needs time to assimilate the information, organize the effort, and develop an image of the completed project before it can actually be drafted. When engaged in organizational-improvement work, first develop a mental image of the organization as you want it to be. Ask yourself, "What will the organization look like? How will it function?" These images are the product of the subconscious and should be shared with the organization in order to make them a reality. Remember, if you have not *seen* the vision, others will not recognize it either.

Personal Mastery and the Fifth Discipline

- *Integrating Reason and Intuition.* Intuition is the creative side of an individual and is used to generate vision. The rational side must be used to test the alternatives generated through this subconscious act.
- *Seeing Our Connectedness to the World.* As we grow older, we have a greater tendency to respond in patterns based on experience. We must guard against this and continue to widen our horizons. *In Search of Excellence* advises that letting lower levels of the organization develop alternatives keeps the whole organization moving.
- *Compassion.* We all work within systems, and everything we do within a system has an impact on others and vice versa. The better we see a system, the more compassionate we tend to be because we are better equipped to take account of our impact on others.
- *Commitment to the Whole.* The system is larger than we are and will eventually serve the world.
- *Fostering Personal Mastery in an Organization.* An organization's culture must encourage personal mastery. It must value growth and create a culture where team members feel safe to create and share their visions. The culture must also offer members of the organization a systemic view of the organization, as well as an understanding of how it relates to its environment.

2. Mental Models

Why the Best Ideas Fail

New insights fail to get put into practice because they conflict with deeply held internal images of how the world works. These internal images are called mental models. People do not always conform to their espoused theories, but they *do* conform to their mental models. This is potentially problematic, as most mental models are inaccurate and/or incomplete. For example, U.S. automakers have been guided by a mental model that assumes U.S. car buyers are much more concerned about style than performance and economy. This incorrect assumption ultimately hurts sales of U.S. autos in the U.S. market.

By becoming aware of these models in yourself, you can ultimately predict—and potentially change—your behavior as it relates to them. This is vital for the effectiveness of the Fifth Discipline. If you want to think systematically, you must be aware of how your mental models potentially predispose you against systems thinking. Awareness of your mental models is also vital for learning. Without such awareness, your capacity for learning is often impeded, as is your ability to effectively understand and improve the functioning of your organization.

Business Worldview

Shell Oil determined the most likely oil supply scenarios. When OPEC would shut off the oil, Shell had a plan. The problem was their managers did not believe in the possibility. The scenario went against their mental model.

Shell recognized the problem and managed to break those models so that when the oil was shut off, it decentralized control to allow for maximum flexibility. Their competitors did the opposite.

Skills

Problems with mental models include what Senge (1994) calls *leaps of abstraction*. This is where one or two facts fit with a preconceived notion and become the basis of a bad decision.

The following information helps to recognize leaps of abstraction:

- Two data points allow a generalization.
- Two workers loafing—no one wants to work anymore. Two data points—two workers not working allow evidence for a preconceived bias. All must be aware of the problems that this causes.

Balancing inquiry and advocacy. Ask questions to learn and then take a stand. The organization should encourage understanding prior to decisions. Institutionalize inquiry so that people will know what to expect. It isn't persecution; learn to provide data.

Face the distinctions between espoused theory and theories in use; what we say vs. what we do.

Prescriptions for Improvement: Internal Boards

A manager learning to work with a group is more effective than a manager attempting to communicate with team members one-on-one. More checks of mental models (assumptions) are made when the group works in concert. Some organizations have internal boards of recognized experts who are available to a wide range of employees. The expert board can meet together to help the organization define positions on new ideas. If a subordinate is right about a matter, a board can help convince a boss and the boss's boss. Forward-thinking organizations require managers to develop alternate scenarios and plans of action for each decision. It gets the manager out of the rut of assuming one future possibility.

3. Shared Vision

A shared vision, especially one that is intrinsic, uplifts employees' and customers' aspirations. It helps members of the organization answer the question, "What does the organization want to create?" The shared vision must be a force of impressive power. As such, it will foster experimentation and risk- taking, as well as provide the organization with long-term focus. It is also vital to creating a culture of learning.

Remember, an organizational goal limited to defeating an opponent or competitor is only transitory and can easily slip into a defensive posture. It is much smaller than a shared vision and unable to sustain a company's long-term success.

Discipline of Building a Shared Vision

The only vision that motivates you is your own. It is therefore key that the organization encourages the development of personal vision and personal mastery, as these are the basis for building a shared vision. When members of an organization develop a personal vision, the organization is capable of building a shared vision.

Personal to Shared Vision

Vision is too frequently developed by top management and a consultant and then fed to the organization in a uni-directional, top-down fashion. To be successful, however, leaders must continually share the vision. They must allow others to commit to it and even expand it, continuously.

Depending on how the vision is shared, team members might accept or reject it in a variety of ways:

- Commitment – Will make the vision happen. Creates whatever "laws" are needed to enact the vision.
- Enrollment – Wants to see the vision achieved. Does what is expected within the spirit of the "law."
- Compliance – Genuinely sees the benefit of the vision and does what is expected and potentially more.

There are two modes of compliance:

- Formal – Does what is expected
- Grudging – Does what he or she can get by with
- Noncompliance – Against the vision
- Apathy – Does not care one way or the other

Committed people perform miraculous tasks. The team that developed the Macintosh computer, for example, signed the inside of the computer case, where no one would see, as a sign of their solidarity and as an indication that the company valued the accomplishments of every team member.

For "converting" weak supporters of the vision, as well as those who are noncompliant and apathetic, there must a developed, well thought-out plan. In doing so, remember that many people have never been asked to commit to anything, so approach the issue deliberately. A critical mass of committed employees is necessary to establish the vision.

For the remainder of the discussion of personal vision and mastery, it is important to understand the meaning of the following terms:

- Vision – A picture of the future the organization and its members seek to create
- Mission – The reason the organization exists
- Values – How the organization acts, consistent within the mission to achieve the vision

Why Visions Die Prematurely

Visions spread when reinforced through clarity, enthusiasm, communication, and commitment. That said, a number of factors might cause a vision to die prematurely:

- Too many diverse views are in play; focus dissipates and unmanageable conflicts arise.
- People are overwhelmed by the demands of their current reality and lose focus on the vision.
- Employees are too busy today to focus on tomorrow.
- The vision is not continually and enthusiastically shared, so people lose their zeal for it and forget their connection to one another.

4. Team Learning

There are three critical dimensions to team learning:

- Thinking insightfully about complex issues, such as the impact a decision has on the global economy. Here teams must learn how to tap the potential of many minds over the one.
- Innovative, coordinated action. To have an impact, many must act together in concert. A division of labor combats and/or inhibits such attempts.
- Learning must happen throughout the organization. Since most implementations are done through and by multiple teams, all involved must understand how their actions or function impacts others. The role of Likert's Linking Pin is vital in this respect.

Prototypes

Prototypes are recurring situations that use a combination of disciplines in an approach to solve problems or deal with major issues.

5. Systems Thinking

Systems Thinking is the fifth discipline. It binds all others together as described in Section 2.5.1.

2.5.4 Openness and Localness

Openness

Most members of the workforce are interested in something more than just internal politics. They want to feel like their work contributes to a larger purpose, whether that's the advancement of the organization's agenda or that of their community or family. In other words, individuals frequently want their own personal vision to align with a larger, organizational goal.

Effective management facilitates this alignment by fostering a culture of reflective openness. In such a culture, management is willing to hear and consider the validity of an individual's thoughts on its managerial decisions. This is more than simply giving employees a forum for speaking their mind (although this is a useful start) and also different from making decisions via group consensus (this is not a particularly practical way to run an organization). Rather, reflective openness requires that managers create a culture where employees feel free to comment on managerial decisions and can expect that such comments will be given their due consideration.

This is especially important in large organizations where top management is far removed from the front lines of production. In these types of organizations, it is frequently the men and women closest to production who have the best sense of what's broken and how to repair it. Without a culture of reflective openness in place, employees are less likely to share their insights and recommendations with management. This would be a true loss for the organization.

Localness

In hierarchical organizations, executive management does the thinking while local employees *act*. In most organizations, however, this centralized model no longer suffices. Those closest to a situation must be able to both think *and* act. To meet these demands, effective organizations implement a decentralized form of management known as *local control*.

In order to implement effective local control, the organization must be dedicated to team learning, quality thinking, and reflection. It must develop and disseminate a shared vision and implement mental models that ensure complex business issues are understood at all levels. It is also important that learning be conducted within the context of actual responsibilities. When people's fates lie in their own hands, learning matters.

While the need for local control might be obvious, few managers actually implement it. Many, for example, are too invested in remaining "in control" themselves. Others claim to have tried local control, only to find that local team members are not good decision makers. These assessments, however, are frequently premature: they are made before local managers have actually had enough time to obtain the experience necessary to become good decision makers.

Similarly, if management merely institutes local control as a short-term response to a change in the competitive environment or as a temporary means for cutting costs, it is not likely to last when conditions improve. To truly hold, local control must be instituted as one of the organization's core values. This is the case at Johnson and Johnson, for example, where more than 200 local divisions regularly make their own decisions.

Sometimes, more ambiguous situations are pushed down for solution while top managers retain those issues that are more clear-cut. This inverts the intended effect.

The New Role of Central Management

Within the context of local control, central management's key function is to design the organization and allow local management to run it.

Forgiveness

Good managers inevitably make mistakes, and within a learning organization, these mistakes must be seized as learning opportunities. Those who make them should be forgiven. As a Johnson and Johnson CEO once pointed out, "If you are not making mistakes, you are not making decisions and taking risks. We won't grow if you don't take risks" (Senge, 1994, p. 300).

A Manager's Time

According to Senge, most organizations assume that a manager's success is directly proportionate to the amount of time spent in motion. Incisive action, however, must not be confused with incessant action. To be truly effective, a manager should also be spending time reflecting and analyzing. As one of the organization's experts, the manager should be continuously developing hypotheses, acting, and then pausing to reflect on results. It is only in this cycle of action and reflection that the manager can attain personal mastery and success. Otherwise, neither the manager nor the organization will be able to learn from past mistakes.

Similarly, most organizations require that their top managers make too many decisions. A top manager's time, however, should be reserved for complex decisions that relate to the organization's direction and future. As Bill O'Brien, former CEO of Hanford Insurance Company said, "It's a big year if I make 12 decisions" (Senge, 1994, p. 304). It's the organization's lower levels of management who should be responsible for less complex decisions or those without significant organizational impact.

Microworlds

Computer simulations of business activities are a useful way for management to develop effective strategy. Using simulation software, managers may test a variety of approaches to any given business scenario or problem, gauge the results of each, then select the best alternative. They can then disseminate that solution to key managers throughout the organization.

The Leader's New Work

To transform a company or practice into a learning organization, its leader must possess the following traits:

- *The Leader as Designer.* As a successful organization expands, managers with a diverse range of backgrounds and experiences are brought in, potentially diluting the organization's vision and values. It is the leader's job to make sure that new managers are quickly and efficiently assimilated into the organization in such a way that it maintains its vision, values, and mission.
- *Leader as a Steward.* The purpose story is the organization's "big picture" story. It describes how and why the organization functions, including the value it creates for its community and for society in general. It is through this story that employees can positively relate to the organization. It is the leader's responsibility to tell this story and make sure that it is effectively disseminated throughout the organization at all levels. The rate at which organizations learn and live the story is its only true competitive advantage in a knowledge-intensive business.
- *Leader as Teacher.* The leader influences events, patterns of behavior, systemic structures, and the purpose story. The continual retelling of these purpose stories is a key leadership function, as it gives people a positive sense of the organization's value. It is rare that you will find a successful organization that does not have a positive purpose story.

How Can Such Leaders Be Developed?

Good leaders continually work at honing their leadership skills. They include the following characteristics:

- Clarity and persuasiveness of their ideas
- Deep level of commitment
- Openness to continual learning

A charismatic leader without these qualities is charismatic without substance. It is the combination of charisma and leadership skills that makes for a strong leader.

2.5.5 Archetypes

Nature's Template

Recurring patterns of structure are called archetypes. We are held prisoner to these archetypes if we lack awareness of them. Some of the most prevalent of these archetypes are discussed below.

Archetype 1: Limits to Growth

Organizational growth is frequently limited by management's failure to add resources in areas that require them. Systems thinking enables leaders to identify these growth limits and make the necessary resource adjustments. For example, a talented engineer started a consulting company. He initially did all the work himself: developed bids, did the technical work, answered the phone, sent out invoices, paid the bills, and so forth. The business grew, so the owner hired another engineer. Meanwhile, the owner continued to do the administrative work as well as the primary technical work. Eventually, he was overloaded and was getting behind in paying suppliers and bidding for future jobs. His solution to the problem was to work harder. As the jobs got further behind and the paper work further backed up, the owner finally hired an administrator. Within a month, the paperwork was in order, bills were paid, and bids were prepared for new jobs. The lack of an administrator was the limit to the firm's growth.

When we experience a slowing of growth, our first strategy is typically to try harder. The more successful approach, however, is not to push growth but to identify and remove the factors that are limiting it. It is important to remember that with every growth effort, there is usually a system acting to oppose it. Leverage lies in identifying that system and making the necessary changes. The primary reason that Quality Circles, Total Quality Management, and Just-In-Time inventory systems quickly stagnated or failed after grand beginnings, for instance, was because management was rarely able to identify and remove the structures and systems that were prohibiting their growth.

Archetype 2: Shifting the Burden

When a manager is unwilling to attack a problem at its root, because doing so is too difficult or costly, and instead opts only to alleviate the problem's symptoms, he or she has shifted the burden. Doing so might have short-term benefits, but these are usually far outweighed by the ongoing negative impact of the unresolved problem. Taking this symptomatic approach also distracts resources from resolving the main problem and perhaps results in missing a critical opportunity.

As an example, a U.S. business is losing domestic business to a foreign competitor who is able to offer a better-quality product at a lower price. The U.S. company considers the following options:

1. Lobbying for higher tariffs
2. Cutting costs by laying off workers
3. Increasing quality and productivity

If the company shifts the burden and opts for 1 or 2, then 3, the option most likely to address the root problem, will become much more difficult to implement. Laying off workers, for example, might generate labor unrest, including a strike. However, even if labor problems were not an issue, option 3 is still likely to be the most challenging but also the one most likely to improve the company's long-term prospects.

In order to avoid shifting the burden, leverage lies in the following principles:

1. Strengthen the fundamental response. Identify and face the problem.
2. Weaken the symptomatic response. Resist the temptation.

The first principle requires an organizational culture that encourages a shared long-term vision. The second principle requires leaders who are willing to expose short-term solutions as frauds.

Archetype 3: Growth and Underinvestment

The time to invest in capacity is before you need it, not after. If the need for capacity already exists, you risk the cost of losing sale, and facing the potentially higher cost involved with producing more product than the system has the capacity for. You also risk problems with quality.

It is easiest to blame a failure to invest on some external force, such as the competition, new regulations, or the union, but most problems are internal. Leverage is in small, focused actions that have the greatest positive influence on the system. You don't have to do everything, just the right things.

Expenditures in capacity are likely to be an investment that generates returns. The lesson here is to build capacities in advance. Hold to values. Invest in capacities most related to success. Leverage capacity.

2.5.6 Identifying Management Systems Applicable to Tech-Driven Organizations

Is Anything Missing?

In addition to improving existing systems and identifying systems that are counter-productive to the organization's mission, it is also important to consider which systems put your organization at a disadvantage if they are absent.

Is there a system that promotes innovation? Every organization wants innovation, but if there are not systems that encourage it, it will not happen. Johnson and Johnson, for example, has several ways that an employee with a new idea for a new product can get funding to try it. 3M mandates that each professional employee spend 15% of his or her time working on ideas for which there are no assigned charge numbers.

Is there a system that tracks developments by competitors and research and development in allied industries? It is easy to become so preoccupied by internal activities that external developments are not adequately tracked. One manufacturer was having difficulty making enough material for prompt delivery to customers. It was losing orders to competitors who could deliver faster even though those competitors charged more for a similar material. The manufacturer countered by having employees work massive overtime to fill a warehouse with material so that shipments could be made almost as the sales were made.

As soon as the warehouse was filled, it was learned that a major competitor had developed new material that was 20% stronger and 10% cheaper than that in the warehouse. Millions of dollars of inferior product that was not salable was in the warehouse. The manufacturer's own research and development was under-funded and out of touch with industry developments.

Is there a system that reward's creative and productive employees? Many compensation systems were designed for organizations with many employees doing similar tasks and contributing similar value. These systems are not adequate to industries employing highly skilled knowledge workers. For those industries, the compensation model should explicitly acknowledge the outstanding contributions made by inventors, process developers, innovators, system designers, and so forth. This approach is better suited for recognizing knowledge workers and encouraging them to continue contributing value to your organization.

Summary

The Systems Thinking block of the integrated management model requires that the organization be recognized as a large system made up of many interrelated systems. It forces the engineering manager to view the organization as a whole and not its parts. Systems Thinking is an intuitive process where we are required to "connect the dots" to understand complex situations and to make appropriate decisions. The management of an organization must see that the organization provides opportunity for employees to develop and meet individual goals.

This places a significant responsibility on the engineering manager, but also provides a significant opportunity to make an organization that allows its employees to do their best.

2.6 Leadership

Effective organizational leadership sets the tone for the organization's culture and establishes it as people-oriented. It drives the selection of organizational structure and the choice of management systems, as well as deploys the resources of the internal environment to meet the needs of the external environment.

2.6.1 Management vs. Leadership

It would be a mistake to assume that leadership is the same as management. The two are, in fact, significantly different modalities.

Management involves the following:

- Dividing scarce resources to meet organizational needs
- Organizing and scheduling activities
- Being mission-oriented
- Coordinating the work system with the support system
- Focusing on yesterday, today, and tomorrow

Leadership, on the other hand, involves the following:

- Establishing the vision for what the organization strives to be
- Setting the values of the organization and living by them
- Motivating the organization through opportunity and empowerment
- Focusing on the future
- Giving credit where credit is due
- Allowing the lower levels of the organization to make significant contributions and decisions

Leadership is a necessary ingredient for a productive organization to sustain itself. Management by control alone is not sufficient. Imparting a shared vision of the organization's goals generates the necessary communication throughout the organization and motivates team members to achieve. In fact, intensive communication and shared vision are the most potent of control systems and are in large part the products of leadership.

Without effective leadership, an organization misses out on significant untapped potential. Consider, for instance, the following statistics:

- Fewer than one of every four job holders says that he or she is working at full potential.
- One half say they do not put effort into their job over and above what is required to hold onto it.
- The overwhelming majority, 75%, said that they could be significantly more effective than they presently are.
- Close to six out of ten Americans on the job believe that they "work as hard as they used to."

Leadership is the function that bridges the delta between a team member's capacity to do something and his or her willingness to actually do it. By sharing a vision of what the organization can accomplish, by opening the lines of communication to empower employees, and by demonstrating the interconnectedness of systems to all levels of the organization, team members are far more likely to perform at their full potential.

Strategies for Effective Leadership

In their work on leadership, Bennis and Nanus (1985) outlined the following strategies for effective leadership:

1. *Establish Vision.* In order to create a productive organization, leadership should first establish clear goals in the form of a vision. That vision should encapsulate the best the organization is capable of becoming and should be good or strong enough to pull team members toward it.
2. *Communicate the Vision.* Leaders should communicate the vision to every level of the organization and be sure to translate it into terms that are understandable to each of those levels. If the vision is effectively communicated throughout the organization and is believed by a majority of its members, the vision will be accomplished.
3. *Remain Determined and Promote Trust.* Keep at the vision and trust that your employees will deliver. Promote trust among the organization's various levels and teams; help each to see that the others are doing their best to achieve the vision.
4. *Have A Positive Self Regard.* You must believe in yourself and your ability to work with and change the organization in line with the vision. The Leader is the catalyst for establishing the vision and sustains it through constant promotion.

Leadership Effectiveness Theories

One school of leadership thought, the European school, holds that leadership is a trait that one is born with. It is not a skill that can be taught or learned.

The Harvard Business School relies on case studies as a critical part of teaching. The reliance on case studies suggests that leadership is at least partially based on experience, even if it is someone else's as in a case. It also suggests that leadership can be taught.

Others say that leaders possess certain traits that make them effective. Trait theories, such as intelligence, extroverted personality, social background, and so forth, have been suggested as traits that enable leadership. Results of research, however, are inconclusive. One's supervisory ability had the most significant correlation.

Leadership style has also been studied. A survey instrument was developed to measure leadership. It was the Leader-Behavior Description Questionnaire (LBDQ). It tested four factors:

- Leader Consideration – concern for people
- Initiating Structure – self-starter
- Production Emphasis
- Sensitivity

Only the first two together had a significant correlation with one's ability to be an effective leader.

2.6.2 The Covey Approach: The 7 Habits of Highly Effective People

The 7 Habits of Highly Effective People, by Stephen Covey (1989), takes a more practical approach to leadership. He developed seven leadership habits from research, observation, and experience:

1. *Be proactive.* Actively cause things to happen instead of merely reacting to situations that are "beyond your control." When management reacts, it seeks to return to or sustain the status quo. While appealing—and almost comforting—reacting prohibits progress. Being proactive, on the other hand, allows each member of the organization to look for opportunities to move toward the vision.
2. *Begin with the end in mind.* Like great golfers lining up a shot, leaders visualize where they want their organization to ultimately end up and *then* decide the steps or actions necessary to get there. They must be able to do this amidst the business of day-to-day business activity and frequently in the wake of conflicting business intelligence, forecasts, research, and so forth. It is the leader's function to stick to the vision and keep the organization on the right track.
3. *Put first things first.* Organize and execute priorities based on the organization's goals and values. Covey suggests that leaders learn the difference between Urgent and Not Urgent activities and between Important and Not Important activities. A leader's responsibility is to help identify which activities are Important and then ensure that the organization is prioritizing them. The leader should also make sure that Urgent activities are dealt with as they arise. This is doing the right things first, as opposed to simply doing things right.
4. *Think win/win, or no deal.* The win-lose model of athletics and politics does not help an organization achieve significant, long-term goals. The only organizational decisions that last are the ones that all parties want to work. The emphasis must be on making major decisions as the result of analysis, discussion, and consensus. As with traditional Japanese management, major decisions should be agreed to by all key parties, and when no agreement can be made, then more study is required. All sides must be convinced about and understand the decision. While this may not always be practical, a culture of trust and respect allows difficult decisions to be made.
5. *Seek first to understand, then to be understood. Do not prescribe before you diagnose.* There is a strong temptation to prescribe before we understand, to make the assumption that a situation is similar to one we have experienced. There may be little evidence to support this assumption. Effective listening and observation help us avoid doing this. It is a necessary step in the identification and solution of a problem. After one understands this, he or she has information worth listening to and is more likely to be understood.
6. *Synergize.* Synergy is what happens when all of the organization's principles are working at the same time for a mutually-recognized common good. Trust, confidence, and mutual respect are present and enable the organization to be much more than its members believed was possible. Contributions are welcomed from all levels. High-performance teams can accomplish much more than its members working independently.
7. *Sharpen the saw.* Personal renewal based on exercising the mental, physical, social/emotional, and spiritual aspects of your life is vital to effective leadership. Remember, renewal is a continuous cycle, not a one-time event.

These principles form a useful start for understanding leadership.

2.6.3 The Kouzes and Posner Transformational Leadership Approach

Kouzes and Posner (2002) took a radical new approach to leadership in their work *The Leadership Challenge*. They proposed five categories of leadership skills:

- *Challenging the Process.* The leader searches out opportunities to change, challenge, grow, innovate, and improve organizational processes. Every employee is expected to do the same. Similarly, leaders encourage management and staff to experiment, take risks, and learn from any resulting mistakes.

  Many researchers have concluded that the best companies encourage experimentation. Johnson and Johnson, for example, has been successful with its dedication to experimentation. Each year, new products—that is, those achieved through experimentation—account for 20% of overall sales.

- *Inspiring a Shared Vision.* The leader commits to envisioning an uplifting and ennobling future.This vision must enlist organization members by appealing to their values, interests, hopes, and dreams. This is a frequently neglected part of leadership, as many "leaders" tend to focus on financial matters and thus neglect the potential of a motivated work force.
- *Enabling Others to Act.* The leader fosters collaboration by promoting cooperative goals and building trust. The leader strengthens by giving power away, providing choice, developing competence, assigning critical tasks, and offering visible support. Much of an organization's success comes from the efforts of team members doing work in its lower levels. Enabling those members unleashes their true capabilities and, by extension, unleashes the organization's full potential.
- *Modeling the Way.* The leader must set the example by behaving in ways that are consistent with shared values. Setting good examples creates a positive control system that people understand and conform to.
- *Encouraging the Heart.* Leaders must regularly acknowledge and celebrate individual and team contributions to an organization's success. This is a key characteristic of any excellent organization.

These five leadership skills put the people emphasis of management into clear focus. This people orientation ties leadership back to the people block of Westbrook's management model in Figure 2-1. Note: that these five categories are not mutually exclusive; each is closely related to the others and rarely occurs in isolation.

2.6.4 Proactive Leadership

Leadership must be involved in all phases of the organization. The current emphasis is on financial affairs. This is an important aspect, but it is the result of the functioning of the organization. Finance cannot be managed. It is the result of managing. It is the result of using people to get the job done. It is a result of having the required facilities and equipment to compete in the global marketplace. It is the result of effectively planning to have the right products and services available when they are needed. Proactive Leadership works with talented people to get these things done. Good finances follow.

2.6.5 Leadership Succession Planning

The mark of an effective leader is the recognition that he or she will not be in that position forever. As a result, he or she should formulate a succession plan. The plan should include the methodology for selecting a successor and specify whether the candidates should come from inside or outside the organization. Note: Small organizations may not have the luxury of promoting an in-house candidate.

If in-house candidates do exist, it is necessary that each person is given the opportunity to develop and demonstrate his or her capabilities prior to taking the leadership position. It may be possible to agree on the successor a few years from the leader's retirement. This is despite the fact that no one ever knows when succession will happen.

The Plan

An executive committee must, with input from all levels of the organization, develop a succession plan. In this way, everyone is familiar with the process and will not panic when the plan is implemented. Uncertainty is a formidable enemy that causes the resignation of valued employees, in-fighting among existing staff, and failing productivity. The plan must allay those fears of the unknown.

Plan functions include the following:

- Naming an interim leader
- Establishing the requirements for the job, as well as necessary attributes
- Naming a selection committee responsible for screening applicants and developing a "short list"
- Identifying a committee chairperson, responsible for communication with the organization
- Establishing the protocol for the interview process
- Identifying the time frame for the search

Summary

Leadership is a much-sought-after commodity. It is not something one is born with, nor is it a set of traits that can be learned. Leadership is a discipline, derived from skill and experience. Successful organizations require effective leaders to do more than just manage; they must also inspire.

Senge (1994) and Kouzes and Posner (2002) provided valuable lessons for leaders. Senge referred to the discipline and habits of leadership. Kouzes and Posner emphasized that leadership is about inspiring, enabling, modeling, and encouraging people while continually challenging the process.

Most importantly, leadership is about people.

2.7 Human Resources Management

2.7.1 Recruitment, Selection, and Compensation Practices

Currently there are more job openings than people to fill them (DePhillis, 2018). As the unemployment rate drops due to retirements and population shifts, it will become progressively more difficult to recruit choice candidates to fill vacant positions and to expand business operations. It is believed that this phenomenon will drive up employee-compensation demands. As competition for qualified applicants increases, companies will need to search for new ways to recruit and retain top performers.

1. Knowledge of Corporate Resources for Company Recruitment and Selection Policies and Practices

Employers have traditionally used the published job market to drive employee recruitment efforts. They advertise job openings on the company website, in major newspapers, and in trade magazines. They post openings on Internet job boards and enlist the aid of professional recruiters known as headhunters to seek the right person for the job. Many companies participate in job fairs and sponsor large-scale recruiting efforts on college campuses. As the number of job seekers decreases, employers have begun to make use of non-traditional recruitment methods, such as the following:

- **Capitalizing on the networks and professional contacts of existing employees.** Many companies offer incentives to existing workers who can influence their colleagues to apply with the company. Employees are encouraged to seek alumni from their colleges and to use networking events to help recruit qualified candidates.
- **Referrals from job applicants and past employees.** Most job applicants know others who are also applying for jobs and can be a good source of referrals. Former employees should also be contacted when openings arise to ask if they know someone who would be a good fit with the position.
- **Use breaking news.** Watching industry news or national news will inform a company about a competitor's plans to downsize or a top executive's decision to retire.
- **Confer with industry leaders.** Industry leaders often know before they are publicized when relocations, mergers, or acquisitions are about to occur.
- **Sign-on bonuses.** Sign-on bonuses are used to lure employees away from their existing positions and encourage retention after sign-on by requiring the new employee to stay a designated period of time to earn the full bonus.

Selection Policies and Practices

Historically, selection policies have been geared as much toward weeding out undesirable candidates for employment as toward seeking the best candidate for the job. Résumé keyword searches can eliminate a large number of applicants without ever speaking to job seekers and might inadvertently screen out excellent candidates with non-traditional experience or education. Wholesale elimination of candidates is losing its appeal as the labor pool shrinks. Instead, employers are using a multiple interview process to select candidates for hire.

Multiple interviewing is a selection process that requires five or more interviews with a candidate for employment. The process often starts with conducting a group interview with a number of potential candidates. Prime candidates are identified and selected by their interview responses and conduct to continue with the process. The next step includes comprehensive testing of prime candidates to determine depth of experience, work ethic, personal traits, aptitudes, and attitudes. Those who make the cut then interview with a variety of people within the company, including team members, managers, and people from other departments who interface with the position being filled. The process concludes with tryout employment, which involves the candidate spending several days working for the company before a formal offer of employment is made.

In addition to the multiple-interview process, employers also have the option of investigating potential candidates. Reference checks, criminal checks, credit checks, and drug testing are used routinely to screen out undesirable candidates.

2. Knowledge of Corporate Resources for Compensation Policies and Practices

The shrinking pool of qualified workers has caused concerns on two fronts. Employers are not only making a larger investment in employee selection but are enhancing employee-retention efforts as well. As the cost of employee turnover rises, employers are looking at creative methods to ensure that their top performers stay with the organization.

The compensation package is a primary means of attracting and keeping great employees. Ensuring that salaries are competitive is no longer enough, although offering salary ranges slightly above that of your competitors in the region remains a good drawing card for attracting and keeping employees. Pay-for-performance plans, pay-for-results schemes, profit-related accomplishment, stock options, profit-sharing, benefits, and non-monetary compensation are used as additional incentives.

Benefits and non-monetary compensation are no longer limited to time off, medical insurance, and a retirement plan, although these are still popular offerings that influence employee retention. Below is a list of benefits that employers are implementing across the globe (Herman & Gioia, 2000):

- Domestic partner benefits
- Electronic bill pay
- Life insurance
- Pet insurance
- Scheduled annual physicals
- Corporate fitness center
- Nutritious snacks
- Employee-barter program
- Child, pet, and dependent care
- Supplemented public-transportation costs
- Direct deposit of paychecks
- Hospitalization and major medical
- Dental and vision insurance
- Adoption support
- Wellness programs
- Subsidized health-club dues
- Discount club memberships
- Tickets to community events
- Longer time off
- Trailing spouse care

There are a number of actions that can be taken to ensure that your compensation package is attractive to current and potential employees:

- *Research competitive pay rates in your area annually.* Governmental agencies, chambers of commerce and trade groups are good sources of wage information.
- *Poll current workers.* Ask current employees what they need. Describe a number of benefit options and ask them to select the most desired from the list. Select the most popular item to institute. Make sure that your offerings suit the demographic composition of the workforce. Older workers value prescription plans and accelerated retirement plans. Younger employees may be more attracted to take-home meals from the company cafeterias so that they can spend more time with their families. Repeat this process as often as economically feasible.

3. Basic Knowledge of Federal, State, and EEOC Fair-Selection Regulations

Generally speaking, fair-selection laws are set by the federal government and are further defined and expanded by state law. In California, for example, the Americans with Disabilities Act (ADA) has been supplemented by state law to include smaller businesses and more broadly defines the Act by expanding definitions and considering a more extensive range of disabilities. Employers need to research the state laws and ensure that they are following the state-specific interpretation of all federal employment laws. These regulations can usually be found on state-government websites.

The following federal laws prohibit discrimination in selection and hiring practices (Equal Employment Opportunity Commission, n.d.):

- *The Age Discrimination in Employment Act of 1967 (ADEA)* protects individuals who are 40 years of age or older from employment discrimination based on age. The ADEA's protections apply to both employees and job applicants. Under the ADEA, it is unlawful to discriminate against people because of their age with respect to any term, condition or privilege of employment including, but not limited to, hiring, firing, promotion, layoff, compensation, benefits, job assignments, and training.
- *Americans with Disabilities Act of 1990 (ADA)* prohibits private employers, state and local governments, employment agencies, and labor unions from discriminating against qualified individuals with disabilities in job-application procedures, hiring, firing, advancement, compensation, job training, and other terms, conditions and privileges of employment.
- *Equal Pay Act of 1963 (EPA)* requires that men and women be given equal pay for equal work in the same establishment. Jobs need not be identical, but they must be substantially equal. It is job content, not job title that determines whether jobs are substantially equal.
- *The Pregnancy Discrimination Act* is an amendment to Title VII of the Civil Rights Act of 1964. Discrimination on the basis of pregnancy, childbirth, or related medical conditions constitutes unlawful sex discrimination under Title VII, which covers employers with 15 or more employees, including state and local governments. Title VII also applies to employment agencies and to labor organizations, as well as to the federal government. Women who are pregnant or affected by related conditions must be treated in the same manner as other applicants or employees with similar abilities or limitations.
- *Title VII of the Civil Rights Act of 1964* protects individuals against employment discrimination on the basis of race and color, as well as national origin, sex, and religion. Title VII applies to employers with 15 or more employees, including state and local governments. It is unlawful to discriminate against employees or applicants for employment because of their race or color in regard to hiring, termination, promotion, compensation, job training, or any other term, condition, or privilege of employment.
- *Sexual harassment* is a form of sex discrimination that violates Title VII of the Civil Rights Act of 1964. Title VII applies to employers with 15 or more employees, including state and local governments. It also applies to employment agencies and to labor organizations, as well as to the federal government. Unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature constitute sexual harassment when this conduct explicitly or implicitly affects an individual's employment, unreasonably interferes with an individual's work performance, or creates an intimidating, hostile, or offensive work environment.

4. Defining Selection Criteria

Federal Government Uniform Guidelines for Employee Selection Criteria require that all standards used either as minimum qualifications or as selection criteria be applied uniformly to all applicants. Minimum qualifications and selection criteria must be as follows:

- Job-related
- Measurable and/or demonstrable
- Necessary to perform the work

The development of good selection criteria is a useful technique for outlining the particular needs of a department for the particular position. This process will make the selection much more straightforward and less subjective.

Job-Relatedness

All qualifications used to screen applicants in the hiring process must be directly related to the job being filled. If, for example, there is a requirement for a bachelor's degree, that standard must be shown to be directly related to the position. A candidate with a Ph.D. (in a field not directly related to the position being filled) would not be more qualified than an applicant with a B.A. in a related field. If specific knowledge of budget procedures is given as a requirement, the position must require the application or use of that knowledge. Job-relatedness means that every standard must be specifically connected to the work to be performed on the job.

Measurability/Demonstrability

Minimum qualifications and selection criteria must be measurable and demonstrable. That means that they can be measured objectively or clearly demonstrated by the applicant or the applicant's past history. If a selection criterion calls for "maturity" or "attitude," there might be many interpretations of what those standards mean. Therefore it would be very difficult to measure the applicant against those vague criteria. A standard such as "Demonstrated ability to work effectively with supervisors, peers, and subordinates" would much more closely fit the requirement of measurability and demonstrability. Demonstration of this ability could be verified through references, letters of recommendation, and checks with previous employers. Even a criterion such as "good typist" is not as easily measured as "Ability to type 60 words per minute with only three errors." The more specific the criterion, the more easily it can usually be measured or demonstrated.

Necessary to Perform the Work Successfully

All criteria listed as minimum qualifications or selection criteria must be necessary to perform the work successfully. If a bachelor's degree is given as a requirement for the job, but it cannot be demonstrated that the actual degree is necessary for the performance of the job, then a criterion like "bachelor's degree or equivalent" must be used instead. Relevance and quality of education may be considered in the selection process but must be shown to be necessary for the particular job.

When to Use Federal Guidelines

Every time a description of qualifications and criteria for a job are developed and recorded on posting notices, advertisements, and personnel forms, all three of the federal requirements explained earlier must be met, both for minimum qualifications and selection criteria. No standard may be used that might have the effect of illegally excluding protected groups either intentionally or unintentionally. In meeting these three requirements, it is essential that a careful and thorough assessment be made of the responsibilities of the position. The assessment should include the following:

- Understanding the precise responsibilities of the job
- Defining those responsibilities in measurable or demonstrable terms
- Determining what education, experience, knowledge, or ability are necessary to perform the work successfully
- Deciding which qualifications beyond the minimum are important to the particular job
- Establishing the way in which those selection criteria should be demonstrated and measured

Selection criteria are useful in tailoring the selection process to any additional necessary qualifications that might not be addressed in a general classification description. When applicants are compared to each other using selection criteria, the most qualified applicants will be those with the best combination of the standards used.

2.7.2 Managing a Diverse Workforce

In today's global economy, a diverse workforce is considered essential to a top-performing organization. By their composition, cross-functional and interdisciplinary teams embrace diversity of discipline and functionality. Beyond that, teams whose membership is culturally diverse are shown to outperform more homogeneous teams over the life of a project. Culturally diverse teams can provide insights into a diverse customer base that culturally homogeneous teams simply cannot provide.

Diversity informs decision-making, expands the number of options generated during brainstorming, and adds perspectives and approaches to problem-solving processes. Culturally diverse teams do not, however, function without challenge. Language barriers, a variety of perception and perspective, and a wide range of behavioral norms can serve to get multicultural teams off to a slow start, and sometimes lead to allegations of bias, equity concerns, and misunderstandings.

1. Knowledge of Regional and Cultural Differences in Management Practices

Clearly, cultural differences are evidenced across international borders but also occur regionally within national boundaries. Recognizing and responding to the cross-cultural needs of a diverse workforce can include a number of considerations to be weighed by the engineering manager. Culture refers to "the customary beliefs, social forms, and material traits of a racial, religious, or social group" or "the set of shared attitudes, values, goals, and practices that characterizes a company or corporation." Survival strategies are not easily altered. They are deeply ingrained and integrated influences that define and distinguish segments of the world population and must be managed with respect and fairness.

Edward Hall popularized the concept of "high and low context cultures" in 1976. He asserted that high, low, and mixed-context cultures exist both nationally and regionally around the globe. Considerations of context will influence the way in which managers lead their teams.

Figure 2-11. Characteristics of High and Low Context Cultures

Characteristics of High Context Cultures	Characteristics of Low Context Cultures
• Less verbally explicit communication, less written/formal information • More internalized understandings of what is communicated • Multiple-crosscutting ties and intersections with others • Long-term relationships • Strong boundaries—who is accepted as belonging versus who is considered an "outsider" • Knowledge is situational, relational • Decisions and activities focus around personal face-to-face relationships, often around a central person who has authority	• Rule-oriented, people play by external rules • More knowledge is codified, public, external, and accessible • Sequencing, separation—of time, of space, of activities, of relationships • More interpersonal connections of shorter duration • Knowledge is more often transferable • Task-centered • Decisions and activities focus around what needs to be done, division of responsibilities

Ways in Which High- and Low-Context Cultures Differ

The Structure of Relationships

- *High:* Dense, intersecting networks and long-term relationships; strong boundaries; relationship more important than task
- *Low:* Loose, wide networks; shorter-term, compartmentalized relationships; task more important than relationship

Main Type of Cultural Knowledge

- *High:* More knowledge is below consciousness—implicit, patterns that are not fully conscious, hard to explain even if you are a member of that culture
- *Low:* More knowledge is above consciousness—explicit, consciously organized

Engineering managers might be called upon to negotiate context differences that arise in values, beliefs, behavioral norms, communication strategies, use of authority and power, and individualistic versus collective orientations among team members. The goal of these negotiations is to assist workers to integrate varying perspectives and behaviors to expand the "area of possible" generated by differing approaches. Both task performance and team relationships benefit from capitalizing on diversity in this way.

2. Knowledge of Fair-Management Regulations and Practices Regarding Race, Gender, and Age

"Fair" does not mean "same." Managers are required to vary their management approaches to respond to the culturally driven needs and habits of employees. While holding all employees to the same performance standards, managers must tailor *performance feedback* in order to ensure that it is meaningful to the individual receiving it. This means that managers need to lead workers in a manner that accomplishes the following:

- Strips away stereotypes
- Listens and probes for differences in an employee's assumptions
- Builds authentic and significant relationships with others one regards as different
- Enhances personal empowerment
- Explores and identifies differences and commonalities
- Capitalizes on identified differences rather than attempting to extinguish them

Failure to do so may result in hurt feelings, withholding of talent, rifts in productive team relationships, and even allegations of discrimination and bias. There are a number of laws that exist to protect workers from discrimination. Violation of these laws can result in costly lawsuits and the potential loss of great employees.

Laws pertaining to age, gender, disability, and race discrimination apply even if the discrimination is not intentional. There are many other labels given to other types of discrimination, such as "indirect," "unintentional," "systemic," and "adverse impact." These types of discrimination refer to situations where the system, rules, regulations, policies, or arrangements have not taken into account the needs of a group protected under the law (which is virtually the entire workforce in the U.S. and Canada), or the system has not evolved with the changing society.

Discrimination in Employment

Definition: "To decide adversely against members of a certain class because of a morally unjustified prejudice against members of that class."

Elements: A decision toward one or more employees, or prospective employees, that is not based on individual merit (e.g., seniority and experience, educational qualifications, and job-performance ratings), that derives from some morally unjustified attitude, such as racial or gender prejudice or stereotypes that have a harmful or negative impact on the interests of the employees by costing them jobs, promotions, or pay.

Responsibilities of Managers in Preventing Discrimination

Not only are managers required to be culturally sensitive themselves, but they must also ensure that employees do not act in discriminatory ways toward one another. Sexual harassment laws, for example, declare a manager is responsible if he or she "knew or should have known" that sexual harassment was occurring down-line in the organization.

Under penalty of law, managers must monitor those they are responsible to and for in the organization to ensure a "safe and non-hostile" work environment. This means that the manager must take any and all allegations of discrimination seriously and facilitate the prompt investigation and resolution of these complaints. Beyond that, it is incumbent on managers to be proactive in noticing and addressing situations where a potential for discrimination exists and in taking corrective action to dissipate potentially biased behaviors before allegations of discrimination occur.

3. How to Maintain an Awareness of and Adapt to the Requirements for Managing a Diverse Workforce

There are four ways in which managers will remain aware of and adapt to the requirements for managing a diverse workforce (Vaughn, 2006):

1. *Regularly review, refine, develop and implement policy and procedure statements that prohibit discrimination:* This involves ensuring that the organization has current and enforceable policies, such as an affirmative action statement; a sexual harassment policy; and a diversity policy that prohibits ageism, racism, ethnocentrism, sexism, and discrimination against people with disabilities.
2. *Enhance self-awareness and cultural awareness:* Managers must periodically examine their own level of cultural awareness and responsiveness and work to neutralize any biases that may exist in their perceptions and actions. Additionally, they should engage in continual learning about the cultural perspectives held by those they work with and manage, including customers, coworkers, subordinates, and superordinates.
3. *Provide learning opportunities to increase the diversity awareness and cultural competence of team members:* Developing cultural competence (appreciation of and capitalization of the differences and commonalities that exist in the workforce and in society) is a long-term process that requires regular input of updated information through training. As laws evolve and the composition of the workforce changes, the engineering manager seeks out and provides ongoing training opportunities for themselves and provides similar opportunities for their staff. Regular diversity-training efforts throughout an organization keep awareness of diversity issues high, reduce allegations of discrimination, ensure that all workers are valued and respected, and prevent costly lawsuits and the loss of great employees.
4. *Proactively intervene in situations where the potential exists for discrimination:* Deliver timely and targeted performance feedback to swiftly limit situations or behaviors that might lead to unfair employment practices or interfere with an individual's right to a safe, non-hostile work environment.

4. Conflict Resolution Techniques

No matter how positively change is presented and initiated, there is still a strong potential for change to create conflict in an organization. Conflict can be defined as "mental struggle resulting from incompatible or opposing needs, drives, wishes, or external or internal demands" (*Merriam Webster Online Dictionary*, 2006).

Knowledge of Common Causes and Forms of Conflict

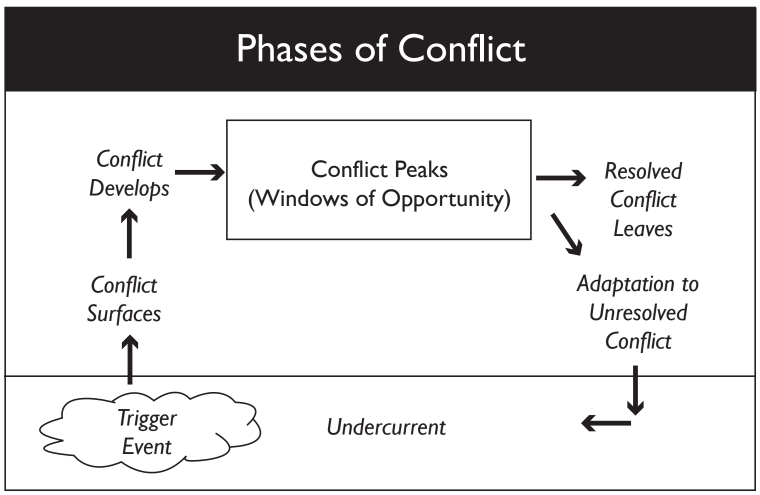
Conflict is inevitable. By nature, it is neither good nor bad. Conflict is always a process, never an event, although when a conflict reaches its flash point, it may initially be experienced or observed as an event. Conflict is composed of both content and feelings, so it consumes energy. Conflict can be managed either proactively or reactively. In any event, it must be managed effectively in order to avoid draining time, resources, and energy from individuals within the system and from the system itself.

Common causes of conflict include values, goals, interests, strategies, structures, relationships, information, knowledge, power, and trust. Conflict can be managed or resolved, but it can't be ignored. Conflicts that are not attended to grow over time, causing greater and greater losses for the individuals or organizations involved.

The conflict process manifests itself in phases. Unless the conflict is resolved at its peak, a repeating cycle of conflict will occur (Constantino & Merchant, 1996).

Conflict usually begins with a trigger event (a difference), and the conflict then begins to develop. The conflict will eventually peak. The peak of the conflict is the window of opportunity, where the potential exists to resolve the conflict. If the conflict is only partially resolved, the resolved issues leave the conflict. Any remaining unresolved issues will be adapted to by those involved and others who are impacted by the conflict. Adapting to the conflict will temporarily drive it underground, where it will exist as an undercurrent, and there it will either remain stagnant or grow. Eventually, another trigger event will occur and the entire conflict will redevelop, this time with even more aspects to be resolved. The cumulative impact of allowing unresolved conflict to languish causes it to grow to the point where it is progressively more difficult to manage or resolve.

Figure 2-12. Phases of Conflict Resolution



Knowledge of Strategies for Resolving Conflict

Only five strategies exist for resolving conflict. Strategy-selection depends upon the importance of the relationships and issues or tasks involved in the conflict. As a manager, it is possible to avoid the conflict only if both the importance of the relationship and the issue or task at hand are very low. Choose to accommodate others if the relationship under consideration is very important and the issue or task is not significantly important. Choose to compromise if the issue or task and the relationship under consideration are both moderately important.

If the issue or task at hand is significantly more important than preserving the relationship, an option is to compete with other parties. If the issue or task under debate is very important, as is preserving relationships, choose to collaborate.

Assertive behavior is called for when the task is of significant importance. Cooperative behavior is called for when the relationship is significant and needs to be preserved. A mix of assertive and cooperative behavior is used when the issue or task at hand is equally as important as preserving the relationship.

During the negotiation of a complex conflict, or a conflict that involves a number of parties, it may be necessary to shift between assertive and cooperative behaviors a number of times during the course of the negotiation.

Knowledge of Role of Mediator in Conflict Resolution

Conflicts involving the manager should not be mediated by the manager. Negotiation techniques (described in Section 2.7.3) are more suited to resolving a conflict where one is personally involved or broad organizational issues are at play. The manager will take on the role of mediator when two direct reports need assistance in mediating a conflict that has occurred between them (Dana, 2001).

Use mediation when the following occurs:

- The conflict involves only two parties
- The conflict has created a business issue that needs to be addressed
- Interdependence between parties is high
- Urgency to resolve the conflict is high and a clash has occurred

Do not use mediation in the following situations:

- In place of discipline
- To replace job training
- To substitute for Employee Assistance Program services
- To address a poorly defined problem or issue

Manager as Mediator

- The business problem may be identified by the manager or those involved in the conflict. The manager will meet with each party prior to the mediation to hear how each defines the problem and to sell both parties on the idea of attending mediation. The problem statement should be unbiased, objective, specific, resolvable, concise, and written.
- The manager will choose a neutral location free from interruptions, set aside two hours for the mediation session, and notify involved parties of time and location. As the mediator, the manager will be impartial, will not decide the solution, and will not be very active. Each employee will talk to the other (not the mediator), will stay on subject, and will remain in the meeting until a solution is found. The mediator will ask the parties to speak respectfully toward the other. The mediator sits at the head of the table with problem solvers face-to-face on either side.

Beginning the Mediation

- Welcome the parties to the mediation, and then read or state the problem as they understand it.
- Read or state the responsibilities of all three parties in the room and ask for agreement and acknowledgment of the roles and responsibilities of each person.
- Focus the parties on one another and ask them to begin discussing their issue.

Role of the Mediator

- Refocus the problem solvers on each other if they try to talk to the mediator.
- Refocus the conversation if it strays from the business problem at hand.
- Recognize "conciliatory gestures" (apologizing, owning responsibility, conceding, self-disclosing, expressing positive feelings, initiating a "both gain" strategy) shown by either problem solver.
- Remind problem solvers of their responsibilities as needed.
- Ask clarifying questions as needed.
- Encourage problem solvers to keep talking when necessary.
- Wait while the problem solvers talk their issue through.
- Propose a "deal" when the parties begin to generate solutions.

On average it takes about 45 minutes to fatigue the two parties and ensure readiness to proceed to a deal. Fatigue, a desire for peace, catharsis, and inhibitory reflex all contribute to the desire to make a deal.

Making the Deal

A good deal is balanced, behaviorally specific, and written; both parties must agree to the deal. A follow-up meeting needs to occur after the deal has had a fair amount of time to work.

During the follow-up meeting, the mediator will hear from both parties as to whether the deal is working and will assist the parties in augmenting, revising, or enforcing the deal if needed.

2.7.3 Labor Relations—Negotiation Strategies

Negotiation can be defined as "conferring with others in a way that brings about the equitable settlement of a matter." Negotiation skills help resolve situations where what you want conflicts with what someone else wants. The aim of negotiation is to explore the situation to find a solution that is acceptable to both parties. When this outcome is achieved it is referred to as a "win-win" result.

It is important to know how to leverage each step in the negotiation process to achieve a win-win outcome:

- *Step 1 — Preparation:* Preparation involves learning as much as possible about the other parties to the negotiation. Research the wants, needs, negotiation style, possible objections, and bottom line of others with whom you are about to negotiate. Additionally, know the same information about yourself and those you may be representing in the negotiation.
- *Step 2 — Information exchange:* In the opening round of a negotiation, establish rapport with other parties by engaging in a reciprocal information exchange. This step surfaces underlying interests, issues, and perceptions while looking for leverage points and identifying expectations.
- *Step 3 — Proposing and countering:* Bargaining begins when one party introduces an initial proposal. Other parties then counter with differing proposals, with each party advocating for the most essential aspects of his or her offers. Concessions are offered in the form of compromises, and collaborative efforts are made to shift positions and gain as much leverage as possible.
- *Step 4 — Agreement and commitment:* An agreement is reached that allows each party to satisfy as many needs as possible without agreeing to unsupportable conditions. Each party must then commit to taking agreed-upon actions to execute and fulfill the terms of the negotiated agreement.

1. Knowledge of Negotiation Techniques

In their book, *Getting to Yes,* Fisher and Ury (1983) contend that there are three negotiation techniques available to negotiators: integrative (interest-based), distributive (positional), and principled negotiation.

- *Integrative negotiation:* This type of negotiation is structured to achieve a win-win outcome. It is used when all parties to the negotiation are motivated by joint gain and when their interests are congruent. This technique is used when a long-term relationship is to be sustained. It works well when negotiating multiple issues. The underlying concept of the technique involves expanding the pie, rather than dividing it, by adding value for all parties. The integrative approach is frequently used when negotiating with employees and partners.
- *Distributive negotiation:* This type of negotiation achieves a win-lose outcome with the more influential party winning the lion's share of the spoils. This technique is used when individual gain is viewed as more important than mutual gain and the interests of the parties are opposed to one another. It is most often used to negotiate a single issue and is only to be used when a relatively short-term relationship is to be sustained. Distributive negotiation divides the pie, often resulting in the party with the strongest position walking away with the greatest share. This technique was used for labor-management negotiations from the early 1900s through the 1980s in most Western cultures. Today a distributive mindset may be required when negotiating cross-culturally with parties who traditionally rely on this technique.
- *Principled negotiation:* This negotiation technique is a variation of integrative negotiation and results in a win-win outcome. Principled negotiation separates people from problems and focuses on interests rather than on positions. All parties to the negotiation generate a variety of options through brainstorming before making decisions. Agreements are based on objective criteria so that implementation efforts can be measured. This technique is designed to sustain and strengthen long-term relationships and expands the pie. The "best alternative to a negotiated agreement," or BATNA, is used as a walk-away option when agreement cannot be reached. Principled negotiation is often used when negotiating with customers, employees, or partners.

2. Knowledge of How to Determine and Prioritize the Needs of Key Stakeholders in the Customer Value Chain

The manufacturing industry magazine *Industry Week* (IW) published an article in September 2005 detailing the results of their 2005 Value Chain Survey. Survey findings revealed that customers in the global value chain experienced shifting priorities and changing needs over the course of the previous two years (Vinas, 2005). Even though a significant number of respondents cited containing cost and generating increased revenues as high priorities, the top priority was to improve customer relations. Product innovations dropped in priority while other considerations such as increased profits, reduced cycle time, increased unit volume, and improved quality remained constant in the priorities list.

According to the survey, customer-relationship programs are paying off. Nearly 40% of the manufacturers responding reported starting or expanding their customer-relationship programs to better assess and meet the needs of their customers. They reported standard means of listening to their customers that included needs and satisfaction surveys, focus groups, and one-to-one interviews.

In much the same manner, engineering managers can learn more about their customers and apply this knowledge to negotiations with key stakeholders in the customer-value chain. Given that needs and priorities shift rapidly in the value chain, managers may need to update this information prior to entering into negotiations.

3. How to Apply Negotiation Techniques to Ensure Win-Win Results

To ensure win-win results when negotiating with others, think through the following points before you start negotiating:

- *Goals:* What do you want to get out of the negotiation? What do you expect the other person to want? Do research to learn what others might want as you prepare for the negotiation.
- *Trades:* What do you and the other person have that you can trade? What do you each have that the other might want? What might each of you be prepared to give away?
- *Alternatives:* If you don't reach an agreement with the other person, what alternatives do you have? This is known as "best alternative to a negotiated agreement" (BATNA). How much does it matter if you do not reach agreement? Does failure to reach an agreement cut you out of future opportunities? What alternatives might the other person have?
- *Relationships:* What is the history of the relationship? Could or should this history impact the negotiation? Will there be any hidden issues that may influence the negotiation? How will you handle these?
- *Expected outcomes:* What outcome will people be expecting from this negotiation? What has the outcome been in the past, and what precedents have been set?
- *The consequences:* What are the consequences for you of winning or losing this negotiation? What are the consequences for the other person?
- *Power:* Who has what power in the relationship? Who controls resources? Who stands to lose the most if agreement isn't reached?

2.8 Teaming

2.8.1 Traditional Teams

Technology has been moving at a very rapid pace. An example is your car. What once were simply four tires, an engine, and a steering wheel can now park itself for you, detect when you are driving outside your lane, or even brake for you when it detects an accident is about to happen. This advance in technology has created projects that can no longer be handled by one person's knowledge. The new car requires a wide variety of engineering types to come together to design, develop, and produce. The most common form of this grouping is called a team, although terms such as *tiger team, integrated product team,* and *working integrated product team* may be used, and terms may be industry dependent (government, private industry, NASA, Department of Defense). In 2017, $90.6 billion dollars was spent for formal training (*2017 Industry Report*, 2017). Interpersonal skills such as communication and teamwork continue to be a part of this training. Although prevalent, teams present a variety of issues for the engineering manager. Some are good, some are not, as shown in Figure 2-13.

Figure 2-13. Team Benefits/Issues

Benefits of Teams	Issues with Teams
Allow for knowledge transfer	Can report to more than one boss
Obtain skills necessary for complex project	May not be co-located
Sum of whole is better than the parts	Do not have a common goal
	Not given empowerment
	Not given accountability
	Team is too large (> 20)
	Team not formally recognized by management

For many, the question is what does a good team look like? Katzenbach and Smith (1999, p. 21) defined a team as "a small group of people (typically fewer than twenty) with complementary skills committed to a common purpose and set of specific performance goals." Their research showed the transition from a simple working group (show up and exchange information) to a high-performance team. What sets a high-performance team apart is the degree of commitment, interchangeable skills and flexibility, shared leadership within the team, care about what is going on with other team members, and a better sense of humor. Katzenbach and Smith cited several approaches to building team performance, such as selecting members based on skills and skill potential, not personalities; setting clear rules of behavior; challenging the group regularly with fresh facts and information; and exploiting the power of positive feedback, reorganization, and reward.

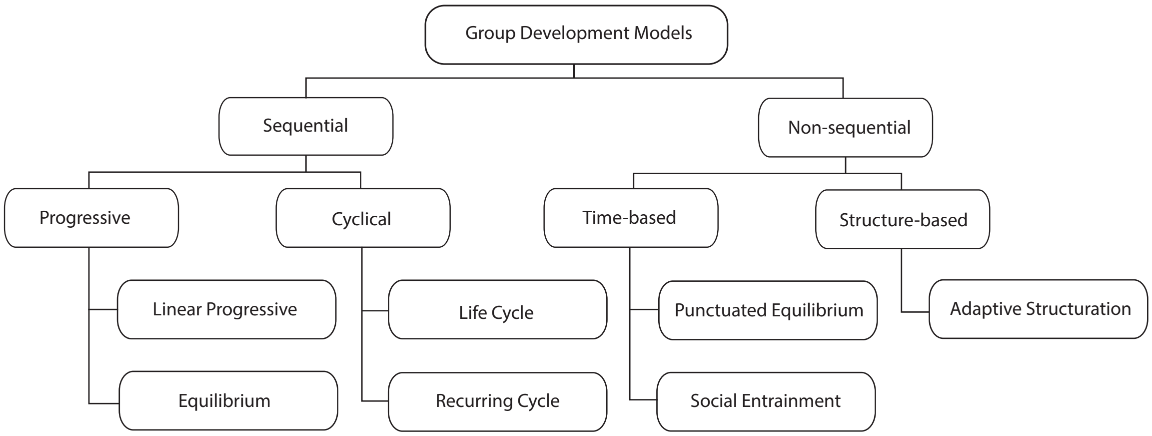
Larson and LaFasto (1989) discovered eight characteristics of an effectively functioning team. These were culled from research performed on a wide variety of teams, not just engineering teams. The characteristics were clear and elevating goals, results-driven structure (identify the appropriate structure for achievement of performance objectives), competent team members, unified commitment, collaborative climate, standards of excellence, external support and recognition, and principled leadership. Unified commitment, external support and recognition, and collaborative climate were cited to have the most problems.

Salas, Shawn, and Cannon-Bowers (2000) presented seven emerging teamwork principles:

- Principle 1 is that teamwork is characterized by "a set of flexible and adaptive behaviors, cognitions, and attitudes" (p. 344).
- Principle 2 is that teamwork requires the team members to monitor each other in terms of behavior and action and be allowed to provide and accept feedback based on what they see.
- Principle 3 is that "teamwork is characterized by members being willing and able to back fellow members during operations" (p. 347).
- Principle 4 is that communication is clear and concise.
- Principle 5 is that teamwork "requires coordination of collective independent action" (p. 348).
- Principle 6 is that it entails leadership that offers items such as direction, coordination of activities, and planning.
- Principle 7 is that teamwork is influenced by the task at hand as to the context of it and the requirements.

Another important aspect of teams is how they develop. There is a wide range of research on this topic. Chidambaram and Bostrom (1996) created a graphic depicting the categorization of these models, as shown in Figure 2-14. One theory from each side of this graphic will be discussed in more detail.

Figure 2-14. Categorization of Team Development Models



An example of a linear progressive, which according to Chidambaram and Bostrom "suggest[s] that groups move from an initial phase that represents a collection of independent individuals to one characterized by conflict, then by cohesion, and finally by productive work" (1996 p. 162), is that of Tuckman (1965). Tuckman performed a meta-analysis of the research that existed and developed a model that suggests that teams move through four main stages: forming, storming, norming, and performing.

An example of a non-sequential model that is time-based is that of Gersick (1988), called punctuated equilibrium. Gersick's model suggests that teams have transition that occurs in the middle of the timeline for the work to be completed. This transition is produced by team members' awareness of time and the deadlines rather than the amount of work they have completed. Gersick theorizes that the midpoint is similar to an alarm clock going off reminding the team that they have limited time to finish, which stimulates their work effort.

For further information concerning other models that fit in each of these categories, Benfield (2005) has excellent summary charts in Chapter 2.

A big issue for teams is how well they are performing. This can be difficult to measure because teams are used in almost every discipline. An emergency-room staff may track performance as lives saved, whereas an engineering team may consider performance to be finished on time and at or under cost.

An important step for any team is to understand what the task at hand is and what the goals of the task are. When the goals are understood, metrics for performance can be derived. One thing to remember is to not measure something just because you can. Create metrics that are meaningful to your project. If you are having difficulty with developing these, check out what other teams have used, what metrics would support the goal of the task being achieved, or what metrics the organization considers important. Also remember that what gets measured is what gets paid attention to.

One method to get teams organized, understanding the goal, establish performance metrics, and ensure management approval is to create a team charter. Team charters have the following benefits:

- Documented team purpose
- Clearly defined roles, responsibilities, and operating rules
- Established procedures for communication, reporting, and decision-making
- Definition of how the team chooses to govern itself
- Ensured management sign-off

The Defense Acquisition University has an excellent example of a generic team-charter template. The key sections are: purpose, objectives, membership, roles, responsibility, authority, agreements, critical success factors, and approval. The membership, roles, and responsibility sections show how the team fits into the big picture, who the users and customers are, and to describe any special circumstances. Purpose and objectives allows for definition of mission and objectives, as well as the high-level goal that the team is to accomplish. Team operating agreements and critical success factors sections describe how your team plans to conduct its day-to-day operations. How the team will make decisions, what happens if you have to replace, delete, or add a team member, and how you will relate to other teams are some examples. It is suggested that while developing the team charter a second set of notes be kept concerning everything that was discussed. The team will find that these notes contain a very good outline of the systems engineering that will be required.

Current research into teams covers a wide range of topics. Military applications is an interesting one because a group of people can be thrown together very quickly with no prior knowledge of each other and be expected to do a wide variety of tasks that can mean life or death to fellow troops. Salas, Burke, and Cannon-Bowers (1995) authored an article titled "Military Team Research: 10 Years of Progress," which covers factors that they considered critical in team performance, as well as other interesting topics in military-team training and performance. Dalenber, Vogelaar, and Beersma (2009) discussed what a military team can do to get team performance quickly. Another topic is that of shared mental models. Mathieu, Heffner, Goodwin, Cannon-Bowers, and Salas (2005) defined a shared mental model "as an organized understanding or mental representation of knowledge that is shared by team members" (p. 38). Basically, it is how closely the team members' understanding of the project match. They concluded that team process and performance were better in teams that had better-shared mental models.

There is not enough time or space to cover all the topics that current research is investigating. If there is a topic you are interested in, most likely you can find information about it.

Managing and leading teams is extremely important. Katzenbach and Smith (1999) stated that as a team manager, the important things to do are build commitment and confidence; do real work; keep the purpose, goals, and approach relevant and meaningful; strengthen the skill level; and create opportunities for others. Two things they said to never do were to blame or allow specific individuals to fail and never excuse away shortfalls in team performance.

Larson and LaFasto (1989) identified two blind spots for team leaders: team leaders are unwilling to confront and resolve issues associated with inadequate performance by team members, and the leader dilutes the team's efforts with too many priorities. Principle 6 of Salas, Shawn, and Cannon-Bowers (2000) discussed what team managers need to do. As mentioned earlier in this chapter, Likert (1961) presented the ideas of supportive management, team management, and his four systems. Of these discussed, many apply directly to management of the teams described herein. Items such as confidence and trust throughout the organization, employees wanting to work together to solve problems and make the organization successful, and measuring performance is used for self-guidance such as that presented in the team charter. A manager of teams must be supportive, friendly, and helpful, as well as showing confidence in the team's integrity and ability. An important point is that communication is with the whole team and filtered as little as possible. Likert's System IV (participative group) is the one that best fits with team management.

Blake and Mouton (1964) observed managers who were successful and found that these managers used teams extensively, confronted issues to resolve conflict (which Larson and LaFasto noted as a blind spot), received extensive input from employees, and developed the team's capabilities and skills. Managerial Grid position 9,9 was identified as the team-manager position that balances both production and people, which offers teams the best type of management in that it understands that people have differences, different motivations, different experiences, and that management is willing to assist in helping to overcome these to be a high-performing team. The manager also understands about performance and hopefully is aware of the issue of too many priorities cited by Larson and LaFasto.

In conclusion, teams in the workplace are not as simple as saying, "You guys get together and solve this problem." There are characteristics of teams that research has found that make them an effective method for solving complex tasks. It is of utmost importance that management is knowledgeable about what makes a good team versus a poorly performing team. Managers also need to understand what they need to do to allow the teams to do the job at hand and be successful. Managers need to be aware of pitfalls that they may fall into, such as not addressing conflict or setting too many priorities. This does not 100% guarantee that the team will be successful, but it gives it the foundation to do so.

2.8.2 Virtual Teaming

Virtual teams are defined as groups of geographically and organizationally dispersed knowledge workers brought together across time and space through information and communication technologies (e.g., email, videoconferencing, or other computer-mediated communication system) on an "as-needed basis" in response to specific customer needs or to complete unique projects (Lipnack & Stamps, 1997, 2000; Jarvenpaa & Leidner, 1998; DeSanctis & Poole, 1997). Members of these working arrangements rarely, if ever, see each other.

To be considered virtual, a team must have three attributes. First, it must be a functioning team—a collection of individuals who are interdependent in their tasks, share responsibility for outcomes, see themselves and are viewed by others as an intact social unit embedded in one of more social systems, and collectively manage their relationships across organizational boundaries (Forsyth, 1999; Hackman, 1987; Alderfer, 1977). This requirement differentiates this working arrangement from groups. Simply communicating with others electronically does not transform a grouping of people into a virtual team. Virtual teams must have real tasks to perform, interdependent members, and shared outcomes that are of higher quality than outcomes obtained if members had worked separately and all individual efforts were combined.

Next, the members of the team are geographically dispersed. Members of the virtual team are not co-located—their primary work sites are different from one another (cities, states, nations, or continents). Team members might belong to the same organization or multiple organizations. Thus, teams may be global and multi-organizational.

Finally, the team relies on technology-mediated communications rather than face-to-face interaction to accomplish their tasks. Virtual teams are supported by both hardware and software. The use of technology by itself does not make a team virtual—it is the degree of reliance on electronic communication that increases virtuality. True virtual teams must communicate via electronic means for the majority of their interactions to accomplish the work at hand. Traditional teams usually have more discretion as to whether or when to use technology.

The virtual team consists of two types of leaders: the task leader and the social leader (Lipnack & Stamps, 1997). The task leader is oriented to the activities of the team and makes decisions required to accomplish results. In a similar vein to earlier theories regarding task-oriented leadership (e.g., the Managerial Grid), meeting productivity measures is the determinant of success for this leader. The social leader is oriented toward creating feelings of group identity, status, attractiveness, and personal satisfaction. A cohesive team is the determinant of success for this leader, and is equally critical to the virtual team for maintenance.

2.9 Introduction to Knowledge Management

Mankind has been creating and losing knowledge for thousands of years. All aspects of knowledge have been lost: art, culture, language, and technology. From losing the Library of Alexandria and its 400,000 papyrus scrolls to losing the organizational memory to build a NASA Saturn V rocket, lost knowledge has beleaguered the world.

It is no surprise then that organizations struggle with managing and retaining key technologies that require deeply learned skills transferred from one employee to another. There are two major influences in the workplace today that impact successful knowledge transfer: (1) an aging workforce, and (2) the changing nature of knowledge.

The first major influence is well known as the aging population. A large aging workforce is being succeeded by a younger generation that is much smaller in numbers. This is not news to the vast majority of leaders. However, the second major influence is not as well understood and will have a much more serious impact to organizations. That major influence is the changing nature of knowledge. In today's technologically advanced society we are witnessing the increased complexity of knowledge and the reality of dealing with data overload in all functional areas of an organization.

Figure 2-15. Data Overload

Data Overload		
Period	Communication Method	Words Per Minute (wpm)
1915	Phone	30
1945	Radio	60
1965	Satellite	100
1995	Networked Computers	192,000
2009	Wideband Datalinks	1,500,000,000,000 (trillion)

Source: Trainor, T.E., Brazil, D.M., & Lindberg, T. (2008, June). Building Knowledge From Organizational Experience: Approaches and Lessons Learned From US Army Base Camp Workshops. *Engineering Management Journal*, pp. 39.

2.9.1 Beginnings of Knowledge Management

Peter Drucker (1994) described knowledge as representing "the key concept to explain the increasing velocity of the transformation of social life in general and the way business and social institutions work in particular." Today there is a paradigm shift toward knowledge-based organizations.

Early knowledge management projects focused on technology and organizations began investing hundreds of thousands of dollars in capital to replace aging computer technologies with management information systems, decision support systems, and expert systems. Capturing explicit (tangible) knowledge was the main objective. These data mining computers collected and saved gigabytes of information and everyone felt good about the process. Unfortunately, this approach failed because databases operate on a pull basis where workers need to know that the data exists to even begin the search for data that might be useful.

2.9.2 Knowledge Management Success Factors

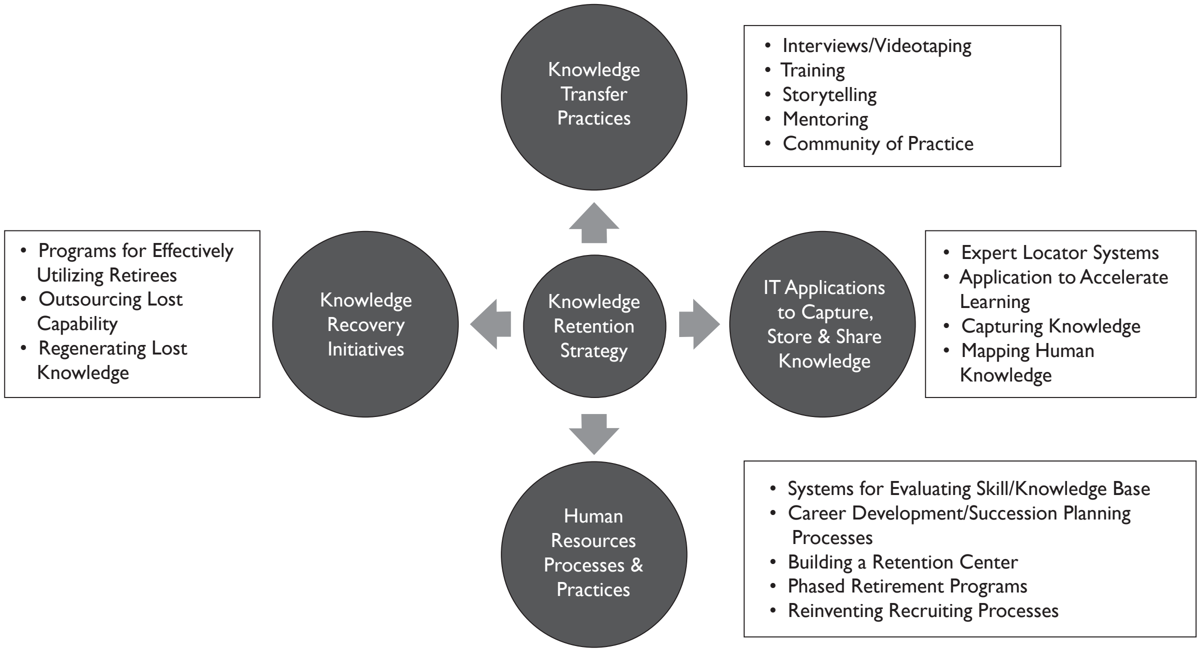
Current thoughts on successful knowledge management projects are that they move away from a technology focus and move to a people focus capturing implicit knowledge. Davenport, DeLong, and Beers (1998) analyzed 31 knowledge management projects in 24 companies and identified eight factors leading to knowledge management project success:

- Link to economic performance or industry value
- Technical and organizational infrastructure
- Standard, flexible knowledge structure
- Knowledge-friendly culture
- Clear purpose and language
- Change in motivational practices
- Multiple channels for knowledge transfer
- Senior management support

2.9.3 Knowledge Retention Framework

DeLong (2004) described a framework that can be applied at many different levels within the organization. His framework for retaining organization knowledge is a customized approach and with an eye toward a long-term strategy. He described four types of initiatives that form a customized retention strategy: (1) knowledge transfer practices; (2) IT applications to capture, store, & share knowledge; (3) human resources processes and practices; and (4) knowledge recovery initiatives. Each type contains strategies to curtail the loss of intellectual capital and build long-term workforce capabilities.

Figure 2-16. Knowledge Retention Strategy



Knowledge Retention Strategy

Source: DeLong, D.W., (2004). *Lost Knowledge: Confronting the Threat of an Aging Workforce*. New York: Oxford University Press, USA.

2.9.4 Key Barriers to Knowledge Retention

Implementing a successful knowledge retention strategy is very difficult. Liebowitz (2009)identified five key barriers: (1) knowledge hoarder versus knowledge sharer, (2) human biases, (3) disgruntled employees, (4) believing it is impossible to capture the knowledge of very tenured employees in an interview, and (5) knowledge retention strategy does not align with the strategic mission or vision of the organization.

The following are key recommendations to help overcome these organizational barriers:

- Acquaint people with knowledge sharing and its benefit
- Integrate knowledge sharing into everyone's job
- Identify incentives to encourage more collection and sharing of lessons among employees and teams
- Apply knowledge management strategies that fit an organization's culture
- Keep the effort focused

Review

Upon completing the study of "Domain 2: Leadership and Organizational Management," you should be able to answer the following questions:

1. Koontz and O'Donnell argued that there are six core schools of management thought. List and describe each of the six schools. Which of the schools—or combination of schools—best describes your own approach to management and why?
2. List and describe the five elements of Westbrook's Integrated Management Model. What is the relationship among the elements?
3. What are the five needs that comprise Maslow's hierarchy of human needs? How might this hierarchy be useful for engineering managers?

4. What are the differences between the traditional organizational structure and one that is team-based? Why is the latter better suited for technology-oriented industries?
5. Describe Likert's System IV and explain why it is the only one of the Likert management systems to consistently achieve normal productivity goals.
6. Describe the five positions on Blake and Mouton's Managerial Grid. Which of the positions is the most useful in managing knowledge workers?
7. What are some of the key characteristics of organic and mechanistic structures? Which is better suited for contemporary, technology-driven industries and why?
8. List and describe the five elements of Mintzberg's organizational design.
9. Win-win negotiation consists of a four-step process that entails comprehensive preparation, information exchange, proposing and countering, gaining agreement and fostering commitment. Describe the actions involved in each step.
10. Fisher and Ury contend that there are three key negotiation techniques. Describe each and explain in what context each is most useful.
11. Compensation practices include both monetary and nonmonetary benefits. Offerings are selected based on their perceived value to employees. How would a manager go about learning what employees value? List five benefits that are being offered in today's workplace that employees in your company might value. Why is employee retention an important consideration in today's job market?
12. The government sets fair selection and employment laws that prevent discrimination against employees. List the six types of discrimination prohibited by federal law and detail the protections provided by each law.
13. When considering what constitutes fair-management practices in a multicultural team, the manager must be aware that "fair" does not mean "same" and will tailor management practices to meet the identified needs and norms of each employee. While holding all employees to the same performance standards, managers must tailor performance feedback in order to ensure that it is meaningful to the individual receiving it. List five considerations managers need to attend to when providing performance feedback to a multicultural workforce.
14. List each of the four conditions that must exist in order for conflict-mediation efforts to be effective.
15. What are the four elements of DeLong's Knowledge Retention Framework?
16. What are the key barriers to knowledge retention as described by Liebowitz?
17. What are the key recommendations to overcome the organizational barriers to knowledge retention?

For Further Information

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3

Strategic Planning and Management

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3.4.6 Product or Service Differentiation Strategy

3.4.7 Focus Strategy

3.4.8 Global Strategy

3.4.9 Core Competence Strategy

3.4.10 Services-Based Strategy

3.4.11 Joint Venture and Outsourcing

3.4.12 Partnering Relationships

3.4.13 Sustainability

3.5 Executing the Strategy

3.5.1 Charters, Time Management, Project Management, and Leadership

3.5.2 Change Management Techniques and Adjustment Strategies

3.6 Strategic Performance Measurement, Control, and Evaluation

3.6.1 The Balanced Scorecard

3.7 Deploying Lessons Learned

Domain 3: Strategic Planning

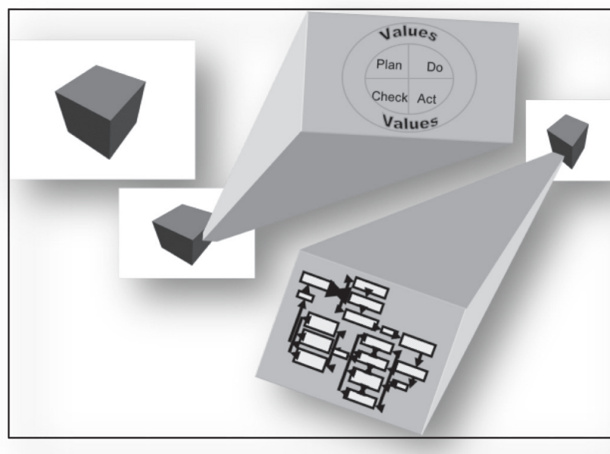
Key Words and Concepts

Balanced Scorecard	A method for balancing strategic and financial measurements including financial, customers, internal process, and learning and growth perspectives.
BCG – Matrix	Boston Consulting Group Matrix analysis with 2 axes: market share (horizontal axis) and growth rate (vertical axis).
CROPIS Analysis	A model to analyze an organization's effort for continuously improving its system. Specifically concentrates on the following elements: Customers – Requirements – Process – Inputs – Supplier.
GRI	Global Reporting Initiative.
MARR	Marginal Acceptable Rate of Return.
Mission Statement	Lists products and services, target customers and markets and has a more immediate business focus with a time horizon.
Outsourcing	Engaging the services of third-party service providers.
PDCA	Plan – Do – Check – Act.
Porter's Five Forces Model	A model providing analysis of five competitive forces: new entrants, suppliers, buyers (customers), substitutes, and competitors.
Product Life Cycle	The four phases of a product life cycle: introduction, growth, maturity and decline.
SBU	Strategic Business Unit.
Strategic Alliances or Partnership	Joint ventures or acquisitions.
Strategic (long-term) Objectives	Organizational goals designed for completion or re-evaluation within two to five years.
Strategic Planning	The processes to establish, implement, correct, and continuously improve a corporate strategic plan.
SWOT	A tool for developing strategies around an organization's strengths – weakness – opportunities – threats.
Tactical (annual) Objectives	Organizational goals designed for completion within one year or a one-year budget cycle.
Vision Statement	What the organization strives to be in the future.
WACC	Weighted average cost of capital.

3.1 Strategic Planning and Management Models

The following provides a short description of common strategic planning efforts the engineering manager will encounter in the workplace. An attempt has been made to outline the frequently used strategic models, techniques, and planning tools. An emphasis has been placed on providing a reference source for activities in which the engineering manager will participate.

Figure 3-1. Thinking-Inside-the-Box Hologram or "All models are wrong but some are quite useful" (Box, 1979).



There are as many strategic planning models as there are strategic planning experts and consultants. George Box's 1979 quote points out that no model can completely predict future events and perhaps this suggests the best model to use is one that best communicates implementation strategy to those who must implement. Some are listed in the references at the end of this chapter.

Every strategic planning model might be considered a part of a planning hologram, as shown in Figure 3-1. A different planning model is seen dependent on how the hologram is held. Turn it a bit and you see a 14-step process emphasizing continuous process improvement; take another twist and you see a 54-step process emphasizing new product development, and a final turn displays a six-step, strategic planning process with emphasis on Lean Manufacturing, Six Sigma, or Sustainability management philosophies. The point is that there are many models and each might have a different number of steps and tools, but the overall purpose of all planning models should remain the same: Set goals, conduct the work, study the effect of the work, and then realign effort to further improve implementation. Deming (1982), Shewhart (1939) and Tague (2004) have one of the simplest portrayals of these steps: Plan, Do, Check, & Act (PDCA).

The models also fall into two major categories, planning and management. Strategic planning has been defined here as the processes to establish, implement, correct, and continuously improve a corporate strategic plan. Strategic management is defined here as the tools and techniques utilized to implement strategy and the efforts needed to quickly respond to special events that occur before the formal planning process recycles.

Most strategic planning models share common implementation activities:

- Develop or improve an in-depth knowledge of the organization and the competitive environment in which the organization operates. This is sometimes known as organizational systems analysis.
- Establish long- and short-term objectives based upon the in-depth knowledge obtained in organizational systems analysis.
- Create a strategy to accomplish the objectives, including action plans for deployment.
- Implement the strategy with proper project management.
- Measure and evaluate the progress of implementing strategy.
- Based upon evaluations, make corrections to implementation activities.
- Recycle the process by periodically revisiting each element listed earlier.

While conducting strategic planning and management, take the following actions: (1) be flexible in accepting new planning model tools and techniques; (2) be cognizant that team members look to the engineering manager to stabilize the "flavor of the month" planning process that sometimes occurs when new management philosophies are constantly introduced; (3) force strategic planning to be a part of a corporate implementation system regardless of the level at which the organization begins; and (4) design the recycling of the planning process, understanding that planning steps might not always be accomplished sequentially and depend upon the maturity and culture of the firm in conducting strategic management. That is, a firm mature in its strategic planning and management might rightly spend more time on strategy building and management than a firm new to strategic planning and management would spend on internal analysis which needs to place a greater effort on knowing itself and its competitive environment before beginning a strategy.

3.2 Importance of Strategic Planning to the Engineering Manager

The literature is sparse on reporting the failure of in-depth strategic planning; however, the popular media and experience points out that merely collecting or creating input—such as vision, mission, and SWOT elements—is not enough for successful implementation. An in-depth analysis of realistic strategies is required. In short, the engineering manager must go beyond simply listing items about a firm under each title of planning elements. Deming (1982) prescribed "develop a profound knowledge" of the organization, its products, its services, and the processes to constantly meet and exceed customer expectations.

The engineering manager provides leadership in exploiting technology and innovation in all phases of strategic planning and management. The resulting work should be the guide for all organizational strategic activities. Further on in this domain different strategies will be suggested based upon the profound knowledge the engineering management team has collected and disseminated throughout the organization.

3.3 Strategic Planning and Management Process

An analysis of the organization is performed prior to setting objectives to establish a baseline and framework for planning. Questions answered in this analysis include the following: What is our definition of success and how is the firm performing against that definition? What is the current business of the firm? What is the future business of the firm? What does the firm do to be successful in this business? Does the firm have the capability or resources of accomplishing these tasks and if not, what capacity must it add? What has the firm done in the past that must continue, be stopped, or modified?

The engineering manager must consider these same questions but with a prejudice on what can be accomplished with existing resources and what is expected from the engineering manager during implementation. One major engineering-management contribution is the identification and exploitation of technology and innovation in strategy and business processes.

Plan

Most strategic planning models include a systems analysis, writing a vision and mission statement, describing the borders of the firm from customer to supplier, evaluating the current performance of the organization, determining the internal strengths and weaknesses of the firm, forecasting its external threats and opportunities, and establishing a list of assumptions and constraints to be used in formulating objectives and strategies.

The completed systems analysis may then be used to formulate long-term goals and then short-term objectives associated with them. The objectives might originate from current concerns identified by analyzing internal weaknesses or external threats or exploiting current internal strengths to take advantage of forecasted opportunities.

The planning horizon for long-term goals is commonly five years. This provides a planning environment that avoids end-of-the-financial-quarter thinking. As Sink (Sink & Tuttle, 1989) stated, "It avoids making tactical errors with strategic implications."

The planning horizon for short-term objectives is typically 12 months to coincide with annual budget preparation. Action items are planned for completion in less than 12 months and depending upon difficulty are suggested by the models to be as short as a week.

Strategy is developed to accomplish each objective or a grouping of objectives. Strategy can follow themes, including functional strategies, growth or downsizing strategies, portfolio strategies, outsourcing and partnering strategies, sustainability strategies, global strategies, and other strategic categories.

Developing strategy also includes the creation and integration of the organization's marketing, operating, and budget plans.

Do

The strategy is now implemented. Many models term this strategic management (David, 2012) and others, project management (Sink & Tuttle, 1989). Regardless of the term, the engineering manager must be familiar with and able to perform project management tasks. Project management can be found in Domain 5: Project Management of this Engineering Management Body of Knowledge.

Check or Study

It is important to evaluate the effectiveness of the strategy toward achieving goals. Metrics should be established to regularly assess progress in reaching objectives as well as the long-term goal. This serves as a looking glass for the project or enterprise manager who must evaluate for any necessary actions or strategy adjustments.

Act

Performance and organizational behavior is adjusted based upon measurement evaluation and recycling of the planning process. Each cycle brings more knowledge about the competitive environment and the organization. Profitable opportunities are realized when the organization can orchestrate awareness of the opportunity, have the capacity to take on the opportunity, and have the willingness to engage.

The remaining material in this domain will cover the specific items that should be generated to make up the strategic plan as required during each phase of the PDCA strategic planning and management model.

3.3.1 Systems Analysis

The purpose of systems analysis is to prepare the leadership to set objectives. Collecting data about the organization to construct, publish and disseminate components of the systems analysis grows the collective understanding of the organization by the leadership team. If it is comprehensive, it provides the team with Deming's "profound knowledge" about their organization. The following are the main components of systems analysis but should not be considered an exhaustive list. Any set of data analysis that furthers the understanding of an organization can be conducted here.

3.3.1.1 Vision and Mission Statements

Some organizations choose to have both a vision and a mission statement. A mission statement lists products/services, target customers, and markets. A vision is what the organization strives to be in the future. It should capture the hearts, minds, and long-term direction of all organizational members.

Formulation of mission statements during strategic planning should not be lightly dismissed. Some bad examples are found in the literature:

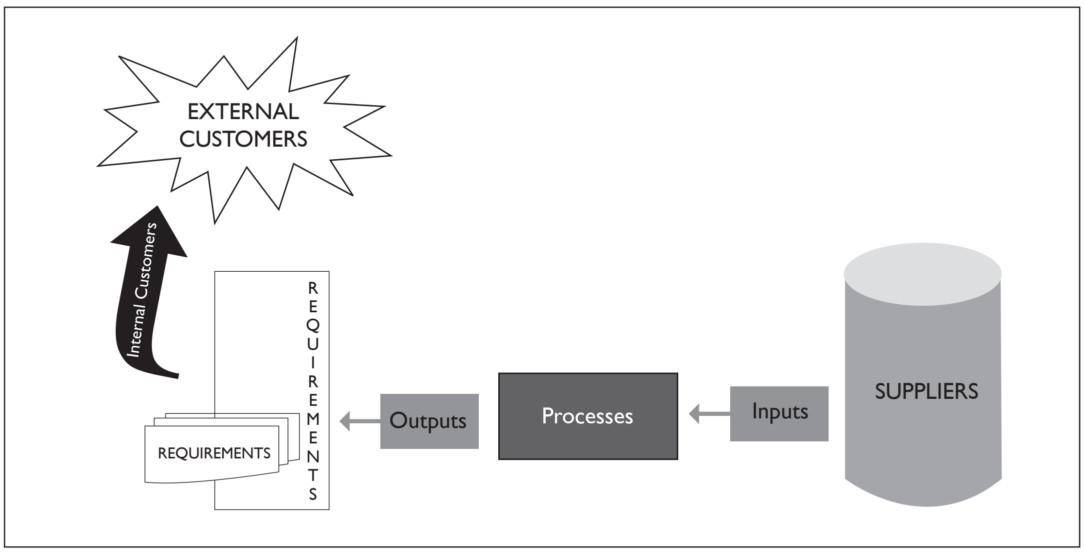
- Airline or transportation? American Airlines declared itself to be in the "destination" business and diversified into rental cars and hotels. It didn't last long.
- Retail or financial? Sears shocked the business world when it announced that it was in the financial business. That was when Allstate Insurance was very profitable. Sears' Retail Division has not recovered from that strategy.
- Pizza or delivery? Domino's figured that since they deliver pizzas, they must be in the transportation business. Fortunately, their customers took little notice and there was minimal negative impacts.

3.3.1.2 CROPIS or SIPOC Analysis

As shown in Figure 3-2, each letter in CROPIS represents a component of the organization: Customers, Requirements, Outputs, Process, Inputs, and Suppliers. We prefer this order of letters and analysis, although it is also referred to as SIPOC in some texts. However, this tool is more than a listing of component parts of an organization. It starts with listing in detail the component, but then an in-depth analysis is conducted at each component by asking over and over the following questions (adopted from Sink and Tuttle,1989, and Deming's short course, 1984):

- What are the components? Describe them in detail. For example, a listing of customers should be first and last name of the point of contact, not just the customer's company name.
- What have we done in the past at this component that has met or exceeded customer expectations?
- What will we do in the future to improve our response to customer expectations?
- How do we know new actions will be better than current actions? What data supports our changing the methods?

Figure 3-2. CROPIS



3.3.1.3 SWOT Analysis

A Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis can be used to first understand the environment to prepare for planning and then as a tool to assist in strategy formulation. The procedure is divided into two steps: first Internal and then External Analysis.

Internal Analysis: Strengths and Weaknesses

Evaluate the internal environment. Determine, in depth, the following:

- Employee demographics and capabilities
- Financial ability of the organization to expand or retaliate
- Adequacy of facilities for new opportunities
- Rate of change that can be tolerated
- The organization culture and management style
- Access to needed skills and resources
- Product or service leadership
- Product or process R&D commitment
- Planning horizon in use
- Limitation imposed by the parent organization
- Resources of the parent organization that may be available to support strategies
- Level of commitment of the parent to the organization

Analysis of this information yields strengths and weaknesses of the organization. This information forms the core of an organization's strategy. David (2012) described a more in-depth analysis. An Internal Factors Analysis Chart is constructed by giving each strength and weakness two values. First, each item is given a weight based on how important it is to the organization's future work. The weights should sum to 100%. The second metric is a measure of how much the organization demonstrates that strength or weakness currently. Multiplying the weight times the current measure of strength or weakness provides a score that is helpful later in developing strategy that leverages strengths and improves areas of weakness.

External Analysis: Opportunities and Threats

Evaluate the external environment and identify the characteristics of the industry understudy. Sample research questions include the following:

- Is the industry expanding or shrinking?
- What is the technology level in use by competitors? Is it changing? Is more technology applicable than is in common use?
- Are we aware and informed on new emerging technology?
- Is the industry stable? Have the competitors changed recently?
- What is the number and strength of competitors?
- Are customers strong enough to have price-setting power?
- Are suppliers providing quality goods? Are they reliable?

Again, David (2012) described a more in-depth analysis. An External Factors Analysis Chart is constructed by giving each opportunity and threat two values. First, each item is given a weight for the probability each opportunity or threat will impact the organization. The weights should sum to 100%. The second metric is an estimated probability on the organization's ability to take advantage of the opportunity or to eliminate the external threat. Multiplying the two probabilities, possible impact times ability, provides a score that is helpful later in developing strategy.

A summary chart showing both the internal factor scores, based upon strengths and weaknesses, and the external scores, based upon opportunities and threats, is useful in strategy development. Also see section 3.4.3.

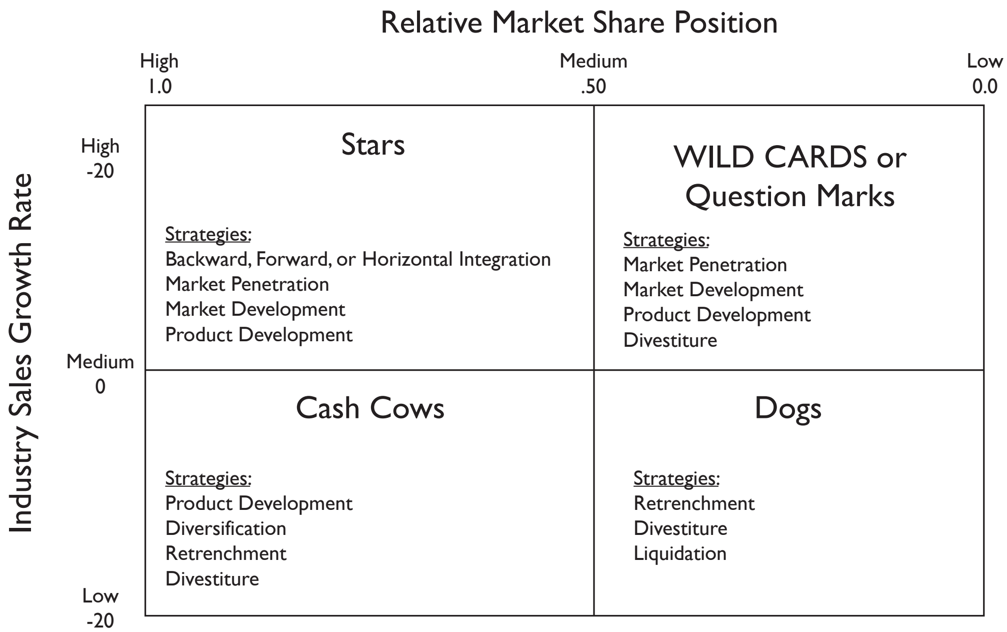
3.3.1.4 Planning Assumptions and Constraints

Planning assumptions are probability estimates of future constraints, while planning constraints are facts currently impacting the organization. An estimate of future economic environment is an example of a planning assumption, while the organization's current Minimum Acceptable Rate or Return (MARR) or Weighted Average Cost of Capital (WACC) would be examples of planning constraints. Not all assumptions and constraints will equally impact an organization, so a weight of impact is usually applied to constraints. The weight of impact is multiplied by the probability of occurrence for assumptions. During each annual planning recycle, these factors are reviewed first to determine the extent of the change in the business environment. Also, during risk analysis and scenario analysis, the previously stated assumptions and constraints are changed to see how sensitive a strategy would be to a change in its values.

3.3.1.5 Boston Consulting Group Competitor Matrix Analysis

The Boston Consulting Group (BCG) Matrix (see Figure 3-3) can be utilized as a pre-planning tool and in strategy formation. Four quadrants are drawn on a diagram. The vertical axis of this model is Growth Rate. The horizontal axis is Market Share. Sales and financial results from recent years can be analyzed to determine within which quadrant a particular product/service, division, company, or organization falls.

Figure 3-3. BCG Matrix



The upper-left quadrant represents high growth, and the company has most of the industry's market share. The quadrant is labeled "Stars." The organization has a competitive advantage.

The lower-left quadrant represents low growth, but the company has most of the industry's market share. The quadrant is labeled "Cash Cows." While there is little growth, the organization could be receiving reliable funding that can be used for investing in "Stars" and "WILD CARDS."

The lower-right quadrant represents low growth, and the company has little of the industry's market share. The quadrant is labeled "Dogs." A significant investment of resources would be required to move to a Stars or Cash Cow quadrant.

The upper-right quadrant represents high growth, but the company has little of the industry's market share. The quadrant is labeled WILD CARDS or Question Marks. This is a high-risk area, as it can move to either a Star or Dog.

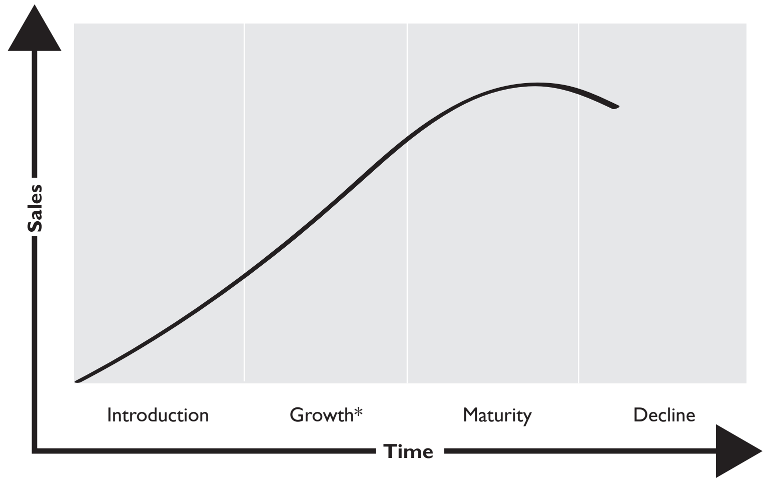
The four-quadrant diagram gives a picture of the health of the organization's product placement and strength. Much like an investment portfolio, risk can be diversified through a proper balance of a portfolio.

3.3.1.6 The Product Life-Cycle Model

Business strategies can also be driven by a product's place in its life cycle. For example, products that are in their introductory phase—i.e., those that are still in development and have only recently been introduced to the market—require different strategies than those that are experiencing high levels of market penetration (the growth phase) or those which have already peaked and are now in a downward decline (aging stage).

Each of the product life-cycle phases is depicted in Figure 3-4 and is explained in the following sections. Following the explanations are a few caveats about the product life-cycle approach.

Figure 3-4. Product Life Cycle



Product Phase: Embryonic or Introductory

When a product is new to the marketplace and its future, uncertain, it is said to be in its embryonic or introductory phase. While embryonic, the organization must find a market where buyers are willing to take a chance. These buyers are usually early adopters willing to take risk and for whom cost is not a significant issue. There are typically quality issues with embryonic products. The manufacturing process also is still evolving as the product develops and grows.

A summary of the embryonic phase follows.

Buyers: High income.

- Products: Low quality. Design is the most marketable feature. There are frequent changes and few standard features.
- Marketing: High advertising cost/sales.
- Manufacturing: Overcapacity.
- R&D: Changing product features; changing production techniques.
- Strategy: Use R&D and engineering to improve products and processes.
- Competitors: Few.
- Risk: High.
- Profit: Low due to startup costs. Profits increase with sales, potentially, due to high prices.

Product Phase: Growth

If a product makes it past the embryonic phase, it has found that market size and sales are increasing. Product quality is also at an acceptable level but still requires improving. Distribution now becomes an issue as the product needs to get to a broader market in a timely fashion. Competitors have also been attracted and are now beginning to advertise but do not necessarily have the name recognition of the original product. During the growth stage, significant emphasis is placed on research and development for both the product and the production process. The product quality improves as a result, and features are added to gain further competitive advantage. The process must shift toward mass production to lower unit cost while at the same time increasing quality.

This growth phase can be generally described as follows:

- Buyers: Growing; accept uneven quality.
- Product: Technical differentiation. Reliability is a key for complex equipment. Quality improves.
- Advertising: Higher cost but lower cost/sales. Advertising and distribution are key issues.
- Manufacturing: Under capacity; shift to mass production. Scramble for distribution channels.
- Foreign trade: Significant exports.

- Overall strategy: Change to price or quality image. Marketing importance increases.
- Competition: There are many competitors. Some of these competitors may enter through mergers and acquisitions. This can provide industry experience not previously available.
- Risk: Low; covered by growth.
- Profits: Generally high.

Product Phase: Maturity

Products in this phase have significant competition from both domestic and foreign companies. Price is a key issue and emphasis is on process research and development to control cost. However, product research and development should not be abandoned. New features might add to product life and profits. This phase is analogous to the "Cash Cow" quadrant in the Boston Matrix discussed earlier.

The maturity phase can generally be described as follows:

- Buyers: Mass market; approaching saturation. There are repeat buyers and brand alternatives.
- Products: High quality; less differentiation, more standardization. Changes are minor.
- Marketing: Segmentation; high-low price lines.
- Effort is made to broaden the line. Service and packaging are important. There are lower advertising/sales.
- Manufacturing: Some overcapacity. There is more stability, lower labor unit cost, longer runs, and process improvement. Distribution channels are refined for efficiency.
- Foreign trade: Few exports, some imports.
- Strategies: Maintain market share. Control costs. Marketing effectiveness is important.
- Competition: Heavily oriented to price. There are more private brands and foreign competitors.
- Risk: Cyclical. Periodic price wars and advertising campaigns can be expected.
- Profits: Lower but may be partially offset through high volume.

Product Phase: Decline

Managers take pride in developing successful products, so few are prepared to do a good job of managing a declining product line. The last phase of such a project is frequently the shutdown of the facility, dispersion of assets and termination of employees.

Conventional wisdom indicates that such products must be divested by the most expeditious method possible. Managers' emotional tie to the product and the people associated with its production make this difficult to execute. Many companies bring in a new team of managers to oversee the shutdown. Note that this strategy is similar to the one taken for organizations or products in the "Dogs" quadrant of the BCG Matrix.

In those instances where divestment is not an immediate option, the overall strategy becomes to control cost. There may be an opportunity, for instance, to acquire competitors at a steep discount, thus reducing supply and increasing the likelihood of continued profit. Another option is to find new or niche markets. Under-served customers should continually be sought out.

General characteristics of a product in the decline phase are as follows:

- Buyers: Sophisticated, with high bargaining power.
- Products: There is little product differentiation and varied quality.
- Marketing: Low advertising/sales and other marketing costs are the norm.
- Manufacturing: Substantial overcapacity and mass production. Specialty channels; discount stores, and house brands are common.
- R&D: Little to none.
- Foreign trade: There are no exports and increasing imports.
- Competition: Several competitors exit the business. There are fewer competitors.
- Profits: Low prices and profits. Profits may rise in late decline.

Extending the Product Life Cycle

Every organization wants to extend the product life cycle as long as possible. This is normally done through both product and process research and development. Addition features can be added so that the product will hold market share. Process improvement can increase efficiency so that profitability can be maintained.

Occasionally, new markets can be identified for a new version of the product. For example, there are now cell phones targeted for the elderly and for children.

Caveats Regarding the Product Life-Cycle Model for Formulating Strategy

The standard product life cycle should not be applied to all products and industries in the same fashion. If a company changes with the times and the marketplace, for instance, life cycles can be drawn out or eliminated. Similarly, life cycles are highly specific to a product and/or industry. For example, hoola hoops and wall walkers lasted days, while rotary telephones lasted several decades. Cell phones, by comparison, have a much shorter life cycle.

3.3.2 Strategic (Long-Term) Objectives

A long-term objective is typically designed for completion or re-evaluation within two to five years. The time horizon can be longer depending upon the product or service lifecycle. Regardless of the cycle strategic objective should be reviewed as part of strategic management each budget year. Development of a complete set of long-term objectives provides a basis for strategy formulation, directs resources of the firm, and is the basis of measurement and evaluation. By setting corporate direction and allocation of resources, strategic objectives guide the priorities, coordination, and synergy required for success. The source for formulating strategic objectives should naturally develop from the diagnostic tools discussed in the Systems Analysis section earlier. Following the creation of strategic objectives, the next two steps occur in a parallel and reiterative fashion: developing a list of tactical objectives and formulating strategy.

3.3.3 Tactical (Annual) Objectives

A tactical objective is designed for completion within a one-year or one-budget cycle. The list of tactical objectives in a firm is the source for creating marketing, operational, and budget plans. There should be a set for each strategic objective but also care must be taken to establish tactical objectives across strategic objectives to ensure an integrative design. Following the completion of tactical objectives, an audit should be performed to match them with the vision, mission, strategic objectives, and strategies.

3.4 Strategy Formulation

Strategies are formulated and implemented to successfully meet the mission, reach for the vision, and accomplish strategic objectives. The short list to formulate strategy includes the following:

- Use the organization's strengths to take advantage of any opportunities identified.
- Shore up any identified weaknesses through the acquisition of key resources (i.e., avoid the negative results of threats that are evident).
- Continually rework strategy to adjust to changes in the internal and external environment.

3.4.1 Strategic Influences

Organizations must avoid tactical errors that lead to strategic error (adopted from Sink & Tuttle, 1989). Organizations review strategic influences to avoid this error. The following strategic influences environmental, technological, and social forces that impact strategy formulation include:

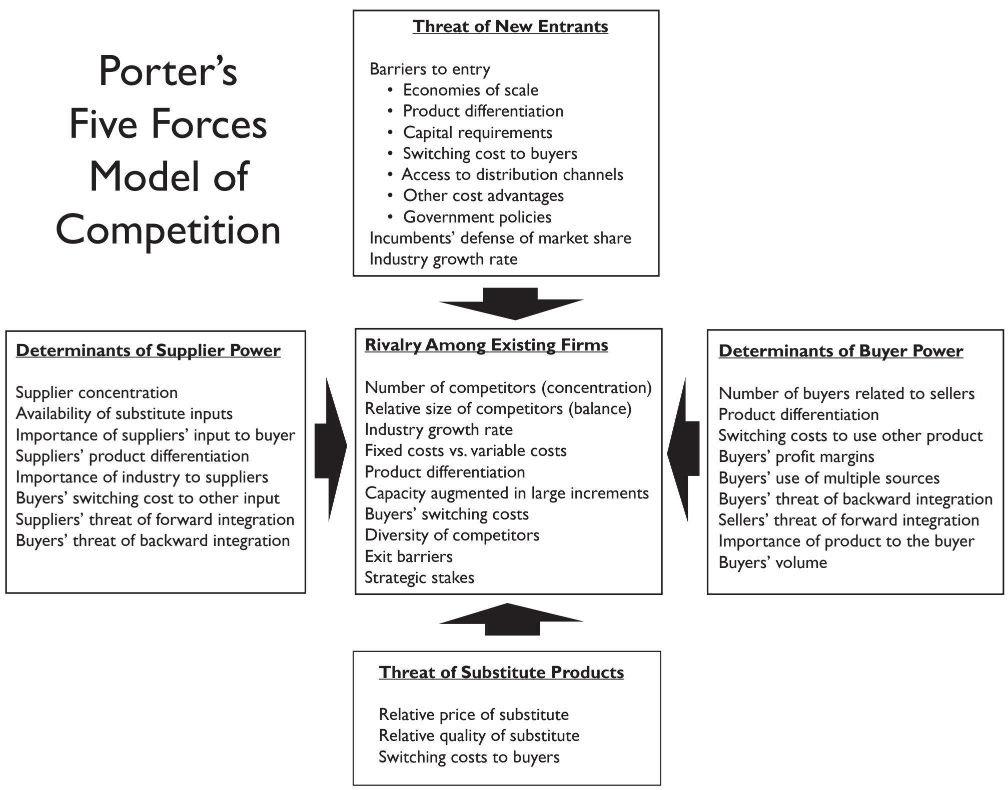
- The global environment and economy. This external environmental factor is growing in importance but is difficult to assess. Competitors are now global, as are markets.
- Rate of technological change. Markets are being rapidly created and replaced. Wi-Fi distribution will be considered infrastructure and continue to spread worldwide. Such a development can be either a threat or an opportunity. Either way, those in this industry must be prepared to deal with a change.
- Societal demands and changes follow:
    - Aging population will create service markets in all developed countries.
    - Skilled worker shortages will create education markets.
    - Emphasis will continue to shift from wages to benefits.
    - Environmental concerns will create new industries.

- Energy availability follows:
  - Natural gas: 25 years (recent finds may extend this)
  - Gasoline/petroleum: Up to 50 years
  - Nuclear: 50-100 years, if we can effectively deal with spent fuel rods
  - Coal: 200+ years, but it causes ecological problems
  - Fuel cells: Currently under development. Large sizes have not yet proved practical.
  - Fusion: May prove practical in the long term but is not feasible in the foreseeable future.

3.4.2 Porter's Five Forces Model Strategy

Porter's model (1998), as depicted in Figure 3-5, was developed to show how elements of the strategy relate to each other.

Figure 3-5. Porter's Five Forces Model



Porter's model suggests that a company must consider more than just the competition as it formulates its strategy. It must also think about the following:

- Potential Entrants
- Buyers (Customers)
- Substitutes
- Suppliers
- Competitors—The box at the center of the Porter Model depicts the position of industry competitors relative to these four considerations.

Threat of Entry

In strategizing, companies must consider both known and potential competitors. Potential competitors are those who have not yet entered the market but who might pose a serious threat at some later date. These include foreign companies that may be relatively unknown but who should be considered nonetheless.

The following strategies may be used to bar new entrants from effectively entering the marketplace:

- Economies of scale
- Product differentiation
- Capital requirements
- Switching of costs
- Prohibitive distribution costs
- Cost disadvantages independent of scale
    - Proprietary product or process technology
    - Favorable access to raw material
    - Favorable locations
    - Government subsidies
    - Learning or experience curve
- Government policies or regulation
- Anticipated retaliation
- Deterring price of entry

Note that entry barriers depend on condition and context. A rise in petroleum prices, for example, may impact foreign competitors more than domestic companies depending on the importance of exports to those domestic companies. Similarly, large-scale operations can make it more difficult for a new entrant via low-cost operations. If the new entrant has a technological advantage, however, the large-scale competitor may be at a disadvantage, as it has a heavy investment tied up in outdated facilities. Another disadvantage of scale is that it tends to lower product differentiation, potentially making entry more viable.

The Bargaining Power of Buyers

The buyer or customer can play a large role in the success of a company. For example, if the customer can control prices, then his or her strategic impact is immense. He or she has the potential to force down prices and profits. This is especially true when one customer buys a large proportion of the company's total goods. In those instances, the customer informs the seller of the price that he is willing to accept.

If the seller is unimportant to the customer, then the seller has little control over prices. The customer can get the product or service from other competitors or provide them internally.

Customers are also powerful if the following occur:

- Products are standard or undifferentiated.
- There are few switching costs.
- Buyer has low profits and requires price concessions from the seller.
- Buyer can potentially backward integrate.
- The product or service has little impact on the quality of the buyer's product.
- The buyer has full information, especially information on the seller's costs.

The Bargaining Power of Suppliers

Suppliers have bargaining power with a buyer in the following instances:

- The supplying industry is more concentrated than the buyer's.
- There are few better alternatives for the buyer.
- Few substitutes are available to the buyer.
- The buying industry is not important to the supplier.
- The supplier's product is important to the quality of the buyer's product.
- The supplier's product is differentiated, or switching costs are high.
- The supplier can potentially forward integrate.

The government as a force can either raise or lower entry barriers through tax incentives or regulations. This impacts a supplier's ability to fix its prices and its ability to be competitive.

Industry Competitors

Below is a list of factors that affect the intensity of rivalry among competitors:

- Cost of production, advertising, new product introduction, customer service, and warranties.
- Numerous competitors. When there are numerous, equally balanced competitors, instability is more likely and the impact of strategies is less predictable. Competitors make moves without expecting retaliation.
- Slow industry growth competition intensifies as industry growth slows. Market share becomes increasingly important.
- Lack of differentiation or switching costs. Price and service competition is intense.
- Capacity augmented in large increments. The capital requirements involved in this strategy increase risk (such as with steel companies).
- Diverse competitors. Differing goals make strategy formulation more difficult. Higher-priced organic food products from small companies, for example, compete with similar products from food conglomerates. Unit profit is much more important to the smaller producers than to the conglomerate who has economies of scale.
- High exit barriers specialized capital equipment with low salvage value makes exiting a market difficult and expensive. Labor costs are high when contracts call for severance packages. This raises exit barriers. There are also emotional barriers, such as ties to the community, which make exits difficult. Government regulations also add cost to a shutdown or layoff.
- Pressure from substitute products. New products provide the same service in a completely different way. The alert strategist must be aware of new products long before they are introduced. Examples include artificial sweeteners impacting the sugar market and flat-screen televisions replacing CRT models.

3.4.3 SWOT Analysis for Strategy Formulation

The SWOT Analysis described earlier can be utilized to develop a SWOT Matrix (also known as a TOWS Matrix [David, 2012]) that can be used in strategy formulation. See Figure 3-6 for a sample SWOT Matrix.

Figure 3-6. SWOT Analysis

INTERNAL FACTORS / **EXTERNAL FACTORS**	**Strengths (S)** List 5-10 *internal* strengths here	**Weaknesses (W)** List 5-10 *internal* weaknesses here
Opportunities (O) List 5-10 *external* opportunities here	**SO Strategies** Generate strategies here that use **strengths** to take **advantage** of **opportunities**	**WO Strategies** Generate strategies here that take **advantage** of **opportunities** by **overcoming weaknesses**
Threats (T) List 5-10 *external* threats here	**ST Strategies** Generate strategies here that use **strengths** to **avoid threats**	**WT Strategies** Generate strategies here that **minimize weaknesses** and **avoid threats**

Similar to the portfolio matrix, sales and financial results from recent years can be analyzed to determine which quadrant a particular division, organization, or project falls within a SWOT Matrix. By categorizing an organization, division, or project into one of the quadrants, certain strategies are suggested.

- WT: If an organization lacks personnel who are competent in a key technology but competitors do have such resources, then the organization is in the WT quadrant. The strategy would be to consider divest-

ing the organization if access to the needed technology and resources is too expensive and time-consuming. Alternately, if licensing of the technology might solve the problem until in-house resources can be attained and if contractors are available, then investment in the organization might be worthwhile.
- SO: If an organization has built up in-house capabilities and uses them in an effective team environment, they might have a strength that presents opportunities. The strategy here would be to continue to invest in personnel and expand the area of business to take on more diverse jobs or roles.
- WO: This quadrant suggests that an organization invest to overcome weaknesses and take advantage of present opportunities.
- ST: An organization is situated within this quadrant when a competitor threatens one of its key areas of strength. In this instance, preemptive strikes may be used to put competitors at a disadvantage. Examples include reducing prices or offering more services for the same amount of money.

3.4.4 BCG Matrix Strategy Formulation

By categorizing an organization into one of the BCG quadrants as discussed earlier, certain strategies are suggested:
- "Dog": This organization should be divested or otherwise shut down and its resources applied to a project or organization with better returns and potential. The opposite strategy may also be elected: resources should be committed to specific areas within the organization where improvement is probable.
- "Cash Cow": Take the profits from this organization and invest it in more growth-oriented enterprises, i.e., "milk" the cow. Since market share is high, continuous investment needs to be made in process improvement and product research and development to maintain profitability.
- "WILD CARDS" or "Question Marks": This organization is experiencing high growth and low market share, so with a resource commitment, it could become a "Star." However, WILD CARDS are difficult to predict; many of these types of divisions or organizations never reach their potential. Management must analyze them closely before deciding to pour further resources into them.
- "Star": This organization type has everything going for it, both high-market share and growth. Conventional strategy is to provide high levels of process and product research and development. Marketing and distribution strategies will also be needed to see if customer satisfaction is established and maintained.

3.4.5 Cost Leadership Strategy

Those organizations deploying an overall cost-leadership strategy demonstrate the following characteristics:
- Efficient, scalable facilities
- Cost reductions through production experience
- Cost and overhead control
- Investment in facilities and research and development (R&D)
- Efficient distribution

The benefits of being a low-cost leader are as follows:
- Good return on investment and sales
- Good defense against competitors
- Reduces power of suppliers
- Raises entry barriers for potential competitors

Companies using this low-cost leadership strategy include Lincoln Electric, Briggs and Stratton, and Whirlpool.

Potential competitors might utilize the following strategies to cut into a low-cost leader's market share and profitability:
- Low price entry, with a competitive advantage such as low labor cost or a perceived higher quality product or service.
- If a competitor has an R&D breakthrough, it could compete on the basis of the new and better and perhaps cheaper product. A competitor with a more efficient operation, higher quality, longer life, higher reliability, etc., could challenge an entrenched company.

- A company with a superior, differentiated product or service could be an effective challenger. The challenger must be perceptively better in some significant respect in the eyes of the customer.

Cost leaders potentially face the following challenges:

- Highly technological firms may offer a more sophisticated product that would make old R&D a sunk cost or a lost or irrecoverable investment.
- On the other hand, the challenger may develop a product that few customers want. For example, one major company wanted to make an entry to a new market with a new programmable logic controller for manufacturing organizations. It had every conceivable feature that any customer might want. However, customers preferred less expensive, less complex controllers with limited specialized functions.

3.4.6 Product or Service Differentiation Strategy

The differentiation strategy involves ensuring that your service or product is perceived as significantly different from those of your competitors.

Advantages of the differentiation approach include the following:

- Perceived uniqueness
- Reduced price sensitivity
- Higher profit margins
- Reduced threat of substitution

Disadvantages of the differentiation approach include the following:

- May preclude high-market share and its benefits
- Makes quality extremely important
- Must have strong marketing capabilities
- Must have strong product engineering
- R&D and innovation are at a premium
- Must attract and hold highly skilled people

Competitors attempting to cut into the market share of a company using a differentiation strategy might attempt the following:

- Standardize the product at a high quality. Copy and improve it. The Japanese did this with automobiles extensively and gained significant market share at U.S. manufacturers' expense.
- Offer a complete range of models/brands within a product line and price them competitively. This is, in effect, creating a one-stop shop that sells all product models/brands, not just high end or low end. This appeals to customers who do not want to spend time looking for multiple suppliers.

3.4.7 Focus Strategy

When deploying a focus strategy, a company focuses its efforts on one geographic region, a narrow demographic, a particular industry, or one product line. This strategy works best when the company has natural advantage in a particular segment of market. For example, a company might concentrate its efforts on a geographic market where it knows local buying habits or focus on the production of one product that it is an expert at manufacturing. The idea is to make high profit with limited sales while remaining small enough to avoid attracting the attention of large competitors.

Examples on companies using a Focus Strategy include the following:

- Geographic Focus: Many restaurants were regional before expanding. Shoney's and Cracker Barrel are regional organizations.
- Industry Focus: A few tool companies sell only to local auto repair shops and do not attempt any conventional retail sales. The construction industry has many suppliers that cater to that one industry.
- Product Focus: Stuckey's, Kroger, and Krystal restaurants are examples of companies that use a focus on food sales. Several food companies—such as ice creams, dairies, and sausage companies—also use the focus strategy

Strategies to use against a company deploying a focus strategy include the following:

- Low-price entry: This can be devastating. Large, well-financed competitors enter a market with cost advantages and can take market share easily. They must take much of the market to generate sufficient profits. Such companies can buy a local competitor and attack the remainder of the local market.
- Heavy marketing: Small companies often do not have adequate resources to counter a bigger competitor's mass marketing.
- Specials: Competitors can offer specials similar to the defender's primary products. This "low price entry" approach can be effective in an industry with low profits.
- Use of distribution system to increase service and reduce cost: Distribution is usually a high-cost item for small industries. Competitors with better systems can make more frequent deliveries from larger warehouses. This can aid an invader against a company using a focus strategy.
- Offer broader line of goods and services, as discussed earlier.

3.4.8 Global Strategy

The globalization of information has led to global competition in most industries. Industries with high transportation costs never expected the degree of competition from foreign companies they are now experiencing. Many foreign brands have high name recognition and a reputation for quality within domestic markets.

Supply chains frequently involve several nations. The brand recognition that suppliers generate makes those countries a potential for retail sales. These same suppliers employ lower-income-class workers who have access to dependable wages. These workers form a new middle class that demands consumer goods. The world economy is expanding in this manner. Recessions, however steep, do not reverse this model, but the rate does slow consideration.

The basic reason for global competition is economies of scale and the opportunities brought about by information technology. Similar products can be sold worldwide from the same design and marketing. The potential for profits increases exponentially with global sales.

The goal is to make and sell the same product in as many markets as possible. The actual situation, however, is rarely that simple. Coca Cola is the same worldwide. Fast-food chains make menu changes that appeal to local populations while they attempt to add their traditional products to the new market.

Many successful global companies manage as if all markets were the same distance from headquarters. However, most do not. They manage the home market as if it were the real business and the rest as if they were there for additional market share and profit.

Geography Without Borders

Information has made the world truly global. Almost anyone in the world can watch Al Jazeera, BBC, CAN, CNN or go online and find out what is going on elsewhere in the world. Prior to the explosion of information technologies, many of the world's citizens were at the mercy of their governments for information distribution. Now it is much easier for any organization to find out about any country or region in which it is interested. The role of government, in this respect, is diminishing, although still felt in certain areas of the world.

English has become the international language of business. Italian, Japanese, and German companies with global interests now communicate in English. Language is a major disadvantage to U.S. industry whose leaders are less conversant in foreign languages than their foreign competitors.

Global Strategy Insiderization

The establishment of local manufacturing and distribution systems is called insiderization (Ohmae, 1989). This occurs when most of an international company's regional organization is made up of locals. Sony, Honda, and Nissan, for example, have become insiders within the U.S. Because it is too expensive to ship all parts from Japan, as they originally did, these companies make parts and products within the U.S. This is advantageous both financially and politically.

Pharmaceuticals would be entirely different. The U.S. model would not work with Japanese doctors. They have specific requirements of drug salesmen.

Where Is the Headquarters?

When new overseas operations are struggling, management is only too willing to let the on-site people handle things. Once some measure of success is gained, the situation reverses.

For example, the new operations are expected to follow home-office accounting systems.

Headquarters begins making decisions for the local offices and immediate profit is expected. If this does not happen, headquarters makes immediate changes to local management. Supervisors forget the requirement for long-term investment and patience.

Successful global companies build regional headquarters in major markets and staff these offices with the best talent available, regardless of the nationality of the executives. Strong headquarters in the home country soon discover problems in foreign markets and do not have the background in local conditions to solve them. They fail to recognize that the problems are really at headquarters, not across the ocean.

There must be local management in each region where there are strong operations. Clone the parent and let the clone manage to meet local needs.

Effective world competitors incorporate superior quality and reliability into cost structures.

Marketing, service, and distribution all must be tailored to the local market. Low-cost entries to foreign markets can only be executed in market segments that are significantly underserved, as local competitors have a natural cost advantage. Initial outlay of capital is critical to expanding into a foreign market.

Many companies find local partners to reduce the risk and obtain valuable information from them before a major expansion.

Companies with major technological advantages are likely to expand globally. Such advantages may be short lived, so windows of opportunity are short. Those who capture market share early tend to be more profitable over time. Even so, continued innovation is required to maintain technological leads.

3.4.9 Core Competence Strategy

In the middle and latter part of the twentieth century, vertical integration was the dominant strategy of the large corporation. Vertical integration allowed a company to control the entire production process, perhaps from raw material sources, raw material processing, subassembly, and final assembly manufacturing. Guaranteeing that each level of the chain had a large customer without the added cost of advertising and sales made an efficient vertical supply chain. This concept was followed by General Motors and many large-scale manufacturers.

The chain was never absolute, but it was substantial and offered economies of scale that were difficult to compete against. Over time, however, competition became global, and the vertical integration model was not effective against foreign companies with wage advantages. Many of these companies were in Japan, and they used a different system of manufacturers and suppliers. Major companies had specified suppliers that worked together as a team. Designs were developed so that suppliers could use their strengths to make the final product better and cheaper.

The allied suppliers were known as "keiretsu." Their combination with major companies, such as Toyota, created a formidable competitor. These suppliers shared not only ideas but employees. When a manager in the primary company retired at the age of 55, as was the custom, he or she went to work with one of the keiretsu companies. Vertical integration was no match for the keiretsu system. Vertical integration required massive amounts of capital to acquire suppliers that were not always the most efficient organization of that type.

The next iteration in the development of strategic moves was the core competence of the corporation. Core competencies are knowledge bases upon which the corporation builds its competitive advantages. In this day of mergers and acquisitions, several major corporations have made decisions based on profits and growth in market share only to later discover that they did not have the knowledge to expand, and competitors did. GTE is cited as an example, as is NEC, which is cited as a company of modest resources that was able to build its core competencies and gained strength and success as a result.

The Roots of Competitive Advantage

In the 1980s Honda was losing out to Japanese competitors in motorbike and motorcycle sales. It had previously enjoyed a high market share and profit. Both began to slip as competitors made significant improvement in their products.

Over a two-year period, Honda completely redesigned its small engines and the products in which they were used. Its engines became world-class core products. These engines were put into motorcycles and bikes; smaller versions were put into generators, lawn mowers, power washers, and many more products. Honda developed a core competence in the design and manufacture of small engines. The engines were core products that went into many end products.

Business units organize the core products into end products. Business units innovate by finding new ways to combine core products and/or new markets for their distribution. They may also combine core products with supplier-provided technology to create new end units.

Other characteristics of core competence include the following:

- Core competencies are enhanced as they are used and shared.
- Core competencies harmonize streams of technologies.
- Core competencies include communication, involvement, and a deep commitment to working across organizational boundaries.
- Products capitalizing on core competencies contribute to the competitiveness of a wide range of end products.

Competencies should not be thought of as bundles of business-making products. They should be considered instead as bundles of technologies used collectively to create products. Systems-integration skill is a fundamental key to core competencies' success.

Identifying Core Competencies

To identify an organization's core competency, utilize the following criteria:

- Does the competency provide potential access to a wide variety of markets?
- Does it serve a niche or specialty market that the product can dominate?
- Does it make a significant contribution to the perceived customer benefits of the end product?
- Is it difficult for competitors to imitate?

Few companies in the world will master more than five or six core competencies.

Core Competencies Generate Core Products

Core products are the components and subassemblies that actually contribute to the value of the end products. To sustain leadership in their chosen core-competence areas, companies must maximize their world-manufacturing share in core products.

As a company multiplies the number of application arenas for its core products, it can consistently reduce the cost, time, and risk in new product development. Well-targeted core products can lead to economies of scale and scope.

Limitations of Strategic Business Units

Strategic Business Units may have core competencies that provide value or economic benefit to the parent organization.

The Strategic Business Unit (SBU) is a unit that has the following characteristics:

- Has control of its own resources, budgets, and revenue.
- Develops and implements its own strategy: research and development, product development, and advertising.
- Controls key personnel: can acquire and pay key contributors.

The SBU is not a good device for integrating technologies. They are rewarded for succeeding independently, not for working cooperatively with other SBUs.

Problem Areas

- Under-investing in developing core competencies and core products.
- SBU managers tend to compete with each other and cut costs more than invest.

Constrained Resources

The SBU manager is reluctant to lend his or her key people to another SBU and have them succeed. Thus, he or she tends to hide talent rather than promote it. This is like hiding money under a mattress rather than investing it.

SBU managers are perfectly willing to compete for cash and never think of competing for human resources. Top management members pay a lot of attention to the capital budgeting process and so little to the human resources that embody core competencies. They seldom look four or five levels down in an organization, identify people who embody critical competencies, and move them across organizational boundaries.

Limited Innovation

Innovation in SBUs is limited to existing product lines due to lack of access to resources. Existing lines may be extended and geographic boundaries may be extended, but multi-technology innovation is very unlikely.

Developing Strategic Approaches

Boundaries within the SBU model are as follows:

Fragmentation of core competencies

- Information systems that are not shared between SBUs
- Pattern of communications that hold information internally
- Career paths—no opportunities outside the SBU
- Managerial rewards—rewarded for local success, not contribution to corporate success
- Strategic processes that are independent of corporate strategy

To be successful, strategic architecture must make resource allocation transparent to the entire organization. For example, the best ideas get the most product development funding. Additionally, the business units must provide technical and production linkages (i.e., communication) across organizational lines.

Taking Advantages of Competencies

SBUs should bid for core competencies the same way they bid for capital. Top management must identify overarching competencies and ask businesses to identify projects and people closely connected with them that will form competitive products.

Core competencies should be viewed as corporate resources that are to be effectively spread across their businesses to yield the highest payoffs. Reward systems must be adjusted accordingly. Managers who provide key resources to other businesses at the expense of their own bottom line must be recognized as making a significant contribution to the corporation.

Also, management should ensure that key people understand that no one business "owns" them. Rotation programs are effective at dispelling this concept. Also, these key people should be brought together periodically to trade notes and to explore cross-organizational opportunities.

The feeling of overall community must be fostered. The SBU is a way of proceeding once direction has been decided. The SBU is not good for the developing of future products or corporate direction.

3.4.10 Services-Based Strategy

In the past 40 years, the global economy has shifted from a manufacturing to a service base, with manufacturing becoming only a small, but significant, part of the overall economy.

With this economic shift comes a corresponding shift in managerial strategy. Instead of building strategies around products, managers now strategize based on a deep knowledge of a few highly developed core services. They focus on what the company does best, avoid distractions, and leverage their organizational and financial resources far beyond what traditional strategies would allow.

Shifting Strategic Focus

In older manufacturing economies, the vertical-integration model was prevalent. One company would own all the processes necessary to bring a product to market, including the research and development, manufacturing, distribution, etc. Conventional management strategy during this period involved reverse engineering a competitor's products and then cloning them more efficiently or improving upon them.

In a service-based economy, that strategy is no longer conventional nor prudent. Instead, management should concentrate on differentiating itself by identifying those core service activities where it has, or can develop, unique capabilities.

Employing service-based differentiation strategy involves the following actions:

- Define each activity in the value chain as a service that can be produced internally or sourced externally.
- Ask the following question: "Do we have or can we achieve best-in-class capabilities for this service?"
    - If the answer is "yes," ask, "Should we make it a part of our core strategy?"
    - If the answer is "no," ask, "What possibilities exist for outsourcing the activity or forming a strategic alliance with someone who does have superior capability?"
- Focus the organization's energies on two sets of activities: (1) those where it can create unique products or services and (2) those it must control to maintain its supremacy in the critical elements of its value chain.

Whenever a company produces something internally that others can make more efficiently and effectively, it sacrifices competitive advantage. The key to strategic success has been a carefully developed coalition with one or more of the world's best suppliers, product designers, advertising agencies, financial houses, and other service providers.

What Stays and What Goes?

Much of most companies' cost is in overhead. Much is being done to lower this through lean manufacturing strategies. To remain competitive, management must ask such questions as the following:

- Which costs are associated with core competencies and which can be outsourced for cost advantage?
- Can costs associated with core competencies be reduced through improvements to processes or supply chain?
- Activity by activity, are we the best? Will outsourcing or forming coalitions improve productivity and improve the long-term competitive position?

Alliances with noncompeting enterprises can add efficiencies that are not obtainable within an organization. By avoiding investments in vertical integration and by managing intellectual systems instead of workers and machines, companies decrease total investment and leverage resources substantially. They also minimize certain unavoidable risks. Also, if an outsourced product is out-performed by a competitor, the company can switch to a supplier that can perform as well as, or better than, the competitor with minimal interruption to its own production. This kind of action reduces concerns about idle capacity and inventory losses.

3.4.11 Joint Venture and Outsourcing

In an effort to streamline operations, managers may choose to engage the services of third-party service providers. This engagement is referred to as "outsourcing," or, if the provider is offshore, "offshoring." Outsourced activities might be small, easily defined tasks, such as payroll processing, data storage, or disaster recovery; on the other hand, they might be larger functions such as IT, human resources, or manufacturing. These outsourcing relationships are frequently more akin to strategic partnerships than to subcontracts, but the term's origins reflect the fact that the work was seen as moving "outside" the company, or "outsourced."

For many companies, the decision to outsource might be the largest, single financial commitment they will make. Effective outsourcing is critical to organizational success. Company goals should not be focused on abdicating responsibility but should instead strategically search for partners on their path to achieving excellence.

Why Outsource?

- Lower costs (due to economies of scale or lower labor rates)
- Variable capacity
- Ability to focus on core competencies by eliminating peripheral ones
- Lack of in-house resources
- Getting work done more efficiently or effectively
- Increased flexibility to meet changing business and commercial conditions
- Tighter control of budget through predictable costs
- Lower ongoing investment in internal infrastructure
- Access to innovation and thought leadership
- Possible cash influx resulting from transfer of assets to the new provider

One of the greatest outsourcing challenges organizations face is the decision of what organization to partner with. To make an informed decision, a considerable amount of effort is required. Begin by clarifying your objectives and the benefits you hope to obtain from the outsourcing relationship.

Transform your needs and priorities into search criteria, and then develop a system to quantify, assess, and track the responses received from potential vendors.

Often, organizations employ consultants that specialize in outsourcing. These consultants can assist with the following activities:

- Assessing your potential outsourcing needs
- Defining requirements and priorities
- Selecting a vendor (e.g., overseeing the Request For Proposal (RFP) process, evaluating responses, performing due diligence, etc.)

Organizations must carefully research consultants' expertise and perspectives. Some advisors may be inclined to coach companies through the outsourcing process instead of helping the organization first determine whether that is the best option.

Some companies are reluctant to involve internal staff in the process because discussions of outsourcing may generate concerns about labor cutbacks. While this is a valid concern, bringing staff into the decision-making and requirements process earlier leads to more effective vendor choices and to openness around the process which goes a long way toward allaying fears.

Outsourcing failures are far more likely to occur when organizations rush to implement a "quick fix" to their challenges and neglect to align their activities to the company's longer-term planning activities.

Rarely successful as a cost-cutting measure, outsourcing is best seen as an investment.

In order to avoid potentially catastrophic results and to best leverage an organization's resources, outsourcing must be aligned with a company's strategic plan.

The strategy planning activities acquired in the Systems Analysis section discussed earlier will help identify the functions best suited for outsourcing:

- Assessments of company goals, strengths, and markets
- Identification of gaps in current product/service lines
- Description of customer needs and market trends
- Determination of transformation strategies (restructuring, TQM, etc.)
- Identification of core competencies that should be kept in-house rather than outsourced. Outsourcing strategies are tactical and/or strategic.

Tactical Outsourcing

In this approach, the decision to outsource is directly tied to an immediate organizational challenge. The tactical relationship may be forged to create immediate cost savings, eliminate the need for future investments, realize a cash infusion from the sale of assets, or relieve the burden of staffing. When successful, these relationships maximize the use of capital investment and management time. Note that this is an older approach to outsourcing but is still in use.

Strategic Outsourcing

When companies saw the benefits gained from the tactical outsourcing of payroll functions, etc., managers realized that their time was released to address more strategic issues. Strategic outsourcing relationships are distinct in that the relationship with the service provider is more of a partnership that creates long-term value than a short-term “buyer and seller” arrangement. Strategic outsourcing focuses on identifying a company’s core competencies and then partnering with a provider to deliver on non-core activities. This allows the company to focus its resources on its core competencies.

Strategic outsourcing is also a means for companies to streamline operations. By selecting vendors who are considered “best in class” integrated service providers, rather than smaller single-service vendors, management time is often reduced because supervisory requirements are reduced.

Establishing Outsourcing Relationships

There is an inherent conflict of interest in any outsourcing arrangement. Outsourcing-services providers are in business to make a profit, and the outsourcing “customer’s” goal is to receive high-quality service—often hoping for lower costs than if the work were done internally. For the relationship between customer and provider to be effective, the needs of both organizations must be carefully managed and met.

Outsourcing activities proceed through 10 stages.

1. Strategy: Upper management’s assessment of goals and needs
2. Reassessment: Re-examination of the decision to outsource
3. Selection: Process for pursuing and selecting vendors
4. Negotiation: Agreement on terms and conditions
5. Execution: Transition phase, including early planning and execution
6. Oversight management: All ongoing program-management activities
7. Program “completion”: introduction to and acceptance
8. Build: Completion of new services
9. Change: Responding to any modification that needs to be made
10. Exit: The end of the arrangement

Final Recommendations

- Because the “culture” of the outsourcing partner organization may dramatically impact the organization, be careful of a good fit—especially if planning a long-term relationship.
- Consider service providers who are established industry leaders and who have a proven track record of success. Do not assume, however, that they are the only trustworthy options. Many smaller vendors exist with excellent capabilities and services.
- Determine organizational priorities. For example, are costs or pricing the primary concern? Which is more effective: vendors with a wide or targeted array of services?
- Develop and implement an evaluation process that enables the organization to weigh the advantages and disadvantages carefully and at a very specific level.
- Avoid allowing contract negotiations to become adversarial.
- Keep lines of communication open and act quickly on concerns. Do not let the relationship devolve to the level where actions are pursued in court.

Developing Outsourcing Relationships
There are additional issues to address when formulating outsourcing relationships:
- Pricing
- Length of contract
- Number of vendors to engage
- Hidden costs of outsourcing
- Location of outsourcing—overseas or local
- Preparing for the transition period
- Options if the partnership doesn't work

Pricing Considerations
The best pricing arrangements meet the needs of both organizations.

Pricing Options
- Unit pricing: Payment based on usage of a service. A flexible option.
- Fixed pricing: The customer pays a flat rate for services no matter what. Attractive because costs are predictable.
- Variable pricing: A fixed price at the low end of a supplier's provided service with allowance for varied prices if differing services are provided.
- Cost-plus: Customer pays for provider costs, plus percentage that becomes supplier's profit. Disadvantage is that this has no incentive for the vendor to improve his or her service delivery.
- Performance-based: Includes incentives for vendor to improve his or her performance and pricing often has penalties for unsatisfactory service levels.
- Risk/reward sharing: Customer and supplier share risks and profits.

The length of outsourcing contracts depends on what's being outsourced and why. For the most part, two to three years is considered too long unless the contract includes provisions that give both parties flexibility.

While having one vendor can streamline management efforts, it minimizes the potential benefits of having healthy competition among vendors. With multiple-service providers, the challenge, especially for smaller organizations, is supervision (e.g., monitoring performance, maintaining effective relationships, and managing inter-vendor relationships, etc.).

The dollar figure quoted on an outsourcing agreement does not represent the total cost of the outsourcing engagement. These administrative costs include the expense of strategic analysis, data collection, advisory assistance, transition expenses, layoffs, and associated HR activities. For offshore sourcing arrangements, there is also the cost of additional advisory consulting, travel, and the various other expenses incurred when working with differing business practice/cultures. Be mindful, too, of currency conversion when working with an offshore sourcing partner.

When outsourcing, bear in mind that the most challenging part of the process is frequently in the initial engagement. It takes time for all involved parties to familiarize themselves with each other and their products, services, processes, resources, expectations, organizational culture, etc. Backing away from outsourcing is rarely easy, hence the emphasis on being sure the relationship is not entered into lightly. Usually, the best option is to renegotiate.

3.4.12 Partnering Relationships

Partnering relationships, referred to as "strategic alliances" or "partnerships," may be joint ventures or occasionally are acquisitions. All partnerships except for acquisitions are similar to outsourcing relationships.

What would have been addressed through outsourcing may now be done through partnering. Vendor and provider interactions are less and less adversarial and increasingly focused on long-term partnerships between equals, where the emphasis is on mutual benefit. In fact, some experts view strategic partnerships and alliances simply as more sophisticated outsourcing agreements.

Why Enter Into Partnering Relationships?

- More customers
- Additional capital
- New or additional distribution channels
- Pre-existing relationships or old-fashioned clout
- Experience with a new business model
- Agility and innovation
- New products or services
- Specialized knowledge, expertise, or experience
- Low-cost or unique production capacity

Competitors Can Be Partners

Strategic alliances may be formed with competitors in order to ally against a common foe. When entering into such an alliance, keep in mind the following:

- Be clear about objectives (e.g., gaining new knowledge and skills, service/product/technology gaps, avoiding capital investment, improving supply chain, reducing time to market, regaining competitiveness quickly with minimal effort).
- Never forget that competitor partners are still competitors.
- Challenging to maintain a win-win as opposed to a dominant partner superseding his or her partner.
- Conflict is healthy—a good sign that collaboration is mutually beneficial.
- Information exchange is part of the benefit for both organizations. The challenge is to ensure that staff knows the parameters for what is not to be shared.
- Protect key product values.
- Secure essential access strengths.
- Hold on to vital operating abilities.
- Safeguard critical technologies.
- Preserve growth options.
- Maintain a strong organization.
- Sustain financial strengths.
- Plan for unreliable relationships.
- Consider the pros and cons of exclusivity.

3.4.13 Sustainability

Sustainability is imperative in any business; even if it is not evident at the center of the company's strategies, it is present in every CEO speech. A lot has been said about sustainability over the years, and concerns are getting stronger as the population becomes aware of diminishing resources—including water and levels of pollution—which affects all countries in the world, since these issues do not know borders. Business is vital, but new sustainable ways of doing it must be developed. The 2017 Bloomberg Impact Report, published April 11, 2018 starts with this statement: "Sustainability is embedded in our products, operations and people. Here's how we measured up in 2017."

The best-known definition for sustainability comes from the Brundtland Report (Our Common Future), published by the United Nations World Commission on Environment and Development in 1987: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Although it has always been a concern, it started to grow with the first United Nations Conference on the Human Environment, also known as the Stockholm Conference, held in Sweden in 1972. This was

20 years before 108 Heads of State among the 172 governments participating in ECO92, held in Rio de Janeiro, conceived Agenda 21, which is still a reference document for sustainability strategies.

The consequences of these movements can be seen all over the world, as most countries are constantly reviewing their environmental legislation. The practice of not in my backyard (NIMBY) is no longer acceptable, and companies that insist on these practices are losing market all over the world.

In 1997, Elkington introduced the concept of the triple bottom line: Profit, Planet, and People. This concept enlarged the idea of sustainability, and today we look at it with four dimensions: environmental, businesses, community/social, and cultural. These four factors are the sustainable bottom line for any businesses.

In a globalization era (see 3.4.8 Global Strategy), we see that in the 21st century, information is one click away and customers are getting more concerned about the consequences of their buying habits.

The best way to incorporate sustainability in your business strategy is from the very beginning.

Sustainability directors must belong to the Board of Directors and have a word in every decision made. Going back to the product life cycle of any product (see 3.3.1.6), a company is responsible for its choice of suppliers, the way it is producing and delivering, all income including energy used, and how its clients are going to dispose of its products.

A good strategy is to include all stakeholders involved in the process, including neighborhoods and other communities affected by your business. They must be listened to so that the business can find solutions to remediate former mistakes and leave a positive legacy for future generations.

Innovation is a must in any strategy today, and it must be achieved through the lens of sustainability. We can no longer think about innovation without considering environmental, social, cultural and, of course, economic issues. Logistics is also growing in importance as it can represent a huge gain in financial and environmental areas. Alliances might also help develop a more sustainable strategy. Companies must evolve, creating value to their customers, sparing non-renewable resources, reusing materials, and reducing waste.

Sustainability has to be integrated into daily operational processes, and transparency is essential. The growing number of companies publishing their annual reports in accordance to GRI is growing all over the world. "While the relative growth in the number of externally assured GRI reports published by U.S. companies is lower than that on a global scale, the number of externally assured GRI reports published by U.S. companies has more than tripled between 2008 and 2013" (GRI 2014).

In order to succeed in the 21st century, organizations must consider their sustainable actions. Governance polices should be implemented with respect to environmental limits while fulfilling social needs and aspirations. These should be innovative and evolve with communities, being flexible enough to make changes whenever necessary. This is a big challenge that calls for major transitions, not only in economics but also in social, political, technological, and cultural behaviors.

Approaching the third decade of the 21st century, we can see an evolution in consumer's behavior. They are more aware of sustainable issues and energy consumption, material choice, labor conditions, etc. used in the production of goods, are now being taken into consideration before making a choice of buying a product. Actually, the population is becoming less interested in goods and more interested in experiences.

PSS—Product-Service Systems appears to be a valuable solution, because it usually leads to more sustainable systems, and offers a better response to customers' wishes. It is a win-win solution: companies who can manage to propose vibrant economical and sustainable product + service solutions to their clients, are probably going to stay longer in the market.

According to the Austrian Federal Ministry of Transport, Innovation and Technology (https://nachhaltigwirtschaften.at/en/fdz/projects/success-strategies-for-product-service-systems-pss.php), PSS can be defined as:

"Sustainable business-to-customer (B2C) PSS are seen as commercial offers of a combination of products and services (or a free offer with the potential of being commercialized) that is able to fulfil consumer demands, INSTEAD of selling the products involved. Sustainable PSS provide consumers with both functional and non-functional values which increase their satisfaction, yet consume less material and energy."

PSS systems can be product-oriented when the provider not only sell a product but also offers services, advices or consultancy. They can be use-oriented, and in these cases we can have leases, renting, sharing, and group pooling. This kind of PSS is very popular in car and bike sharing in big cities. The last one is result-oriented where some management activities can be shifted from user to provider, or the customer can pay per unit use. Although PSSs are not the panacea, when well-planned they can produce sustainable results in all levels, environmental, economic, cultural and social.

3.5 Executing the Strategy

3.5.1 Charters, Time Management, Project Management, and Leadership

Once each strategy is formulated, implementation teams must be formed. These can be ongoing functional teams such as the accounting or manufacturing department, multifunctional teams, or special teams assembled just for accomplishing a tactical objective or implementing a strategy.

Regardless of composition, a team charter should be constructed. It should include a detailed description of the objective or strategy; expectations for end results; listing of team members or accountable business unit manager, milestones, and deadlines; budget; and a brief listing of tasks to be accomplished. The engineering manager responsible for executing the strategy is referenced to Domain 2's Leadership and Organizational Management, Domain 4's Financial Resource Management, and Domain 5's Project Management, in addition to Blanchard, Parisi-Carew, and Carew for situational leadership (2000); Senge (1994) for systems thinking; Hobbs (1987) and Covey (2004) for time management; Kerzner (2003) for Project Management; and Morris (1978) for modes of professional functioning.

3.5.2 Change Management Techniques and Adjustment Strategies

Effectively managing change is key to the smooth, orderly functioning of organizational operations. Change must be led, not mandated. To successfully manage change, all management levels must visibly commit to and lead the change process.

Some characteristics of a change leader include the following:

- Understanding business by engaging in system analysis, discussed earlier
- Understanding the dynamics of organizational change
- Possessing the respect and trust of coworkers
- Having the ability to accomplish the following:
    - Multitask
    - Simplify complex issues
    - Handle uncertainty
    - Manage conflict well

Knowledge of Change Process Dynamics

Rules of Change

- Change cannot be mandated.
- Change is non-linear.
- Change occurs on several levels simultaneously.
- Change does not occur without problems.
- Change can be blinded by premature vision and planning.
- There are no one-sided solutions; individualism and collectivism must occur in tandem
- Effective change does not occur in either a centralized or decentralized organization.
- Change occurs best simultaneously from a top-down AND bottom-up strategy.
- Interaction with the wider environment is necessary for change.
- Every person is a change agent.
- Leadership commitment is vital for success.

Conflict

Conflict is a part of the change process. Conflict can be either functional or dysfunctional. The change leader must strive to maintain functional conflict within the group.

- Functional conflict accomplishes the following:
  - Increases/strengthens team mentality.
  - Increases cohesion.
  - Improves communication.
  - Produces effective ways of operating.
  - Contributes to better quality.
- On the other hand, dysfunctional conflict has the following characteristics:
  - Prohibits team from completing task.
  - Is personally destructive.
  - Lowers quality of decisions.
  - Threatens team's survival.

Knowledge of Factors Contributing to Resistance to Change

Common reasons for change resistance include the following:

- Lack of clarity in stating the problem (If the problem cannot be described, it's difficult to get others to believe it exists.)
- Not getting the required information
- Poor communication within the team
- Premature testing of alternative strategies
- A critical, evaluative, competitive climate (An open, positive environment facilitates change by allowing communication to occur.)
- Pressures for conformity
- Lack of problem-solving skills
- Inadequate motivation
- Group think (The more ingrained and successful an activity is from a management and engineering point of view, the more difficult it is to question and change.)

Even with a majority acceptance of change, there will still be those individuals who resist.

High-Performance Team Characteristics

Team dynamics play a critical role in the ability to implement change. The characteristics necessary for the existence of high-performance teams include, but are not limited to, the following:

- Good leadership
- Fluid leadership that makes the most of each member's strengths
- Open communication
- Clearly defined team goals
- Clearly defined roles for each team member
- Support from upper management
- Recognition of the unique contributions of each team member
- Personal satisfaction derived from team activity
- Shared experience
- Comfortable honesty between team members
- Diverse talent and personality
- Desire for excellence
- Ability to disagree
- Passion for mutual success
- Willingness to share responsibility
- Mutual respect and trust
- Humor-performance with fun

Facilitating Change through Assessing Team Performance

High-performing teams are dynamic, successful groups of individuals who are highly task- and people-oriented. They are characterized by high morale, an emphasis on achievement, and a genuine willingness to solve problems. Use the guidelines below to evaluate a team's performance levels. Additional references can be found in Blanchard et al. (2000) and Senge (1994). If teams are not yet high performers, use these guidelines to help identify opportunities for improvement.

Participation: Look for differences in the amount of participation among members.

- Who are the high participators?
- Who are the low participators?
- Is there any shift in participation, e.g., highs become quiet, lows suddenly become talkative?
- What possible reasons are there for this in the group's interaction?
- How are the quieter team members treated? How is their silence interpreted?
- Who talks to whom?
- Who keeps the ball rolling?

Influence: Influence and participation are not the same.

- Which members are high in influence—when they talk, others seem to listen?
- Which members are low in influence- others do not listen to or follow them? Is there any shifting in influence? Who shifts?
- Are there any rivalries within the group? Is there a struggle for leadership? What effect does it have on other group members?

Styles of Influence: Influence can be positive or negative; it can enlist the support or cooperation of others or alienate them.

- Autocratic—Does anyone attempt to impose his or her will or values on other group members?
- Peacemaker—Does anyone consistently try to avoid conflict or keep unpleasant feelings from being expressed? Do any members appear to avoid giving negative feedback?
- Laissez-faire—Are any group members getting attention by their apparent lack of involvement? Does any group member go along with group decisions without seeming to commit himself or herself one way or the other?
- Democratic—Does anyone try to include everyone in a group decision or discussion? When feelings run high and tension mounts, which members attempt to deal with the conflicts in a problem-solving way?
- Conflict—Does anyone always disagree or try to find fault in every move, trying to postpone all decisions?

Decision-Making Procedures: Many kinds of decisions are made in groups without considering the effects of these decisions on other members.

- Does anyone make a decision and carry it out without checking with other group members?
- Does the group drift from topic to topic?
- Who supports other members' suggestions or decisions?
- Is there any evidence of a majority pushing a decision through over other members' objections? Is a vote called for?
- Is there any attempt to achieve consensus—getting all members to participate in a decision?

Task Functions: These functions illustrate behaviors used to accomplish the task the group has before it.

- Does anyone ask for or make suggestions regarding the best way to proceed?
- Does anyone attempt to summarize?
- Who keeps the group on target?

Maintenance Functions: These functions are important to the morale of the group.

- Who helps others get into the discussion?
- Who cuts off or interrupts others?
- How well are members getting their ideas across?
- How are ideas rejected? Do members support others when they reject their ideas?

Group Atmosphere: Are the realities of the situation acknowledged and understood?

- Is there any attempt to suppress conflict or unpleasant feelings?
- Do any members provoke or annoy others?
- Do people seem involved and interested?

Membership: The degree of acceptance or inclusion in the group.

- Is there any sub-grouping?
- Do some members appear to be "outside" the group? How are they treated?
- Do some members behave as if they are better than others? How are they treated?
- Do some members move in and out of the group? Under what conditions do they come in or move out?

Feelings: Are the feelings of group members observable?

- What signs of feelings are observable in group members—anger, frustration, warmth, affection, excitement, or competitiveness?
- Are there any attempts by group members to block the expression of feelings?

Norms: The "rules" of the group.

- Are certain topics avoided by the group? Who seems to enforce this avoidance?
- Are members overly nice or polite to each other?
- Do questions tend to be restricted to intellectual topics or events outside the group?

Once improvement opportunities have been identified, you can develop strategies to address them. As change occurs, individuals are often forced to move outside of their comfort zone. Change-management programs should achieve buy-in from all, or at least a healthy majority, of those involved in the change. It's also crucial that the change program explicitly address staff concerns, communicate the rationale behind the change, and clearly state the intended results.

3.6 Strategic Performance Measurement, Control, and Evaluation

The golden rule in measurement system design is to know the purpose of measurement. Measurement systems can be used for control, feedback, and prediction and to promote capabilities. Overall, a properly designed strategic measurement system will promote understanding and unity of purpose (Deming, 1982).

Corrective action requires a tracking system and therefore a measurement system. Significant coverage of the topic would require several texts. Below is a summary of procedures and tools, but the engineering manager in charge of measurement, evaluation, and control is encouraged to complete a detailed study of the reference provided at the end of this material.

Mundel (1986) suggested that all work efforts are separated into a hierarchy of work units that will separate levels of measurement for vision and mission, strategic objectives, strategy, tactical objectives, tasks, and action plans. The purpose of the hierarchical approach is to separate the scope of work into increasingly smaller bits of measure. This assists in selecting improvement tools and measurement techniques. It also provides data structure for automated reporting and thus is similar to the work breakdown structure

Checklist on measurement points or work units follows:

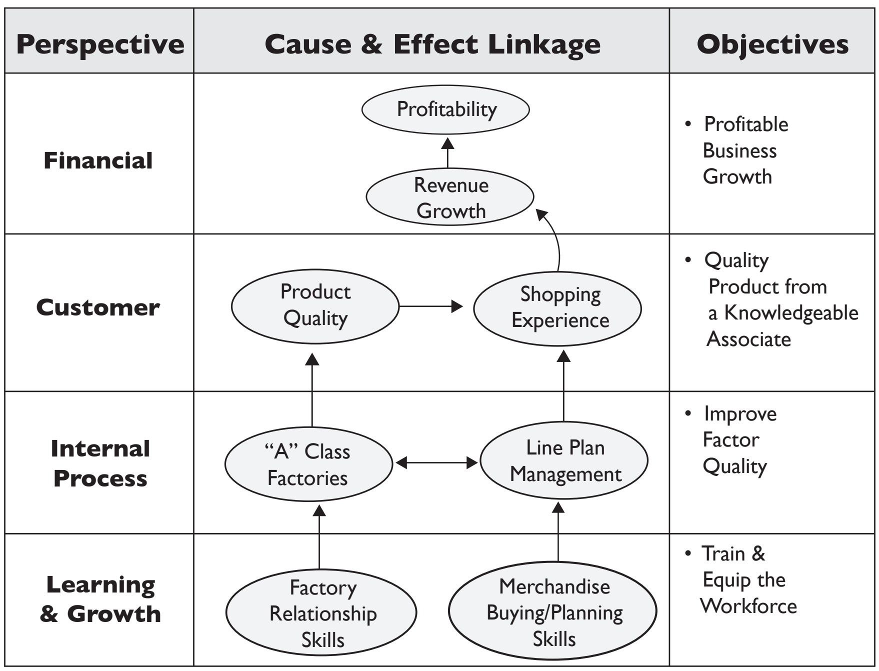
- Consistent and definable to avoid double counting
- Counts verifiable by at least two collection methods
- Easy to collect so that costs of collection are justifiable for their use

The smaller measures can be summed into the next level up and so forth until the measures for vision and mission are obtained. This linear design has shortfalls in practice. For example, performance across tasks, objectives, or strategies can be missed. A technique to balance out measurement creation is suggested by Sink and Tuttle (1989): measurement dimensions. The set of metrics at each level are audited for missing elements by placing each into the dimensions of efficiency, effectiveness, productivity, quality of work life, quality, innovation, and profitability. If a dimension is absent of a measure, then one or several are constructed to represent that dimension.

3.6.1 The Balanced Scorecard

The Balanced Scorecard is a method to monitor performance toward goals and objectives. It is often used to balance strategic and financial measurements and includes internal or external customers, processes and learning and growth perspectives (see Figure 3-7). It is structured to allow managers to assess their teams' execution of activities or progress toward milestones. As a tool, it may be used for to measure and track strategy implementation, management of operations, or personal performance or development.

Figure 3-7. Kaplan and Norton Balanced Scorecard



The measures on the balanced scorecard are developed by management. Data is assessed against established targets on a regular basis. This may be at least daily for a production cell or monthly for an enterprise. The data serves to identify and track trends in the activities supporting key objectives. They may measure production outputs within various cells or production centers (volume production), cost of production, or customer feedback.

Effective monitoring of trends often requires evaluating measures against a standard. For example, measures of production quantities don't provide useful assessment of productivity when the quantity of personnel changes. A more effective measure may be to measure production quantity per the number of labor hours expended for the activity (e.g. "number of widgets per 100 labor hours"). Individual measures may also be colored to provide a ready indicator of trends in performance—such as red for negative trends or green when targets are being achieved.

The Balanced Scorecard is often used in setting personnel goals and assessing performance. Individual measures on a scorecard may be included in performance objectives for an individual. Managers' performance assessments may include the entirety of the scorecard measures for their area of control.

3.7 Deploying Lessons Learned

Business does not wait for an orderly annual recycle of the planning process. Therefore, action plans and strategy must also consider immediate corrective action. Corrective-action techniques are discussed in Domain 5: Project Management. When the annual, strategic planning cycle does occur, the first steps are to review the measure system to evaluate performance to date on objectives. Next is to review the systems analysis to see if the competitive environment has changed. Updating ALL the system analysis data must take place before adjustments to strategies are made. Organizational discipline is required to "Hold the Gain," as stated by Juran (1988). A useful process is to update the original planning documents along with a statement of how significant changes in the environment will impact the organization's current strategy.

Review

Upon completing the study of "Domain 3: Strategic Planning and Management," you should be able to answer the following questions:

1. What are the basic components of strategic planning? List and describe them.
2. What is the difference among strategic objectives, strategy formulation, tactical objectives, and action plans?
3. What is the purpose of systems analysis?
4. What are the possible reasons for strategic measurement?
5. What resources are helpful when initiating an outsourcing relationship?
6. What must the engineering manager consider when outsourcing?
7. How does the SWOT or TOWS matrix differ from the BCG matrix?
8. What are the differences between functional and dysfunctional conflict?
9. What can the engineering manager do to facilitate the acceptance of change?
10. What must be done to prepare for a strategic planning recycle?
11. What considerations must the business make to ensure sustainability?
12. How may the Balanced Scorecard be used?

For Further Information

The Engineering Management Handbook, by the American Society for Engineering Management, 2010.

A Guide to the Project Management Body of Knowledge, 2013, Newtown Square, PA: Project Management Institute. Consult this ANSI publication for more information about organizational structures.

Managing Engineering and Technology, by L. C. Morse and D. L. Babcock, 2013 (Sixth Edition), Upper Saddle River, NJ: Pearson.

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4

Financial Resource Management

Domain 4 Champions

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4.4 Engineering Economics

4.4.1 Nomenclature and Fundamental Equation

4.4.2 Formulas and Factors

4.4.3 Cash Flow Tables and Spreadsheet Block Functions

4.4.4 Measures of Economic Value

4.4.5 Mutually Exclusive Alternatives, Replacement Analysis, and Capital Budgeting

4.4.6 Depreciation and Taxes

4.4.7 Public Sector

4.4.8 Inflation and Exchange Rates

4.4.9 Analyzing an Uncertain Future

4.4.10 Integrating Economic and Non-Economic Criteria

4.5 Cost and Benefit Estimating

4.5.1 Types of Costs and Benefits

4.5.2 The Cost Estimating Environment and Types of Cost Estimates

4.5.3 Cost Estimating Methods

Domain 4: Financial Resource Management

Key Words and Concepts

Accrual	A future payment or receipt entered in the books as an allowance to reflect its present value.
Assets	Items owned by the enterprise.
Balance Sheet	Financial statement that provides a snapshot of the total accounts for assets, liabilities, and equity.
Credit	One of the columns used in double-entry accounting to show decreases in expenses and assets and increases in liabilities, income, and equity.
Debit	One of the columns used in double-entry accounting to show increases in expenses and assets and decreases in liabilities, income, and equity.
Double Entry	The system of accounting whereby all transactions consist of entries in two columns that have offsetting values.
Equity	The owners' value of the organization, determined by subtracting the total liabilities from the assets.
Expenses	Moneys paid by the organization for the operation of the business.
Fixed Costs	Also called overheads, expenses that are not impacted by small changes in sales, such as property rentals.
Income Statement	Financial statement that provides information on the profitability of the enterprise over a specific period of time.
Liabilities	Debts and other payments owed by enterprise that will be repaid in the future.
Margin	The difference between selling price and cost of production.
Ratio Analysis	Calculations based on data from the financial statements that provide bases for improved comparisons between different organizations or time periods.
Revenue	Money generated through the sale of products and services.
Variable Costs	Also called direct costs, expenses that result from incremental increases in sales, such as raw materials for components.

4.0 Overlapping Financial Disciplines

Money is the common metric for the activities of organizations. It measures transactions, inputs, outputs, the creation of value, organizational performance, etc. The different financial disciplines overlap, but the simplified descriptions in Figure 4.0 are a useful starting point.

Figure 4-0. Principal Focus of Financial Disciplines

Sub-Domain	Discipline	Focus
4.1	Accounting	Accurate value of transactions & of organization up to current date
4.2	Finance	Organizational assessment and decision-making
4.3	Budgets	Control of organization
4.4	Engineering Economics	Which projects and which design choices should be done
4.5	Cost and Benefit Estimating	At the project level to support decision-making
5.5	Project Management	Monitoring and control of project costs and progress

4.1 Accounting

For almost all activities that engineers are engaged in, and in particular engineering management, money is an appropriate tool to measure the value of the output. The principles of sound engineering design are all based on the concept of producing the maximum benefit for the minimum expenditure of resources. Without concern for cost, anyone could design a bridge that would carry a given load—simply keep pouring concrete until there is sufficient mass to fill the span to be crossed. The measured performance of engineering managers is predominantly based upon the value generated by their decisions, in terms of the impact on the financial performance of their organization. Tracking the flow of money through standard accounting practices supplies the means for measuring the relative success of this generation of value. Only through an understanding of the processes involved in the accounting of money can engineering managers ensure the decisions made will optimize the use of financial resources and create the greatest value for their organization.

In the U.S., the Generally Accepted Accounting Principles (GAAP) govern how this money reporting is done, while the International Financial Reporting Standards (IFRS) govern in most other countries. Because many large firms operate in multiple countries, there are significant ongoing efforts to harmonize the two sets of standards. Among the challenges is a difference in their approach. GAAP is generally regarded as rules based, while IFRS is principles based.

4.1.1 The Sarbanes-Oxley Act

Around the turn of the 21st century, several high-profile companies were exposed for engaging in fraudulent activities centering on their accounting practices. The investing community had relied upon the information being provided by these firms, which generally overstated the earnings generated and the level of security in the companies' holdings. The result of a string of convictions of senior executives, the failure of their companies, including the loss of shareholder wealth, and the collapse of the associated accounting firms resulted in a push for stricter regulations regarding the methods used to prepare the books of publicly traded companies. The Sarbanes-Oxley Act of 2002, commonly known as *Sarbox* or SOX, became a U.S. federal law aimed at rebuilding public confidence in the securities markets. The regulations focus on establishing more rigorous methods for ensuring independent auditing, increasing accountability, greater transparency, and reducing variance in accounting practices.

4.1.2 Bookkeeping Principles

All activities within an organization that involve money are carefully recorded by bookkeepers using principles that are largely unchanged since they were developed during the Italian Renaissance. All transactions (and there may be millions of these each day for larger enterprises) are recorded chronologically in a set of books called *journals*. Each transaction involves recording the flow of money in a *to-from* format. Buying a tool to be used for processing involves a transfer of money from the buyer to the seller. Buyers see a reduction in their cash on hand and an increase in the value of their equipment. The sellers will see an increase in their cash on hand and a decrease in the value of their inventory. Each detailed entry of the journal is transferred to an appropriate *ledger* or account, which is the way to group similar transactions in a manner useful to management. Regardless of the size or complexity of an organization, there are only five basic types of accounts that are standardized across all organizations:

- Assets—the value of the items owned
- Liabilities—the value of debts and outstanding payments due to others
- Revenue—money received through the sale of goods and services
- Expenses—the costs incurred in the running of the business
- Equity—the value of the organization to the owners

Standard bookkeeping practice has established the use of two columns to track whether any transaction results in the increase or decrease of the affected account. These columns are named *debit* and *credit*, and they form the basis of the *double-entry accounting system*, as shown in Figure 4-1. Initial exposure to the terms *debit* and *credit* can be confusing because there is a common usage among the public where a credit to one's account is an injection of cash and a debit signifies a withdrawal, as is true when considering it from the financial institution's perspective that your account is actually a liability to them and your balance indicates money they owe you. In the double-entry accounting system, all transactions will result in an equal total of debit and credit entries, and the totals of all debit accounts will exactly match the total of all credit accounts. This balancing of the books provides a check to assure no errors were made during the bookkeeping process.

Figure 4-1. Double-Entry Accounting Principle

Account Type	Increase	Decrease
Assets	Debit	Credit
Liabilities	Credit	Debit
Revenue	Credit	Debit
Expenses	Debit	Credit
Equity	Credit	Debit

4.1.3 Accrual Accounting

Many businesses deal with the sale of large items that may take many years to complete. Consider a company that builds aircraft carriers. It is conceivable that there will be months where millions of dollars are expended on the normal construction activities and no sales or other forms of revenue come in during that same time period. If one only considered the purchase of raw materials or labor as expenses at the time the money was spent, the resulting analysis of the operation of the company would appear as if it suffered huge losses in some periods and even greater profits in other periods when its product was transferred to the purchaser. A scenario more reflective of the true nature of its business is that it was creating value during the entire time the ship's construction was underway. Similarly, large payments might be made to cover regular expenses for a long period into the future, such as a multi-year insurance premium or increasing inventory levels to meet an expected demand. These situations are handled through *accrual accounting*, whereby expenses or revenues are leveled off through posting to appropriate asset or liability "holding" accounts, such as *prepaid expenses* or *work in process* (WIP). Major assets, such as buildings or machinery wear out over time, so the replacement cost is spread over the expected life as *depreciation*.

4.1.4 Fixed and Variable Expenses

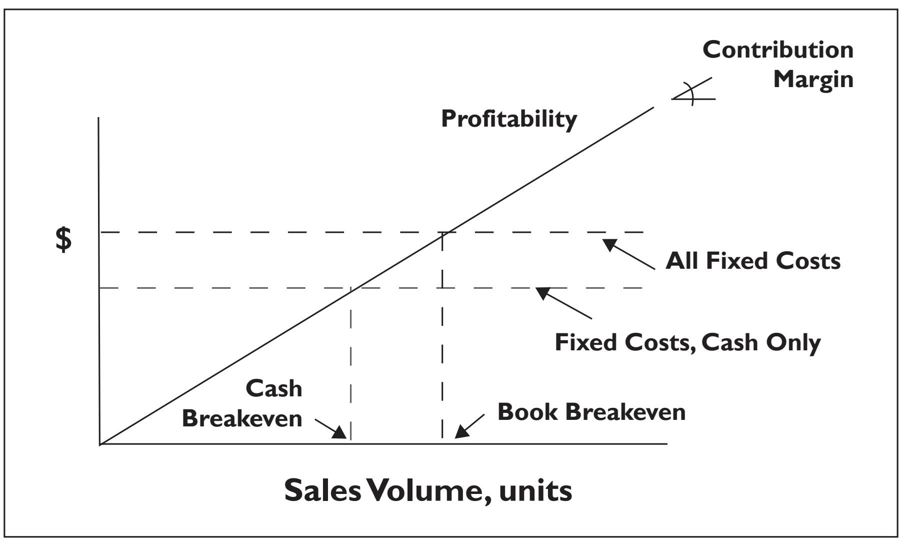
A key question that is critical to the health of a business and is often very difficult to determine is, "Are we selling at a price sufficient to cover the cost of production?" Usually the selling price is clear, but the link to each supplied item and system may not be clear. The cost of the products and systems can be a matter of managerial interpretation, so it is important to be consistent within the organization once the methods are defined and implemented. By maintaining consistent methods, year-over-year changes are meaningful and not the result of a change in accounting methods.

One factor in the variability of how a given enterprise may determine cost is the treatment of fixed and variable expenses. One fixed cost is also the overhead cost, for example SG&A—selling, general and administrative—expenses. A variable cost is also called a direct cost, or may be referred to as COGS—cost of goods sold. The desired outcome of separating costs into these two categories is to determine the marginal cost of one more unit of product—that is, how much will it cost to make one more unit? The cost of the electricity to a factory and the salaries of management personnel do not change if one more or one less unit is sold.

Variable costs are tracked by product. Fixed costs are tracked at an organizational level. For strategic purposes, a manager may decide to offer a large discount and sell a product at cost so that all costs associated with the order are covered, but the company makes no profit. Such strategies are sustainable, provided other sales exist to cover the fixed costs. Selling at a price below the total direct cost is not sustainable and might jeopardize the short-term health of the business. Again, the criticality of knowing the variable cost becomes apparent.

Contribution margin is the difference between the selling price and the direct cost of a unit. The aim of the operations management of the business is to grow the sales of enough units so that the total contribution margin is greater than the fixed costs of running the business. This is the point where profitability starts. Since some expenses have been paid for in the past, as is the principle of accrual accounting, a portion of the fixed costs will be non-cash in nature. The point where the contribution margin is sufficient to cover the cash outflow is called *cash breakeven*. The point where the sales are high enough that the contribution margin covers all costs, including accrued expenses, is called *book breakeven*.

Figure 4-2. Increasing Sales Volume to Reach Profitability



4.1.5 Financial Statements

Just as the five basic categories of accounts are standard across organizations, the format of financial statements looks very similar across all enterprises, from the very small to the very large. All publicly traded companies are required to make their financial statements available to potential shareholders. This provides free access to a wide variety of businesses and allows direct comparison of their financial statements. The common statements that are typically produced quarterly are the *income statement* and the *balance sheet*.

The income statement answers the question of the business's profitability over a given time period. The balance sheet provides a snapshot of the financial status of the business at one specific point in time. The *statement of cash flow* provides a summary of the effect of the financial-management decisions made over a period of time. The income statement is also referred to as the statement of profit and loss or simply as a P&L. The statement of cash flow can be derived from the income statement and the two balance sheets from the beginning and end of the period covered.

Figure 4-3. Standard Format of the Income Statement

Revenue
Minus allowances (warranty, bad debt)
= Net Revenue
Minus COGS (Direct Costs)
= Contribution Margin
Minus SG&A (Fixed Costs)
= Operating Income
Plus Other Income (Minus Other Expenses)
Minus Income Tax
= Net Income

Figure 4-4. Standard Format of the Balance Sheet

ASSETS	LIABILITIES
Current Assets	Current Liabilities
Cash	Short-term Credit Line
Receivables	Accounts Payable
Short-term Notes	Accrued Expenses
Inventory	Taxes Payable
Prepaid Expenses	Current Portion of
Fixed Assets	Long-term Debt
less Accumulated Depreciation	Long-term Debt
Long-term Investments	Repayable Grants
Goodwill and Intangible Assets	
	EQUITY
	Capital Shares
	Retained Earnings
TOTAL ASSETS = TOTAL	LIABILITIES + EQUITY

The income statement is the primary tool for investors, as it measures the value generated by the enterprise. The focus of financial reporting when a company releases its statements is the *earnings*, which is another term for net income. The balance sheet is the primary tool for bankers or other creditors, as it gives a snapshot of the business's ability to convert assets to cash to cover debt repayments. The balance sheet is arranged by order of *liquidity*, with the most *liquid* items appearing closer to the top. The liquidity of an asset or liability is a measure of the ease to convert it to cash.

4.1.6 Intangible Assets

With increased globalization and high tech business, intangible assets have increased in importance. Some intangible assets, such as patents, trademarks, and the value of customer relationships can even be amortized or depreciated like physical assets. The value of a major brand or a suite of patents may be the large majority of a firm's market value. For example, intangible property has been estimated to be more than 80% of the value of Apple and Alphabet. The modern engineering manager is faced with assessing decisions based on the strength of faith in the intangible value of their brand.

4.2 Finance

Financial management requires continually optimizing all the complex variables to find a balance that creates value. One example is simply establishing the right price to charge for the company's output. Raising the price can have the effect of increasing revenue, because of the extra money received per unit sold, but it can also have the opposite effect, if too many customers pursue less costly alternatives. Successful financial management becomes an art, since there are no clearly explicit rules that will work across companies or in different situations. This issue is exacerbated by the reluctance of successful companies to openly share their proprietary methods that allow them to gain strategic advantages against their competition.

4.2.1 Ratio Analysis

Because of the large variability in the relative sizes of different enterprises, the absolute value of a particular measure is difficult to evaluate for a newly hired manager. For example, a convenience store may have a well-stocked backroom with $20,000 worth of inventory. On the other hand, an inventory of $1 billion might represent a crisis for an integrated multinational oil company. Continually performing in-depth analyses for every aspect of a business would be excessively time consuming. The solution has been the development of standard ratios that provide a meaningful value for key aspects of the business operation. By trending these ratios, rather than the single values that comprise them, the manager can better understand changes in the business and develop strategies for improvement. As well, the ratios provide a means to better benchmark against industry averages and the top-performing competitors.

Unlike scientific pursuits, financial management has few universally accepted definitions for terms, and it is important to understand the meaning in each specific usage and organization. A listing of types of ratios and some of the more common examples of each are provided below. Most of these are included in the ratios developed by DuPont in the 1920s and are sometimes referred to as *DuPont ratios*. An additional category contains ratios measuring the investment community's perception of the value of publicly traded stocks. These are not dealt with here.

- *Liquidity ratios* provide a measure of the likelihood that the business can stay solvent in the short term.
  - *Current ratio*—the value of current assets divided by current liabilities. Lenders will avoid a company that has a low value, as it may not have sufficient assets to cover its debts. A high value may suggest that opportunities are being lost, since deploying the cash could result in increasing the value generation of the enterprise.
  - *Quick ratio*—similar to the current ratio with the inventory excluded. Useful if the nature of the inventory suggests it may be difficult to sell it quickly, such as at an auction. A high value would be attractive to a lender.
- *Activity* and *asset management ratios* measure the effectiveness of the management at using the company's assets.
  - *Inventory turnover*—sales divided by inventory. This ratio indicates how much of the company's value is tied up in inventory. A very high number may suggest that some sales are being lost because of inability to fill orders in a timely manner. A very low number suggests that too much cash has been tied up in maintaining stock that sits on the shelf.
  - *Average collection period* or *days sales outstanding*—receivables divided by sales x 365 days. This is a measure of how effective the company is at getting the customers to pay their bills. Providing the opportunity to buy on credit allows customers to realize future profits that they can then use to pay their debts. Failing to collect on the debts promptly may suggest the debt may become uncollectible, or it may suggest that there are quality issues prompting customers to refuse payment.
  - *Fixed assets turnover*—sales divided by net fixed assets. This measure can indicate how effective the organization is at using its fixed assets. This ratio is meaningless to evaluate differences between companies in different industries and might require caution when comparing competitors. A company with old buildings or land purchased prior to a real-estate boom would have much lower book values for its fixed assets than a newly formed company with identical operations.
  - *Total assets turnover*—sales divided by total assets. This ratio is similar to fixed assets turnover, with the same reservations on comparing between companies.

- *Leverage* or *debt management ratios* measure the long-term financial strength of the business and the likelihood that it can repay its total debt. Lenders are attracted to companies with very low debt. Investors may prefer more debt, as it allows more aggressive use of the financial resources and perhaps optimizes profitability.
  - *Debt ratio*—total debt divided by total assets. This ratio is sometimes called the *debt to equity ratio*, even when the calculation uses assets in the denominator. In using ratios, it is important to clarify exactly how the calculations were made.
  - *Times interest earned*—EBIT divided by interest expense. EBIT is the earnings before interest and taxes. Lenders will charge a higher interest rate to borrowers that are deemed to be higher risk. The times interest earned ratio is a measure of the cash coming into the company compared to the interest it is paying. EBIT is used rather than earnings because interest payments are obviously available to meet interest payments and taxes are available in the sense that they will reduce toward zero should the company become less profitable.
- *Profitability ratios* generally provide insight into the profitability of the entire enterprise. It is generally more significant to recognize changes over time using consistent methods than to strive for uniformity in calculating methods between organizations.
  - *Profit margin*—income divided by sales. The value used for income could be expressed as operating income, EBIT, or earnings after dividends. It is a very powerful tool for comparing competitors, as when one organization consistently has higher profits than another in the same market.
  - *Return on assets*—income divided by total assets. It measures how effectively the resources are being used. It is effective for measuring against competitors and between divisions within the organization. A consistent low return suggests that there might be better alternatives for the organization's investments going forward.
  - *Return on equity*—net income divided by shareholders' equity. The return on the shareholders' investment is critical to the senior management of the organization. The return on assets is largely independent of the financing of the organization, but return on equity is strongly influenced by the level of leverage employed. Highly leveraged organizations will have wider swings in return on equity over time.

Paralleling the development of the modern accounting system since the Italian Renaissance, businesses have grown away from the owner as manager and financier to the more complex relationships of today. The development of the role of the professional manager narrows the concern of modern owners to focus simply on the value being generated from the business created from their investment. From the perspective of the owner (and therefore the employer of the professional manager), the primary focus is expressed by the fundamental set of the DuPont ratios, expressed as:

$$ROE = \frac{Net\ Income}{Sales} \times \frac{Sales}{Assets} \times \frac{Assets}{Equity} \qquad (4\text{-}1)$$

where ROE is *return on equity*.

4.2.2 Using Financial Information for Operational Management

A major purpose in compiling financial reports is to guide action. Financial statements provide quantitative indications for appropriate management actions. There are other sources of information that can augment the decision-making process, such as market share within an industry and forecasting. The following are examples of the key information commonly looked at by management as indicators for guiding action and the decision-making processes.

- *Sales*—Sales levels are of key concern to the business, but more important is the change in market share. All competitors may see a drop in sales during slow periods in a business cycle, but management should focus on changes in the organization's share of the market. A drop in market share can be a signal for underlying operational problems, such as quality control or delivery issues.

- *Margin*—A continual decline in margin can be expected as a market for a particular product matures. Price increases from suppliers should be monitored, and management should continually evaluate the need to pass increases in costs on to customers.
- *Overhead costs*—Normal business cycles require continual monitoring of overhead costs and the impact of controls on spending in the organization. During good times, increases in overhead costs might be required to retain staff, but these become difficult to reverse smoothly when downturns occur.
- *Inventory*—Inventory levels must be sufficient to allow effective operations without delays from waiting on materials. Inventory is a use of cash that reduces its deployment in other productive areas. The demise of many start-up businesses has resulted from the inability to maintain sufficient cash following large purchases of inventory to meet growing sales demands.
- *Receivables*—Increases in receivables can result from inattention to debt collection, but it may also be a symptom of quality issues.

4.2.3 Financial Risk Management

For-profit organizations operate in a highly competitive environment. The inability to fully anticipate risk events is a major cause of the ongoing failures of businesses of all sizes. The elements that contribute to financial risks are numerous and include items such as large changes in inflation or interest rates, technological advances that can erode price or provide competing products, natural disasters, political changes, regulatory changes (including taxation), and labor disruptions. Assessing the potential impact of risk events involves determining the probability of the event happening and determining the consequence should that event happen. Managing financial risk generally involves one or a combination of the following strategic approaches:

- *Risk avoidance*—Potential changes to regulations, operations, or technology might create risks that warrant either terminating or not taking on particular ventures. Not pursuing the option will eliminate the potential associated risks.
- *Acceptance*—When the risk is low, management may simply decide to accept that it might happen without taking special action.
- *Contingency*—When the consequences of a series of potential risk events are relatively low but above a level that would impact the financial health if simply ignored, management may earmark special funds set aside to deal with the associated costs.
- *Increasing minimum acceptable return*—Investments that are higher risk may be undertaken when the potential returns are sufficiently high to justify their approval. Higher returns on the successful ventures will compensate for the downside of the failures.
- *Transfer of risk*—When the consequences of a relatively unlikely event are higher than the organization can handle without impacting its financial health, this risk can be shared with other organizations that are better aligned to handle the consequences. The transfer of risk comes with a cost, so over the long term profits should be higher, if the organization does not go bankrupt from the short-term impact of any specific risk event.
- *Insurance*—Premiums represent the cost associated with transferring the risk to a company that specializes in compensating for low-probability but high-consequence events.
- *Joint ventures*—By sharing the costs and profits with other organizations, the consequences of high-impact risk events can be kept to a level that will not cause the company's demise.
- *Outsourcing*—Different aspects of business can be given to specialist organizations that might have more resources or expertise in one area.
- *Risk mitigation*—Actions can be taken to reduce the probability and consequence of risk events.
- *Hedging*—The selling price and costs for inputs can be controlled by locking into long-term contracts at an agreed-to price. Reducing the risk of price variations should reduce profits over the long term, but the cost comes with the reduction of wide variations that might create short-term crises.
- *Redundancy*—Equipment failures and similar unavailability of critical elements may be controlled by implementing additional resources on a standby basis.

- *Buffers*—The impact of critical elements can be reduced by planning on allowances for buffers in the schedule that allow for potential delays.
- *Subcontracting*—The organization can become a specialist business that provides a good or service at a predetermined price to a customer that engages in the more capital-intensive and risky enterprises.

4.2.4 Funding Sources

Many organizations operate in environments that limit successful entry by new competitors through the large amount of capital required to build the facilities and infrastructure needed for production. Similarly, large projects or capital ventures used to maintain or grow markets might put a strain on the financial health of the organization. The choice of source of funds to execute these endeavors will have differing impacts on the levels of risk and future benefits for the business. As with the strategies for mitigating risk, multiple sources of funds can be tapped to reach an acceptable balance of risk and potential reward.

- *Sale of shares*—New finances can be injected into the company by selling shares to existing or new owners. The firm's ownership is now distributed between the existing shareholders and the new equity, thereby reducing the portion of the firm (and share of profits) held by the original owners.
- *Existing cash*—When a company has sufficient cash on hand, this can be used to fund the new venture. The financial strength of the organization will be weakened, but the new expenditure will provide a new earning potential for the funds that were sitting unused. Organizations may decide to fund large projects through expected future cash flow, which reduces the requirements for having cash on hand but increases the risk of a lack of sufficient funds for completion should the business environment change.
- *Preferred shares or debentures*—This form of financing has the advantage of raising cash through shares that entitle the holder to a defined payment without the right to vote on the control of the company or entitlement to share in profits beyond the agreed amount. Lenders tend to view preferred shares as equity, and owners view them as debt when calculating financial measures for the organization.
- *Debt*—Borrowing funds from a bank or similar institution is typically the lowest-cost alternative and provides the potential for high return on equity. Assuming the business case is reached and profits are realized after interest payments are allowed for, these earnings are reached with no additional equity required. Lenders will provide the funds with explicit terms for the seizure of the organization's assets should the potential for default reach a defined level.

The level of funding required for business growth may be reduced by tapping available grants or other government funding should the expenditure be viewed as having societal or economic benefits worthy of public investment. Other strategies might also be available for special circumstances where the burden may be shared with public or corporate partners.

4.3 Budgets

Budgets are planning tools—statements of the company's intentions that also represent a plan of action. Organizations differ in the specific formats and methods used. All aim to reflect the most realistic views of the upcoming period. Whatever the form, the results of the budgeting process typically include projections of the following:

- Sales
- Expenses
- Resource requirements

Budgets usually cover periods of three months to one year and break down longer-term financial goals. Budget documentation, so often the focus of budgeting activities, is actually only one part of a very important and comprehensive process. The budgeting process itself is exceedingly effective because of the thorough analysis required and the range of individuals it involves.

One of the most important financial activities for engineering managers is budgeting. Budgets serve many functions within organizations, such as (Rachlin, 2004, p. 1.1):

- Provide an accurate and timely analytical tool
- Offer a vehicle to predict performance

- Supply assistance in allocating resources
- Facilitate the ability to control current and ongoing performance
- Present early warning of departures from forecasts
- Offer early signals of oncoming opportunities or threats
- Force the organization to examine itself
- Function as a means of communication
- Reduce uncertainties
- Force managers to think in concrete terms

4.3.1 The Budgeting Process

Figure 4-5 shows the key steps in a budgeting process and represents activities both by engineering managers and individuals involved at the corporate level. Business divisions/units develop a strategy by analyzing their resources, the market for their products, and the impact they estimate new products will have on business. Plans are then developed, taking into consideration past and current performance. This information is exchanged with and analyzed by corporate-level reviewers in preparation for actual preparation of budgets.

Figure 4-5. Budget Flow Process

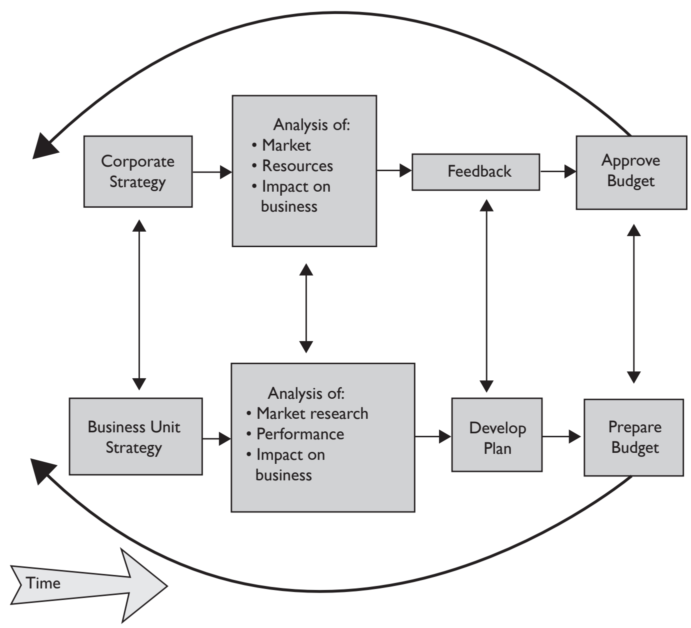


Figure 4-5 also demonstrates the powerful combination of "bottom-up" and "top-down" approaches that facilitate effective communication among different levels of management. To be successfully implemented, budgets require the following (Mazda, 1998, p. 284):

- A well-defined organizational structure, where all individuals are clear about their tasks and responsibilities
- Effective accounting procedures in place to develop and monitor budgets
- Management support from all levels to implement the budget
- Solid feedback and control procedures with associated corrective actions determined
- Flexibility — a willingness and ability to modify the budget as needs and circumstances change

4.3.2 Techniques in Preparing Budgets

The elements of a budget vary from project to project and company to company. In general, the cost estimates (capital expenditures, direct costs, indirect costs, labor figures, materials, maintenance, sales, administrative overhead, etc.) usually match the coding structure of the firm's chart of accounts.

Estimating costs can pose the following challenges:

- Omission of some costs in the assignment process
- Use of inappropriate methods for assigning costs across segments
- Assigning of costs to segments that are really common costs of the entire organization

Forecasting sales revenues involves using the best available data to make the most informed estimates. This may be achieved using qualitative methods (e.g., Delphi method, normative-relevance analysis, scenario building, informed judgment) or quantitative methods (e.g., linear regression, exponential smoothing).

Develop budget documents so that users can identify the following:

- Activity included in the budget
- Resources being employed
- Results and measurements that can be anticipated from the budget
- Parts of the corporate plan that are satisfied (and to what degree) within this budget element, considering the funding proposed (Hampton, 1994, pp. 6–12)

Communicate frequently. Involve all affected parties. Check that the budget as written is complete, reasonable, and acceptable to all. Give participants opportunities to voice their issues and concerns, look for areas of overlap, identify unstated opportunities, and declare their commitment to implementation.

4.3.3 Alternative Budgeting Procedures

Approaches to budgeting vary according to company or project needs. Some of the most common alternatives are discussed next.

Zero-Based Budgeting (ZBB)

As an alternative to traditional incremental budgeting, zero-based budgeting forces managers to thoroughly re-evaluate their activities and determine whether activities should be ceased, minimized or expanded. Proponents of zero-based budgeting state that this is actually not a new concept but rather a traditional idea that is not currently practiced. ZBB is designed to address some of the challenges of common, contemporary budgeting practices. The challenges include managers frequently padding budgets based on the assumption that they will be reduced by upper management. Budgetary problem areas and alternatives are difficult to assess, and newer projects are often the first to be slashed as part of budget reduction.

Key elements of a zero-based budget include the following (Rachlin, 2004, p. 27.3):

- Identifying objectives
- Evaluating alternative means of accomplishing each activity
- Evaluating alternative funding levels
- Evaluating workload and performance measures
- Establishing priorities

Bracket Budgeting

In complex budget systems, the ways in which components of budget line items interact to change the bottom line are not always obvious. Bracket budgeting is achieved by creating a tactical budgeting model with a series of equations that show how the individual elements selected combine. This approach lends much-needed transparency to derivating various line items in the budget.

Activity-Based Budgeting (ABB)

Activity-based budgeting shifts budgeting focus from costs to activities or business processes. Its goal is to enable the budgeting process to identify all costs with activities and to avoid the distortions introduced by allocated indirect costs. ABB is especially applicable in manufacturing firms with a diversity of products or processes. The key elements of ABB include:

- Type of work to be done
- Quantity of work to be done
- Cost of work to be done (Rachlin, 2004, p. 31.4)

Budgeting in Not-for-Profit Organizations

Not-for-profit organizations are growing at a tremendous pace. Because not-for-profit organizations are designed to be driven by motivations other than profits and measure their success differently, budgeting activities reflect a similar shift in orientation. Budgeting in the not-for-profit sector requires managers to carefully establish organizational objectives with clear and quantifiable success measures. Extra care also needs to be taken when associating revenues with the goods or services delivered.

4.3.4 Budgets as Managerial Control

The previous sections have focused on budgets as planning documents. New engineering managers must often first use budgets at a very detailed control level. They are now responsible for their unit's budgetary performance. This is typically measured on a monthly, quarterly, and annual basis. It typically includes salaries and wages, payroll taxes, overtime, vacation, compensation, travel, training, capital depreciation, maintenance and repair, consultants and contractors, rentals and leases, supplies, shipping, projects, etc.

Every organization has standard ways of tracking past expenses. Most have monitoring mechanisms, such as actuals to plan with positive and negative variances (similar to project management). The calendars used for these budgets may be calendar or fiscal years. Fiscal-year budgets may use a normal calendar or a 4-4-5 or 52-53 accounting calendar. The 4-4-5 calendar has 4-week or 5-week accounting months, and the 52-53 week fiscal year always ends on a consistent day (such as the last Saturday of the calendar year) so that data comparisons are not affected by when the first or last day of the month falls. For both accounting calendars, there is an adjustment every five to six years since neither 365 nor 366 days is divisible by 7.

One challenge in planning and tracking budgetary performance is that some systems do not do well at tracking committed or planned expenses. Accounting routinely tracks all budgetary items once an invoice is received, but some systems do not track orders made, overtime planned, maintenance costs that will be needed, etc. Tracking of planned and committed costs is why some organizations have inter-linked accounting and project control systems.

4.3.5 Cash Flow Techniques and Requirements

Engineering projects occur over a period of time. It is extremely rare for the income for a project to be received by the company at the same time that expenditures are paid. Company financial managers will be looking for the engineering manager's assistance with managing the cash flow challenge by creating some form of communication, usually referred to as cash flow diagrams (when a figure) or schedules (when a table). Both document forms are simple and effective ways to represent the income and outflow of cash funds throughout the life of an engineering project. When focused on the short term (see Figure 4-6), these are typically part of the budgeting and working capital management processes. When focused on the long term (see Section 4.4), the tools of engineering economy are applied to judge which projects should be implemented.

Cash Flow Schedules

Cash flow schedules (see Figure 4-6) are created in spreadsheets. The rows represent periods of time (e.g., months, quarters), and the columns represent categories of receipts and expenditures (e.g., sales, prepayments, equipment maintenance). These are forecasting tools used to predict inflow and outflow of money and enable financial managers to prepare and implement effective cash flow strategies.

Figure 4-6. Sample Cash Flow Schedule

Month	Capital Costs	Materials	Maintenance & Repair	Admin
Jan	45,000			1,500
Feb		7,000		1,500
Mar			5,000	1,500
Apr		2,000		1,500
May	15,000			1,500
June			5,000	1,500
July				1,500
Aug		9,000		1,500
Sept			5,000	1,500
Oct				1,500
Nov		3,000		1,500
Dec			5,000	1,500

Expenditures are scheduled in the months that payments are due. When sizeable expenditures (materials, machinery, etc.) will occur before customer invoices will be paid, income from customer sales or payment schedules are also input. Rows/columns are totaled to reveal the estimated net losses or gains for each period. From this analysis, finance managers have a greater insight into actions to be taken.

For example, some engineering contracts may ask the company to invest a sizable amount of capital for expenses that are reimbursable and will not necessarily be included in the project budget. Nevertheless, they do require an expenditure of cash and must be addressed with planning.

There are several strategies that companies can use when a considerable outlay of funds is required, including the following:

- Customer can pay the supplier invoices directly.
- Customer deposits funds into a purchasing fund.
- Progress stage payments, where funds are paid as the project achieves certain milestones (Lock, 1993, pp. 254–255).

4.4 Engineering Economics

4.4.1 Nomenclature and Fundamental Equation

Engineering economy focuses on finding equivalent values for cash flows that occur at different times so that it is accounting for the *time value of money*.

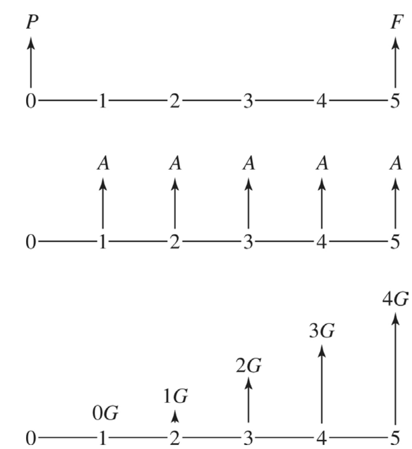
Nomenclature

A	Uniform amount per interest period
B	Benefit
BV_t	Book value at the end of year t
C	Cost
D_t	Depreciation in year t
F	Future worth, value, or amount
f	General inflation rate per period
G	Uniform arithmetic gradient per period (0 in period 1)

g	Uniform geometric gradient or constant rate of change per period
i	Interest rate per interest period
N	Number of periods in horizon or life of an asset
P	Present worth, value, or amount
S_N	Salvage value in year N

Figure 4-7 summarizes the assumptions that are made for the formulas and factors that are used in engineering economy. If a cash flow is a P, it occurs at the beginning of period 0. An A is a uniform amount at the ends of periods 1 through N. These N periods are usually measured in years but shorter periods, such as quarters or weeks, may be used. An F occurs at the end of period N. A G is a uniformly changing amount that begins at 0 at the end of period 1 and increases or decreases to $(N - 1)G$ at the end of period N. When drawing cash flow diagrams, money that is received (revenues, savings, etc.) is shown as an upward arrow; downward arrows are used for costs.

Figure 4-7. Cash Flow Diagrams for *P, F, A,* and *G* (Eschenbach, 2011)



To help explain these assumptions, consider an economic feasibility analysis for an engineering project (for example, a more energy-efficient process in the private sector or a road in the public sector). The first cost would be a cash flow at time 0, and the arrow would point down since it is a cash expenditure. The first-year savings in energy costs or the benefits of time savings are typically assumed (for initial economic feasibility studies) to continue at the same level until the horizon in 10 or 50 years. As benefits or savings, those cash flow arrows point up. If energy costs or road traffic increases each year, then a positive gradient could be used to model the change. Finally, at the project's horizon, there is often a salvage value for the equipment or an estimated value for future use for the road. The typical time period is a year.

The fundamental equation (Equation 4-2) for the time value of money compounds a *present* or current value into its equivalent *future* value N periods later. This is where the interest rate for the *time value of money* is introduced:

$$F = P(1 + i)^N \qquad (4\text{-}2)$$

4.4.2 Formulas and Factors

There are many simple problems in engineering economy that can be solved with the formulas and factors in Figure 4-8, and they can be combined to solve more complex problems. The analogy of clearing fractions can be used to select the correct factors. For example, to find the present worth, P, of a uniform cost or revenue that continues for N periods, A; multiply A by the factor $(P/A,i,N)$. The A of the uniform cash flow cancels with the A of the P/A factor label, leaving a P. (All of this happens at the given interest rate, i, and for a uniform series of N periods.) Tables of these factors can be found in engineering economy texts, the supplied reference for the Fundamentals of Engineering exam, many finance texts, and on the Internet.

Figure 4-8. Factors and Formulas

Factor Name	Symbol	Formula
Compound Amount	$(F/P,i,N)$	$(1 + i)^N$
Present Worth	$(P/F,i,N)$	$(1 + i)^{-N}$
Series Compound Amount	$(F/A,i,N)$	$[(1 + i)^N - 1] / i$
Series Present Worth	$(P/A,i,N)$	$[(1 + i)^N - 1] / [i(1 + i)^N]$
Sinking Fund	$(A/F,i,N)$	$i / [(1 + i)^N - 1]$
Capital Recovery	$(A/P,i,N)$	$i(1 + i)^N / [(1 + i)^N - 1]$
Gradient Present Worth	$(P/G,i,N)$	$[(1 + i)^N - iN - 1] / [i^2 (1 + i)^N]$
Gradient Uniform Payment	$(A/G,i,N)$	$1/i - N/[(1 + i)^N - 1]$

Figure 4-9 summarizes the more powerful spreadsheet formulas that correspond to the factors tabulated in Figure 4-8. These formulas are solving Equation 4-3, where any four values chosen from i, N, A, P, and F can be entered, and then the fifth variable is solved for. Equation 4-3 is written so that if two values of A, F, and P are positive, then the third one must be negative, which is why there are minus signs in the first three functions of Figure 4-9. The type argument is optional, and it allows the A (uniform series) variable to be specified as beginning-of-period rather than the default end-of-period. There are many financial calculators with five keys or a menu-entry system that solves Equation 4-3 for the same results. The one difference with the calculators is that an interest rate of 8% is entered as an 8, rather than the 0.08 or 8% that is used in the formulas or a spreadsheet. Note that the spreadsheet and calculator functions do not include G, the arithmetic gradient:

$$A(P/A,i,N) + F(P/F,i,N) + P = 0 \tag{4-3}$$

Figure 4-9. Spreadsheet Annuity Functions

PV(i,N, –A, –F,Type)
PMT(i,N, –P, –F,Type)
FV(i,N, –A, –P,Type)
NPER(i,A,P,F,Type)
RATE(N,A,P,F,Type,guess)

4.4.3 Cash Flow Tables and Spreadsheet Block Functions

Many projects have a complex pattern of cash flows. Start-up expenses may span several years, and then volumes and prices might change at different rates that vary over time. There might be renovation, overhaul, or expansion expenses. Determining the economic value of a complex project is best done by building a cash flow table in a spreadsheet. The two spreadsheet functions in Figure 4-10 are used to calculate equivalent economic values for a range of cells that corresponds to the net cash flow for each period. These functions assume the following:

- Cash flows are at the end of periods 1 to N.
- Each time period is the same length.
- The same interest rate applies to each time period.

The NPV (net present value or present worth) function also assumes that the cash flow at time 0 is not part of the specified block of cells. The total PW = CF_0 + NPV(i, range). The internal rate of return is the interest rate at which the cash flows have a PW of 0.

Figure 4-10. Spreadsheet Block Functions

NPV(i, CF_1:CF_N)
IRR(CF_0:CF_N, guess)

4.4.4 Measures of Economic Value

There are numerous measures of economic value that properly use the time value of money. Listed with alternate names or synonyms, the main ones follow:

- Present worth (PW), present value, net present worth, net present value
- Future worth (FW), future value
- Equivalent annual worth (EAW), equivalent uniform annual worth
- Equivalent annual cost (EAC), equivalent uniform annual cost
- Benefit/cost ratio (B/C), present worth index, profitability index
- Internal rate of return (IRR), rate of return (equals interest rate where PW = 0)

In each case, all cash flows associated with a project are converted to a single value matching the name of the measure. In every case but the internal rate of return, this is done at an identified interest rate.

Another measure of economic value is payback period (equals time until initial investment is recovered). This is usually computed without considering the time value of money, which is like using an interest rate of 0%. For projects where the payback is measured in months and the returns continue for at least a few years, this measure usually works well enough. Payback period has the virtue of simplicity, but it is generally better to use more theoretically correct measures.

There are two more measures of economic value that are typically applied at the firm level but are sometimes applied at the project level. Return on investment (ROI) is an accounting measure that, like payback period, ignores the time value of money. ROI equals income before taxes and interest divided by average operating assets (e.g., inventory, accounts receivable cash).

Economic value added (EVA) is especially useful in companies that are considered to be asset intensive. Calculations over time typically discount future cash flows to include the time value of money. If done as a calculation for performance in one year, EVA equals income before taxes and interest minus the weighted average cost of capital (WACC) times the capital deployed.

Making a decision about a project or a choice between projects is straightforward as long as the time value of money is properly considered. A positive present worth is good, a higher present worth is better, and a smaller equivalent annual cost is better. Thus, the choice of which measure of economic value to use is one of convenience. Present worth is best if deciding how much to pay for a building or business. Equivalent annual cost may be the best way to evaluate a process improvement where the savings are difficult to quantify, but it is possible to use judgment to decide if the estimated annual savings exceed the equivalent annual cost. When comparing projects with different horizons and different risks, it may be easiest to use judgment to compare the rates of returns on the different projects.

4.4.5 Mutually Exclusive Alternatives, Replacement Analysis, and Capital Budgeting

Applications of engineering economy can be broken into three relatively distinct areas where the easiest route to a correct answer might use different measures of economic values:

- Choosing between mutually exclusive alternatives
- Choosing whether it is time to replace a current piece of equipment
- Choosing which projects to do subject to a limit on the capital budget

Mutually Exclusive Alternatives

Mutually exclusive alternatives are the starting point in many engineering careers and most engineering economy courses. As an example, an engineering graduate may get one job offer with a consulting firm to design bridges and another with an electronics firm to support customers with their products. These offers are mutually exclusive because choosing one and starting work automatically removes the ability to accept the other. Engineering design often considers which alternative will be more economical, and only one alternative will be implemented. In this case, the interest rate is usually specified by higher corporate levels, or for the federal government, by OMB Circular A-94.

If the lives of the alternatives are the same, then either PW or equivalent annual measures can be used. The best alternative has either the highest worth or the lowest cost. If the lives of the alternatives differ, then it is usually best to use equivalent annual measures, since the EAW and EAC are stated on a per-year basis. Calculating the exact incremental EAW or EAC between two alternatives assumes that the alternatives repeat with no cash flow changes until the lives match. Simply comparing the alternative values is a robust decision-making technique that focuses on the best data for this decision, but the horizon should be longer than the longest-lived alternative.

To use IRR or B/C techniques, the alternatives must be compared incrementally, as the best alternative may not be the one with the highest IRR or largest B/C ratio.

Replacement Analysis

Replacement analysis is a choice between mutually exclusive alternatives, but correctly analyzing the cost of the existing asset uses different measures than the potential new asset. This is required because the existing asset has already incurred the costs of installation and continued use of the asset can avoid (at least for now) the costs of removal and sale. In addition, the existing asset is typically nearing the end of its economic life while the potential new asset typically has a much longer life. The correct analysis approach depends on how much data is available and how far along the existing asset is in its life-cycle.

The typical situation is that the marginal cost to use the existing asset for one more year is compared with the lowest equivalent annual cost over all possible lives for all potential new replacements. If the existing asset's marginal cost for one more year is lower, it is kept for a year and analyzed again next year. If the existing asset's marginal cost for one more year is higher, it is replaced by the best new alternative, whose expected life is chosen to minimize its equivalent annual cost.

Capital Budgeting

Capital budgeting is selecting which projects will be done when there are more good projects than the capital budget can fund. Projects only reach the stage of final consideration if they have a positive PW and an acceptable IRR, so the problem cannot be solved by eliminating bad projects. (Those are already out of consideration.) These projects often have different lives, different scales (some are much more expensive than others), and different levels of risk. Thus, they cannot be compared by selecting the largest PWs.

There are two analytical approaches for numerical results. One approach uses mathematical programming to select the best set of projects to maximize PW. If the number of projects being considered is small and even fewer will be funded (for example, 2 out of 6 for 15 different pairs), then this can be done by hand rather than through mathematical programming.

The second approach ranks projects from highest to lowest by each project's IRR. Then, projects starting with the highest IRR are tentatively selected for funding until the budget runs out. The IRR of the last project selected or the first project not selected is the *opportunity cost of capital* for that set of projects and that level of funding. This is one approach for defining what interest rate should be used for capital budgeting.

The analytical approach for defining which projects should be selected is followed by a decision-making stage, which often includes judgments by decision makers on strategic direction (a promising project that is not a good strategic fit may simply be a distraction that should be ignored), the relative amount of optimism in the numbers for different projects, the risks of different projects, the resources available, and information that could not be numerically quantified in monetary terms for inclusion in the analysis. Particular managers will also often promote projects that will be undertaken by their group. This stage integrates more easily with ranking on IRR, which is why that approach is somewhat more common in practice. Virtually all capital budgeting processes consider PW, IRR, and other information such as that described in Section 4.3.10. Maximizing the benefits from the deployment of limited resources is what provides competitive advantage and increased chances of success. Wise deployment of capital is what creates strong firms and economies.

4.4.6 Depreciation and Taxes

In many countries, the principal corporate tax is the value-added tax (VAT). In the simple case of a small firm with one product, the costs of purchased materials, components, and services are subtracted from the revenues from selling that product. The difference is the *value added* by the firm, which is taxed at a percentage. This is similar to a sales tax except that it is paid by each firm in a supply chain and not just by a final consumer.

Property taxes are paid in many countries, counties, and cities. The basis for these taxes is either the *assessed* or *book* values of a firm's physical assets, such as land, buildings, and equipment. Book values will be based on acquisition costs minus accumulated depreciation (known as capital allowances in some countries). Land is not usually subject to depreciation, and the particular depreciation techniques permitted for buildings and equipment often depend on the jurisdiction and the type of building or equipment. In the U.S., many firms have two different sets of accounting for fixed assets—one for tax calculations and one for financial statement valuations. The set for valuation may use straight-line (Equation 4-4) or declining balance (Equation 4-5) depreciation. A limited number of countries also permit sum-of-years' digits in addition to one or both of these methods:

Straight-line $D_t = (BV_0 - S_N) / N$ for $t = 1, N$ (4-4)

Declining balance at rate α $D_t = \alpha\, BV_{t-1}$ and $BV_t = BV_{t-1} - D_t$ for $t = 1, N$ (4-5)

Figure 4-11 illustrates the variety of systems and rates used around the world. In the U.S., the set of accounts for the calculation of taxes typically uses the Modified Accelerated Recovery System (MACRS), which is briefly summarized in Figures 4-12 and 4-13. Figure 4-12 with the type of asset is used to determine the asset's recovery period. Then, the percentages shown in Figure 4-13 for that recovery period are multiplied times the asset's initial book value to determine each year's depreciation. The MACRS system assumes that the asset's salvage value is 0, and the recovery period is usually significantly shorter than the asset's expected life. The depreciation in the first year is one-half of the depreciation for declining balance, and the other half-year depreciation is one year later than the length of the recovery period.

The U.S. also uses bonus depreciation that allows immediate expensing of capital expenditures up to a maximum percentage. From 2018 until 2022 that upper limit is 100%, then it is scheduled to decline 20% per year.

Figure 4-11. Depreciation and Taxes in 10 Countries (from Tables 11-2 & 12-1 of Newnan, Eschenbach, & Lavelle, 2016)

Country	Straight Line	Sum-of-Years' Digits	Declining Balance	Maximum Corporate Income Tax	Value Added Tax (GST)
Australia	✓		✓	30%	10% GST
Brazil	✓			34%	17-25%
Canada			✓	44%	5-15%
China	✓			25%	17%
India			✓	40%	12.50%
Mexico	✓			28%	15%
Russia	✓		✓	24%	18%
Spain	✓	✓	✓	35%	7% / 16%
Turkey	✓		✓	20%	18%
USA		MACRS		39%	N/A

Figure 4-12. MACRS Recovery Periods

Recovery Period	Description of Assets
3-Year	Tractors for over-the-road tractor/trailer use and special tooling
5-Year	Vehicles, computers, office machinery, construction equipment, and R&D equipment
7-Year	Office furniture, most manufacturing and mining equipment, and items not otherwise classified
10-Year	Marine vessels, petroleum refining equipment, and single-purpose agricultural structures

Figure 4-13. MACRS Percentages

Recovery Period	3-year	5-year	7-year	10-year
1	33.3	20.0	14.3	10.0
2	44.5	32.0	24.5	18.0
3	14.8	19.2	17.5	14.4
4	8.4	11.5	12.5	11.5
5		11.5	8.9	9.2
6		5.8	8.9	7.4
7			8.9	6.6
8			4.5	6.6
9				6.5
10				6.5
11				3.3

In the U.S., the principal corporate tax is an income tax, which is a percentage of net income. One of the expenses that is subtracted to compute that net income is MACRS depreciation. Because MACRS depreciates assets to a book value of \$0, the final salvage value at the end of the asset's life is taxed as *recaptured depreciation*. Figure 4-13 summarizes the marginal tax rates that are used for each tax bracket.

Figure 4-14. U.S. Corporate Income Tax Rates

<table>
<tr><th>Starting 2018 Flat Rate</th><th>Through 2017 Marginal Tax Rate</th><th>Income Bracket</th></tr>
<tr><td rowspan="8">21%</td><td>15%</td><td>x ≤ $50,000</td></tr>
<tr><td>25%</td><td>$50,000 < x ≤ $75,000</td></tr>
<tr><td>34%</td><td>$75,000 < x ≤ $100,000</td></tr>
<tr><td>39%</td><td>$100,000 < x ≤ $335,000</td></tr>
<tr><td>34%</td><td>$335,000 < x ≤ $10,000,000</td></tr>
<tr><td>35%</td><td>$10,000,000 < x ≤ $15,000,000</td></tr>
<tr><td>38%</td><td>$15,000,000 < x ≤ $18,333,333</td></tr>
<tr><td>35%</td><td>$18,333,333 < x</td></tr>
</table>

In computing after-tax cash flows (Equation 4-6), the chief complication is income taxes. Cash flows to buy or sell a capital asset are not included in taxable income, but the non-cash flow accounting entries for depreciation and the difference between book value and salvage value are included in taxable income. Other taxes are considered as expenses:

$$\begin{aligned} ATCF_t &= \text{BTCF Capital}_t + \text{BTCF Taxable}_t\,(1 - \text{tax rate}) + \text{Depreciation}_t \times \text{Tax rate} && \text{for } t = 0, N \\ &\quad - (\text{Salvage} - \text{Book value}) \times \text{Tax rate} && \text{for t} = N \end{aligned} \qquad (4\text{-}6)$$

4.4.7 Public Sector

Benefit/cost ratios are most commonly used in the public sector, but PW, EAC, and IRR are used as well. Depreciation and taxes are usually not an issue for the assets to be built or purchased since governments do not pay taxes. Thus, all but Section 4.4.6 applies to engineering economy in the public sector.

Applying engineering economy in the public sector does face more challenges than in the private sector. The products or services that are sold by firms bring in revenues that flow to the firm's bottom line. Future revenues have to be estimated, but those estimates are based on known current values. Benefits of public projects are sometimes defined the same way (such as for a toll road), but most public projects have benefits that are difficult to measure and to state in monetary terms. What are the benefits of a road improvement project that reduces the accident rate while handling a larger volume of traffic where some trips are completed more quickly and others are made by new users? Vehicles can be counted, but how valuable is each trip and each saved minute? This requires knowing the value of a human life; of injuries avoided; of travel time for truckers, commuters, and people going out to dinner or on vacation; of the value provided by the new trips; and so forth.

Other challenges in applying engineering economy in the public sector include projects with multiple objectives, interest groups with opposing viewpoints, uncertain probabilities for rare events, long time horizons, and how to select the interest rate.

4.4.8 Inflation and Exchange Rates

Many engineering economy analyses address inflation by using constant-value dollars. Labor costs, energy prices, and revenues are estimated as $\$X$ per year. The assumption is that the impact of inflation is not that great since each increase in price is balanced by a similar decrease in the value of the dollar. In this case, the interest rate (i) that is used in the analysis is a *real* interest rate—that is, a rate adjusted for the value of inflation. Sometimes the choice of constant-value dollars is made because of the difficulty in forecasting the rate of inflation, since introducing a poor-quality estimate risks distorting the results.

Other analyses are done using actual or nominal-value dollars and market interest rates (i_m). Equation 4-7 shows the relationship between market and real interest rates and the *inflation rate* (f). The inflation rate captures the effect of goods and services costing more—a decrease in purchasing power of dollars. The inflation rate is measured as the annual rate of increase in the number of dollars needed to pay for the same amount of goods and services:

$$i_m = i + f + if \tag{4-7}$$

When conducting an economic analysis in actual dollars, the use of a spreadsheet is virtually a requirement. Typically, this modeling choice is made because different costs and revenues have different inflation rates. Labor costs may match the inflation rate for the economy, but depreciation deductions have an inflation rate of 0% and the cost to buy computers and other electronics may be declining in actual dollars while energy costs may be increasing faster than the inflation rate for the economy. As another example, inflation rates for services in a country might be closely linked to that country's general inflation rate, while inflation rates for goods affected by imports and exports may be moderated or increased by the inflation and exchange rates of major trading partners. Each rate can be individually modeled in a spreadsheet, and then the economy's inflation rate can be applied as needed, depending on whether a real or market interest rate is being used.

Many firms operate internationally or deal with international vendors and/or customers. Changes in the relative value of currencies are both a cause and a consequence of inflation in different countries' currencies. These changes in exchange rates are usually modeled just like other inflation rates as x% per year. Particularly, in international calculations it must be recognized that in some years in some countries, high or very high inflation rates may exist—such as 50%, 400%, or even 1,000%. Inflation rates at these levels with the associated uncertainty about future rates can destroy the validity of calculations so that inflation may be better treated as an unquantified risk factor.

4.4.9 Analyzing an Uncertain Future

The focus of engineering economy is the analysis of engineering projects, where the largest costs typically occur in the near future and the benefits may extend for decades into the future. That future is inherently uncertain, but even so, decisions must be made now. One approach to uncertainty is stage-gate decision-making, which is used, for example, in new product development. Instead of a single decision to build a plant and sell the product, there are stages for R&D, prototype development, pilot plant production, and, finally, production and sales. At each stage, more is known about cost and performance and about the competition the product will face when marketed. Typically, at each successive stage, the level of required investment is much larger.

Another approach to uncertainty focuses on alternatives. For example, renting is less of a commitment than leasing, which is less of a commitment than owning. Buying a component or a service is less of a commitment than buying the equipment and hiring the people to do it yourself. Some alternatives simply have more flexibility to adjust to changed circumstances. Such alternatives will be more robust in the unavoidable uncertainty of the future.

The value of flexibility is extremely difficult to quantify, but managerial flexibility is the foundation of *real options*. This is a newer analytical approach that applies modeling tools developed for financial options to real projects. While some engineering economy texts devote a chapter to real options (Park, 2016), there are also articles that question the validity of many published examples (Lewis, Eschenbach, & Hartman, 2008).

There are also several analytical tools that are applied to make better decisions when faced with uncertainty. These include sensitivity analysis, expected value analysis, decision trees, and simulation and risk analysis.

Breakeven analysis (Figure 4-2) is a commonly used example of sensitivity analysis. Other examples include scenarios and what-if analysis. More analytical approaches start by asking how much each variable can change (lower limit, base case, upper limit) and then calculating the measure of economic worth for each of those limits. These results are displayed through spider plots or tornado diagrams. The goal is to identify which uncertainties are most likely to lead to a different decision.

The use of expected values relies on identifying a probability distribution for each uncertain variable in an economic analysis. Using expected values allows consideration of how likely the different values between the lower and upper limits are. For more complex problems, this is combined with the use of decision trees, which show the decisions available at each stage and what uncertainties exist. At a decision node, the best choice is made, and at a chance node, an expected value is calculated.

For a project with few uncertainties, it may be possible to directly calculate measures of risk. These include the probability of a loss, the maximum loss, and the standard deviation of the economic measure. If a project has more than a few significant uncertainties, simulation is likely to be the best approach to measure risk. Because engineering economy discounts cash flows more if they're further in the future, the average result from a simulation may be different from and better than the calculation using the expected value from each variable.

One of the challenges in properly modeling uncertainty and risk is that the variables are usually modeled as being statistically independent when that may not be true. However, estimating the nature and strength of *future* statistical dependencies might be very difficult. For example, we know that electricity, natural gas, coal, and oil prices are related, but the relationships seem to be in constant flux.

4.4.10 Integrating Economic and Non-Economic Criteria

There are three common approaches to integrating economic and non-economic criteria. The first was outlined in the Capital Budgeting sub-section of Section 4.4.5. Managerial judgment is exercised by individuals and/or committees. The second approach relies on the tools of multi-objective decision-making, such as additive models and the analytical-hierarchy process.

The third uses a balanced scorecard or visual dashboard to summarize organizational goals and key performance indicators (KPIs) that measure results (Kaplan & Norton, 1996). The scorecard can be simple (Figure 4-15) or more detailed. For example, the customer perspective might focus on the customer's value proposition or on the customer's satisfaction. The focus can be strategic planning or managing operational performance.

Figure 4-15. Balanced Scorecard.

Perspective	Goals or Focus	KPIs
Financial		
Customer		
Internal Process		
Learning & Growth		

4.5 Cost and Benefit Estimating

4.5.1 Types of Costs and Benefits

Economic decision-making requires estimates of current and future costs and benefits. For linguistic simplicity, most of Section 4.5 will simply refer to costs, since most of the estimating methodologies have their roots in estimating costs. While estimating benefits may be even more important for good decision-making than estimating costs, benefits are usually harder to estimate. Usually, benefits occur further in the future, are harder to measure, and sometimes even if they can be measured, are very difficult to state in monetary terms. For example, a highway or a mine ventilation project may be designed to improve safety, but estimating how many lives will be saved and when and what each life is worth in monetary terms is very challenging.

In many cases of economic decision-making, the fundamental question is, "Do the benefits exceed the costs?" Thus, to answer a question about how many, the *marginal cost* of one more unit is compared with the *marginal benefit* of one more unit. To answer a question about 100 more units, the *incremental cost* of 100 more units is compared with the *incremental benefit* of those 100 *incremental* units. To describe performance, often an *average* cost or benefit will be calculated. If a cost is *recurring*, its importance is magnified by its repetition.

An *opportunity cost* is incurred by using a resource for one task, which means it is unavailable for another task. Its value for that other foregone task is its opportunity cost. A *sunk cost* is a cost that has already been incurred. Since sunk costs cannot be changed, in general they are not relevant to future decision-making. In some cases, sunk costs are part of calculating the income-tax consequences of disposing of a capital asset.

The *base case* represents what the future looks like if current activities continue. This may not have the same results as those activities do now. For example, if a firm simply continues to make and sell existing products, its market share will decline as competitors introduce new and improved products.

4.5.2 The Cost Estimating Environment and Types of Cost Estimates

One of the first environments in which cost estimating developed was construction. Whether for ships, pyramids, castles, or a Great Wall, quantities of materials, labor, and the money to pay for them had to be estimated. Today, construction estimating often has specialists in *quantity surveying* (how many cubic meters of earth must be moved and how far) and other specialists in *unit costing*. Today, enormous quantities of data and detailed models are available, but estimates might still be wide of the mark. Ground conditions may be different from expected, design changes may expand or shrink the project's scope, or "boom" conditions may change the price and availability of labor.

Construction projects can be used to illustrate two different design objectives—both of which depend on cost estimating to be done successively. In the private sector, it is common to use *minimizing life cycle costs* as a design objective. For example, the goal is to balance the costs now for more insulation or a more efficient heating and cooling system with energy costs that occur later and to choose the alternative with the lowest total costs over time. Because of the public budgeting process, it is common in the public sector to use *design to cost*. The public process can require that funding be specified and approved by legislators or voters before detailed cost estimates are available. Changing the initial budget may be difficult, so it is better to design to that budget by changing the project scope or accepting the trade-off of lower costs now and higher costs later.

Every industry has to estimate the costs of the products and services it provides. However, the environments differ substantially. Construction cost estimating relies on enormous quantities of data, available both from a firm's past projects and from other firms that specialize in gathering and distributing that data. The wealth of past experience and data can often produce very accurate estimates. On the other hand, new product development and software projects typically have much greater uncertainties about features, design challenges, and scope, so the estimates may be much less accurate.

However, in every industry, achieving greater accuracy for an estimate comes with an increasing cost. Typically, an *order-of-magnitude estimate* is done first. Simple models with one measure of size are often used, such as cost per square foot or the capacity function models described in Section 4.5.3. More detailed breakdowns are used to construct a *budget estimate*. Finally, once a go-ahead decision is made, a *definitive estimate* is based on a design that is nearing completion.

While the methods used to construct early estimates might be simple, Figures 4-16 and 4-17 illustrate the importance of early decisions that are based on these early estimates. Figure 4-16 describes typical curves for the costs actually incurred and costs determined at different project stages. Early in a project, costs incurred are low, but decisions are being made that determine what costs will be incurred later. While described as for a new product, this also applies to construction and other projects. Figure 4-17 simply describes the ease and cost of changing a design.

Figure 4-16. Cumulative Life-Cycle Costs Committed and Spent (Newnan, Eschenbach, Lavelle, & Lewis, 2020)

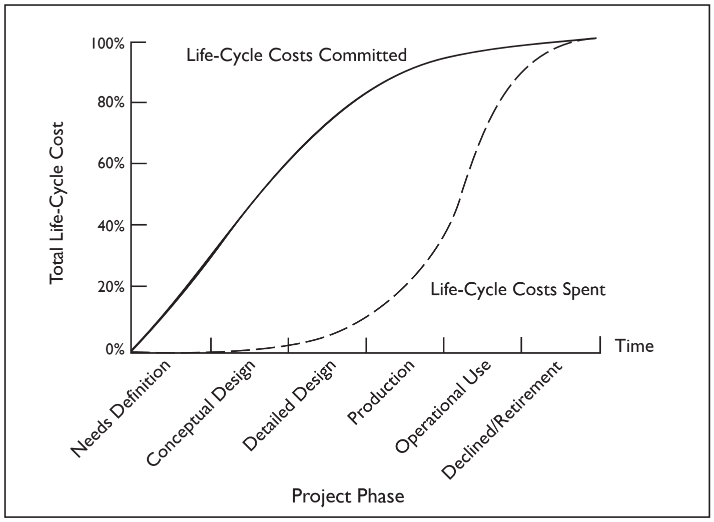
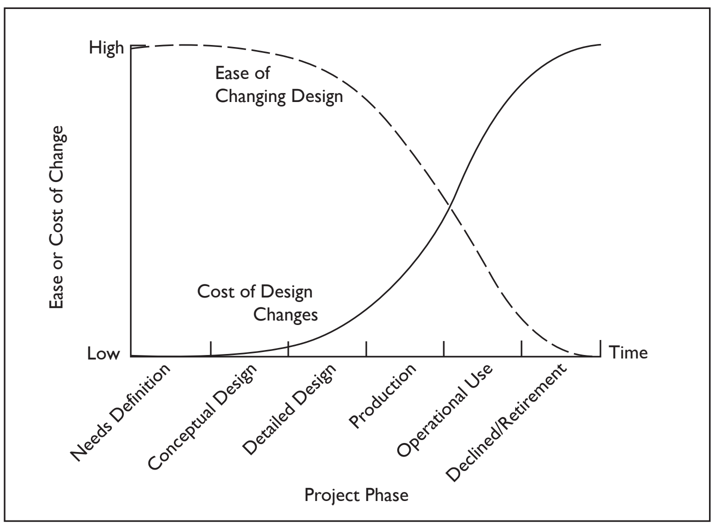


Figure 4-17. Ease and Cost of Design Change (Newnan, Eschenbach, Lavelle, & Lewis, 2020)



4.5.3 Cost Estimating Methods

Two of the most commonly used estimating methods are also the simplest. *Checklists* are used to protect against errors of omission—that is, forgetting to include one of the costs. *Factor estimates* can be as simple as estimating the cost of a building by multiplying its planned size by an appropriate cost per square foot. Or for that same building, a definitive estimate can be based on a detailed breakdown of quantities and unit costs for steel, concrete, windows, floor coverings, mechanical equipment, and so forth.

Cost indexes are a more sophisticated type of factor estimate. Common examples include indexes for inflation, location, size, and building type. These indexes are often stated with a base 1 or of 100 (for 100%). Then, a base-year is used to define the inflation index. An average location, an average size, and a typical building type define the 1 or 100 for the other indexes. Consider the problem of estimating the cost of a new high school when you already have data on sizes and costs of schools across the country. High schools will have a cost index greater than 1, middle schools may have an index close to 1, and elementary schools will have an index less than 1, because there are more specialized rooms and equipment in higher grades. A school that is larger than the average school will have lower costs per square foot, because of economies of scale. A school that is built in a major metropolitan area will have higher costs than a school built in suburbia. Thus, the estimated cost of a school would then equal (size) × (unit cost in base-year $s) × (inflation index) × (location index) × (index for size) × (index for building type).

Another type of factor estimate is based on using multiple regression to identify statistically useful relationships. For example, the value of an existing building is a function of its square footage, the number of floors, its age, its condition, and so forth.

Capacity functions or *power sizing functions* are often used to estimate the costs of process facilities using Equation 4-8. The starting point is data on the known (k) size (S) and cost (C) of a constructed facility (or at least a definitive estimate). Then, the cost for a proposed (x) facility is based on the relative size of the two facilities and the *power function factor* (n) for that type of facility. These factors are tabulated, but they are typically between 0.5 and 0.9 for different levels of economies of scale:

$$C_x = C_k(S_x/S_k)^n \tag{4-8}$$

Learning or *experience curves* are used to estimate costs when costs per unit decline with volume. These productivity gains typically come from learning by workers, process improvements, and product redesign. Because inflation, overtime, and overhead rates also influence costs, learning curves are best applied using units of time, and then other estimating methods are used to convert to costs. The learning-curve percentage describes the decline in unit time for each *doubling* of the cumulative volume. We start with the unit time for the first unit. Then, we multiply this time by the learning percentage to find the second unit's time; multiply again to find the fourth unit's time, multiply again to find the eighth unit's time; and so forth. Equation 4-9 generalizes this to find the time (T_N) for the N^{th} unit based on the time for the first unit (T_1) and the learning-curve percentage (b). Simple processes, where little learning is possible, have percentages of 90% to 100%. Complex processes, such as assembling an airplane, might have rates of 70% or lower, since more learning and improvement is possible. Tabulated values for different processes can even be found in Wikipedia:

$$T_N = T_1 N^{\ln b/\ln 2} \quad \text{or} \quad = T_1 b^{\ln N/\ln 2} \tag{4-9}$$

Review

Upon completing the study of Domain 4: Financial Resource Management, you should be able to answer the following questions:

1. What is an aim of the Sarbanes-Oxley Act?
2. Why should cost be a primary concern of any engineer?
3. What is the difference between cash breakeven and book breakeven? Which is more critical to the short-term health of an organization?
4. Explain how balance sheets and income statements (P&Ls) are used to express the status of a company at any given time. What do they communicate?
5. Explain why looking at ratios may be preferable for driving managerial decisions over using the numbers found in the financial statements.
6. What is the difference between the current ratio and the quick ratio? When might the quick ratio be of higher concern?
7. Explain how lowering the price for a product might either raise or lower a company's profit.
8. What are some different methods of handling risk within the organization? What are some situations where doing nothing (accepting the risk) would be a viable alternative?
9. Explain what is meant by liquidity. Why might a piece of real estate sell much below normal market value?
10. What are two reasons a company would decide to rent a piece of equipment for 20 years when it could buy it for a lower total amount now?
11. Explain how debt level can impact return on equity. What are the risks of maintaining low debt levels? What are the risks of maintaining high debt levels?

12. Why is a combination of a bottom-up combined with a top-down approach to budgeting usually most effective?
13. Why is it important for an engineering manager to work with cash flow tables and diagrams? What tools should be used in economic analysis?
14. Explain present worth and internal rate of return. How do they help determine the success of a project or company?
15. Explain the similarities and differences between economic evaluations in the following contexts: mutually exclusive alternatives, replacement analysis, and capital budgeting.
16. What are the objectives and advantages to the balanced scorecard approach to economic analysis?
17. Give examples of and explain the differences between the following costs: average, marginal, incremental, recurring, opportunity, and sunk.
18. Why is the distinction between when costs are determined and when they are incurred important?

For Further Information

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Acknowledgments

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5

Project Management

Domain 5 Champions

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5.4 Executing

5.4.1 Project Team Management

5.4.2 Models of Team Development

5.4.3 Project Procurement Management

5.4.4 Project Contract Management

5.5 Monitoring and Controlling

5.5.1 Earned Value Management

5.5.2 Project Quality Management

5.6 Closing

5.7 Introduction to Agile Project Management

5.7.1 The Stacey Matrix

5.7.2 The Agile Process Framework

5.7.3 Agile versus Traditional Project Management Summary

Domain 5: Project Management

Key Words and Concepts

Agile Project Management	An iterative and incremental framework that allows project manager, teams, and organizations to adapt to the changing conditions of uncertain project environments.
Cause and Effect Diagram	Used in root cause analysis to help uncover factors that may be the source of problems. Also called Ishikawa or fishbone diagram.
Critical Chain Project Management	Critical chain method is an emerging network analysis technique that emphasizes the importance of resources and the overall schedule duration as the key constraints governing the project schedule.
Critical Path	Represents the longest path through the network and includes all the tasks that have zero slack. Delays in the tasks on the critical path will result in increased project duration.
Gantt Chart	Gantt charts are bar charts that represent schedule-related information, and are frequently used to illustrate project schedules.
Earned Value Management (EVM)	An analysis technique used to integrate the scope, time, and cost performance on a project. The three key dimensions of earned value are planned value (PV), earned value (EV) and actual cost (AC).
Fast Tracking	Fast tracking is a schedule compression technique in which activities that would normally be performed in sequence are performed in parallel.
GAPPS	An alliance of government, industry, professional associations, national qualification bodies and training/academic institutions working together for the purpose of facilitating mutual recognition and transferability of project management standards and qualifications by providing the global project management community with a reliable source of comparative information.
Knowledge Areas	The *PMBOK® Guide* defines 10 Knowledge Areas for project management: integration, scope, schedule, cost, quality, resource, communications, risk, schedule, procurement, and stakeholder, which are mapped into the five process groups, defining 49 project management processes.
Network Diagram	Graphical representation of the work to be completed on a project created during the planning phase to provide guidance for the execution of the work. Represents the sequence of the tasks or activities to be performed based on the information in the WBS.
Pareto Charts	Pareto charts are a specific type of histograms that are used to rank the causes of defects or problems related to a specific process and identify the defects or problems that occur most frequently.
PMBOK® Guide	*A Guide to the Project Management Body of Knowledge* (*PMBOK® Guide*) is a recognized standard for project management provided by the Project Management Institute (PMI). The *PMBOK® Guide* establishes a common vocabulary and identifies the generally accepted best practices for the project management profession.
Portfolio	A collection of individual projects and programs undertaken by an organization. All the projects and programs with a portfolio should be consistent with an organizations' strategic goals.
PRINCE2	(PRojects IN Controlled Environments) is a structured project management method and practitioner certification program. PRINCE2 emphasizes dividing projects into manageable and controllable stages.

Process Groups	The *PMBOK® Guide* defines the five project management Process Groups (Initiating, Planning, Executing, Monitoring and Controlling, and Closing) that are essential to effective project management.
Product Backlog	Product backlog is the list of requirements that defines the scope of the project and is updated as needed by the customer.
Product Roadmap	Product roadmap represents the releases against time and provides a visual artifact to plan and track project progress.
Project	A temporary endeavor undertaken to create a unique product, service, or result.
Project Charter	A document that specifies the initial requirements that satisfy the stakeholder's needs and expectations. When the project charter is finalized and approved, the project becomes officially authorized and project planning begins.
Project Management	The application of knowledge, skills, tools, and techniques to project activities to meet the project requirements.
Project Performance	Project performance can be defined as the extent to which the project met or has met the project requirements.
Quality Assurance	Quality assurance is the process of auditing the quality requirements and data generated through the quality-control procedures to ensure proper quality standards are in place and continuous process-improvement strategies are employed.
Quality Control	Quality control is the process of monitoring, documenting, and analyzing performance to detect poor process or product quality and identify the causes in order to recommend and/or take action to eliminate the causes.
Quality Metrics	Quality metrics define a project or product attribute and how the quality-control process will measure it.
RAM	Responsibility assignment matrix (RAM) is commonly used for illustrating connections between work packages and project team members.
Release Burndown Chart	Release burndown chart represents the remaining work in abstract points across the different iterations that are included in the release.
Risk	An uncertain future event or condition that, if it occurs, has a positive or negative effect on at least one project objective.
Risk Register	The preferred tool for managing risks and documenting the of characteristics of the risks for the project, which includes the list identified risks, risk category, risk owner, risk causes and triggers, probability of occurrence, impact, risk response plans, and status.
Rolling Wave Planning	The progressive elaboration planning of defining activities for work packages is known as rolling wave planning.
Scope Statement	A document that defines the project deliverables and the work required to create the deliverables. Identifies what is included in the project as well as what is not included in the project.
Three-point Estimate	The variability of activity time estimates are approximated and used to estimate the probability of completing the project by a specific time.
Time-phased Budget	The aggregated estimated costs of the individual activities are placed on a schedule as they are expected to occur over the life of the project.
Tracking Gantt Chart	A bar chart that represents schedule-related information to communicate project schedule status by comparing actual start and finish times to the baseline schedule.
WBS	A work breakdown structure (WBS) is a deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables.
WBS Dictionary	Provides detailed information about the components in the WBS.
Work Package	A work assignment and administration tool that includes deliverables from the lowest level of the WBS.

5.1 Introduction to Project Management

A project is a temporary endeavor undertaken to create a unique product, service, or result. The operative words in this definition are temporary and unique. Temporary indicates a definitive beginning and end. A project begins when an organization recognizes a need and develops a project charter, which formally authorizes the project and documents the initial requirements. A project ends when the objectives are met or when the project is terminated for reasons other than successful completion. Although the project itself is temporary, the products, services, or results created by the project typically are not temporary and normally have a lasting outcome. The second important term in the definition for a project, unique, indicates that the requirements, the tasks that the project team perform or the products, services, or results created by the project, are not routine. Although some repetitive elements may be present in some of the deliverables, many aspects are unique. For example, when a heavy civil firm undertakes a new highway-construction project, the location, design, circumstances, and stakeholders typically differ from previous projects, generating a fundamental uniqueness for each project.

Organizations often use projects to achieve their strategic goals and objectives. In some cases, related projects are grouped together in programs to achieve benefits that would not be realized if the projects were managed individually. The collection of individual projects and programs that an organization undertakes is known as its portfolio. Unlike the projects within a program, the projects and programs within a portfolio might not be related or interdependent. However, all projects and programs within a portfolio should be consistent with an organization's strategic goals.

5.1.1 Why Project Management?

Engineering managers are employed throughout the world in different industries encompassing different technologies and domain expertise. Engineering managers carry out a wide array of different roles within this global technological and industrial landscape. For example, many engineering managers lead technical professionals within ongoing operations such as manufacturing as well as service industries that dominate the modern information-age economy. However, much of what engineers and engineering managers do is associated with the production of unique deliverables. Engineers in product, software, or process design often create unique works resulting from the application of technical and management skills. These unique end-products may be delivered directly to the client for immediate use as in the case of the design of a ship or a major software application. Other works emerging from engineering and engineering management practice may result in a prototype that is delivered to manufacturing for volume production. The engineers who develop prototype products apply skills in producing a one-off unique product whereas the engineers working within the manufacturing line operation are tasked with producing significant numbers of copies of the prototype product in a consistent, high-quality, and efficient manner. Engineering managers are therefore observed to operate both within roles within ongoing operational environments as well as in discrete research and product development teams. The fact that engineers often lead teams working on the production of unique deliverables within temporary organizations points to the need for engineering managers to be familiar with project management practices. Various definitions of project management exist, but the essence of project management relates to the management of a temporary effort to produce unique deliverables using resources as well as technical skills. Because much of engineering work takes place within the context of a project, it is essential that engineering managers be familiar with the body of project management standards and practices.

5.1.2 Project Management Practices

The use of project management in organizations has grown steadily over the last 50 years. As the management profession has grown, so has the formalization of project management methodologies. Different regions of the world have emphasized different aspects of project management practice and this has led to the development of related, yet different approaches to managing projects. Engineering managers benefit from being familiar with some of the most prominent standards that are used in regions in which they are operating. The United States is the home of the Project Management Institute (PMI), publisher of the recognized global standard for project management, *A Guide to the Project Management Body of Knowledge*, also known as the *PMBOK® Guide*. PMI also grants a highly recognized industry professional certification, the Project Management Professional (PMP®), as well as several other specialized project management certifications. The *PMBOK® Guide* however is not the only global standard for project management. Internationally engineering managers will likely encounter project managers who have training or certification in PRINCE2 or from the International Project Management Association.

PRINCE2, or "PRojects IN Controlled Environments" is an open standard for project management originally adopted by the government of the United Kingdom. In contrast to the granular process-intensive approach of the *PMBOK® Guide*, the PRINCE2 framework focuses on the overall management of projects from a lifecycle management perspective. Although the *PMBOK® Guide* includes a description of the project lifecycle and how the lifecycle aligns with its associated process methodology, the PRINCE2 method is more concerned with formulating projects and directing them through lifecycle stages. PRINCE2 offers certifications for project managers who master the PRINCE2 methodology. PRINCE2 certifications are highly valued in Europe and Asia but not popular in the American continents.

IPMA is a project management standards organization based in Europe. IPMA and its associated framework has a strong presence in Europe, the Middle East, and Australia. IPMA standards outline practices for project managers and organizations. The organization of IPMA recommendations, like the PRINCE2 methodology, begin with a conceptual top-down perspective. However, IPMA has competence as its focus rather than lifecycle and stage management and governance. IPMA provides recommendations for organization and individual competence as well as a project excellent baseline.

PRINCE2, IPMA, and PMI are but three of eight regional and national project management frameworks. These include the following:

1. Australian Institute of Project Management Standards (AIPM)
2. Australian National Competency Standards for Project Management (ANCSPM)
3. IPMA Competence Baseline (ICB®)
4. Project Management Association of Japan (P2M)
5. Project Management Institute's *PMBOK® Guide*
6. PRINCE2® 2009
7. SAQA National Qualifications Level 5 Standard (South Africa)

Given the proliferation of global standards, attempts have been made to create a repository of information about these standards to understand how closely related they are as well as their respective areas of emphasis. The Global Alliance for Project Professionals has created a set of tools that maps each of the standards so that a holistic view of the project management standards throughout the world may be attained. The sun never sets on engineering management work within projects, therefore, it is useful to become familiar with the standards that are in wide use within the region in which engineering project teams are led.

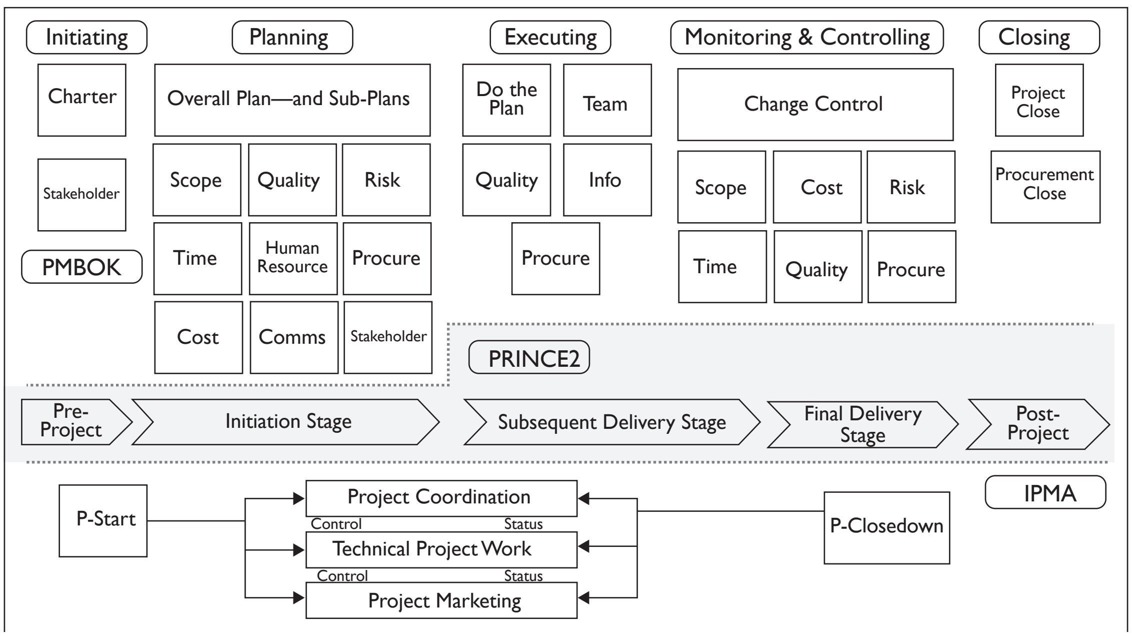
The *PMBOK® Guide* is in wide use in the Americas and known throughout the world. It is characterized by its in-depth process approach to identifying the sequence of steps as well as the management expertise required to carry out every aspect of managing a project. Much of the underlying process detail found in the *PMBOK® Guide* differs little from the activity characterized in other project management process frameworks. The 6th edition will therefore be used as the lens in which project management is explained in detail. As each major element of project management is introduced using the *PMBOK® Guide*, reference to other major standards such as PRINCE2 and IPMA will be introduced as appropriate. Additionally, the *PMBOK® Guide* includes significant support for Agile methodology. The Agile approach has been widely adopted within engineering and project management worldwide. How Agile relates to both project as well as engineering management as well as recommendations for its incorporation by engineering managers is addressed in Domain 5 of the *EMBOK Guide*.

5.1.3 A Guide to the Project Management Body of Knowledge

Project management is the activities undertaken by project and engineering managers in which knowledge, skills, tools, and techniques are applied to project activities to meet the project requirements. The term "requirements" is key in project management as the requirements of the client define the ultimate deliverables of the project. Since projects exist only to produce deliverables and are then terminated, acquiring, understanding, vetting, and implementing requirements are essential for fulfilling the purpose of the project.

The *PMBOK® Guide* defines the five project management process groups (Initiating, Planning, Executing, Monitoring and Controlling, and Closing) for completing projects or project phases. The process groups could also be employed as a means for completing any complex work that requires multiple steps. All complex work must be started (initiating), thought through in advance (planning), carried out (executing), carefully managed (monitoring and controlling), and then finished (closing). Both PRINCE2 and IPMA mirror this structured process. Both process frameworks formally start, outline many management activities, and then deliver the outcomes of the project and close.

Figure 5-1. Project Management Framework Comparison



In addition, the *PMBOK® Guide* defines the following 10 knowledge areas for project management: integration, scope, schedule, cost, quality, resource, communications, risk, procurement, and stakeholders, which are mapped into the five process groups, defining 49 project management processes. The 49 processes may appear to be overly complex for engineering managers. Given the challenge of daily management struggles involved in conceptualizing, planning, and executing project deliverables, taking the time to adhere to 49 processes would likely not appear very useful at first glance. However, like many problems and process frameworks encountered by engineering managers, the PMBOK process framework is best understood by first understanding the overall rationale. The five process groups are intended to characterize the order of events within a project. Further, these five process groups are intuitive and easy to remember. What then is the purpose of the knowledge areas? Unlike the process groups, the knowledge may be thought of as a content model of project management. They describe areas of domain expertise that project managers apply within each of the process groups. The process groups are therefore "the five things project (or engineering) managers must do," while the knowledge areas are the "10 things project (or engineering) managers must know." Taken together, the process groups and knowledge areas form a matrix of nearly 5 x 10—in this case 49 individual processes.

Figure 5-2. PMI Process Framework

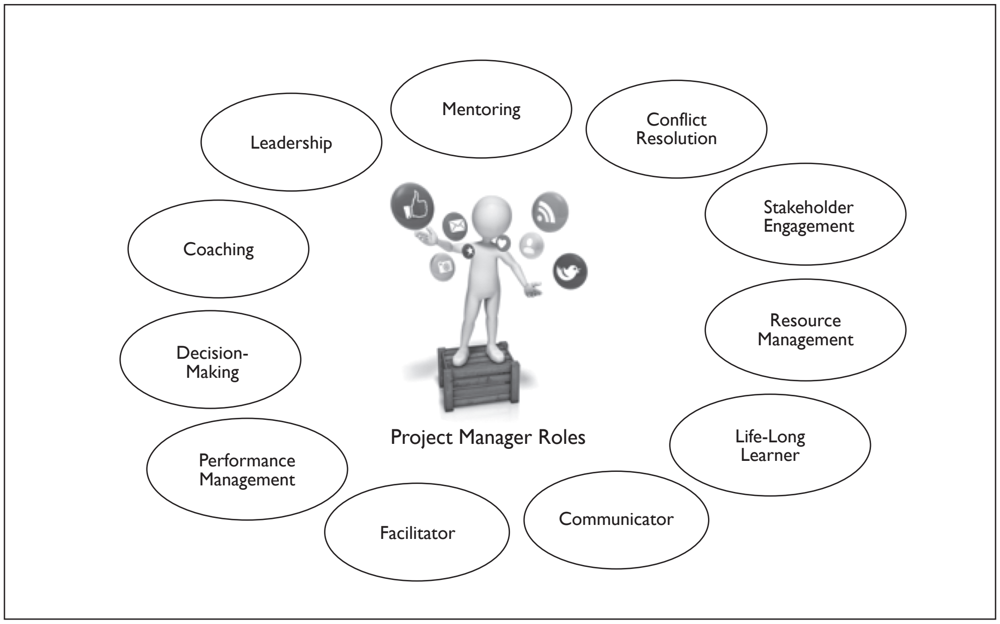
Mapping of PMI Knowledge Areas to Process Groups					
	Process Groups				
Knowledge Areas	Initiating	Planning	Executing	Monitoring & Controlling	Closing
Integration	X	X	X	X	X
Scope		X		X	
Time		X		X	
Cost		X		X	
Quality		X	X	X	
HR		X	X		
Communications		X	X	X	
Risk		X		X	
Procurement		X	X	X	X
Stakeholders	X	X	X	X	

The activities found in the combination of process groups and knowledge areas are also found in the PRINCE2 and IPMA frameworks. They are referred to in most cases implicitly as similar activities and are found in project coordination, technical project work, and managing project stages.

A project is led by the project manager, who is the ultimate individual accountable for the performance of the project. A project manager can be seen as the CEO of a temporary organization (i.e., the project) in which he or she makes decisions throughout the life cycle of the project (i.e., from initiating to closing) to meet the project requirements. These project management decisions are made based on knowledge, information, and data that are processed through a reflection process creating an understanding of project status as well as project progress projections. The project manager uses this understanding to analyze the situations, to assess and manage project risks, to generate and evaluate alternatives, and to make decisions to move the project toward the desired future situation. Project managers follow decision-making processes daily as they make operational, tactical, and strategic decisions.

Project managers perform several key roles in a project. For example, they lead project work by facilitating project communication, fostering creativity, resolving conflict and decision-making. They administer the project by planning, collecting, allocating, protecting, and controlling project resources, as well as by assessing and controlling project performance. They lead the stakeholders of the project by articulating the vision and current state of the project, providing soft support, developing a high-performance project culture, and inspiring the key stakeholders of the project, especially the members of the project team. They coach and mentor the stakeholders of the project through continuous feedback and focus on the development of the next generation of project managers. Finally, they exert constant personal-reflection processes that enable them to continuously improve their project-management performance (e.g., becoming a better facilitator, a better leader, better learner) through active learning. Figure 5-3 represents these key project manager's roles.

Figure 5-3. Key Roles, Influence, and Decision-Making Parameters of Project Managers



Because of their multiple roles and overarching responsibility, project managers exert significant influence over the project. The project manager has the ability to impact the attitude and performance of personnel in every aspect of the project.

End-to-End Management of Projects through the lens of the PMBOK® Guide Process Groups

5.2 Initiating Process Group: The Project Begins

The initiating process group involves those processes necessary to define a new project or project phase and to authorize the project manager to begin using organizational resources to perform the subsequent project activities. Often, the decision to undertake a project is established through strategic planning in which alternatives are evaluated. These activities may be performed outside of the project boundaries but should include key project personnel, such as the project manager, whenever possible. Once a project is selected, the project manager is assigned, a clear description of the project activities is developed, and the justification for the project is documented, noting the selection criteria and comparison to alternative projects considered to satisfy the requirements. An important step in the initiating process is the identification of all of the people and organizations that are impacted by the project, both positively and negatively, known as the stakeholders. During initiation, the stakeholders' interests, involvement, and impact on project success are documented. A project charter, which is a document that specifies the initial requirements that satisfy the stakeholders' needs and expectations, is created. Expert judgment is often used to assess the inputs used to develop the project charter. The customers and other key stakeholders should be involved in the development of the project charter to improve the probability of stakeholder buy-in throughout the project and customer satisfaction at completion. The project charter normally includes the following:

- Project purpose and description
- Sponsor or individual(s) authorizing the project
- Project manager name, responsibility, and authority level
- Project objectives and success criteria
- High-level requirements
- Identification of major risks

- Summary milestone schedule and budget
- Project-approval requirements

Generally, projects are authorized by someone external to the project at a sufficiently high level to appropriate the funds for the project. This may be the project sponsor or a high-level steering committee. When the project charter is finalized and approved, the project becomes officially authorized and project planning begins.

5.3 Planning: Documenting How the Project Goals are Accomplished

The largest number of processes in the *PMBOK® Guide* framework are to be found in the planning process group. The presence of so many planning processes reveals the emphasis in the *PMBOK® Guide* of "planning before doing." The planning process group consists of all the processes necessary to define the requirements and establish the scope for the project, outline the work required to meet the project objectives with the desired quality, determine the resource (human and other) requirements, assess the project risks, plan the purchasing decisions, and develop the detailed schedule and time-phased budget based on the amount of work required and the availability and cost of the required resources. Appropriate stakeholders, particularly the customer as well as the project team, should be involved in the planning process. Team involvement in plan development is said to be essential for "buy-in" as well as accountability. The rationale for this is that it is easier for a customer to support the project, and the team to work hard to achieve project goals if they are involved in planning to the degree that they could see it as their plan rather than something handed off by another group. The planning process is iterative, with continuous refinements as more information becomes available. When the project plans contain a satisfactory level of detail, the initial planning effort ends, and the execution phase begins. The processes in the planning process group direct the project team to think through and document the strategy for how the work is to be accomplished. The same concept of plan development exists in other project management frameworks although implemented somewhat differently than that provided in the *PMBOK® Guide*.

5.3.1 Project Management Plan

The project management plan—a compilation of subsidiary plans addressing the scope, time, cost, quality, communication, human resources, risk, procurement, and stakeholders' concerns of the project—is the major output of the planning process. Development of the project management plan is an ongoing and iterative process. The plan is progressively elaborated and becomes more refined and precise as additional details about the project are gathered. The project management plan guides how the project is executed, monitored, controlled, and closed. Once a baseline of the project management plan is established, changes are made to the plan only when a formal change request is generated and approved through the integrated change control process.

5.3.2 Estimating Resources

Prior to employing resources to develop a detailed project plan, it is recommended to consider the overall likely cost involved in the project. Costs are linked to resources therefore initial high-level resource estimates are prudent. Project resources include people, equipment, and materials. Cost estimates, normally expressed in some type of currency, are based on what is known about the tasks that must be completed on the project and the resources required to complete those tasks and the volume of the resources required. Costs for resources such as labor, materials, equipment, services, and facilities are estimated.

Because labor represents a significant portion of the cost for most projects, much of the effort in the planning stage focuses on estimating the human resources required for a project. Prior to committing to a full project deployment, the human resources and associate costs estimates are kept at a high level. The output of this is the ROM or "Rough Order of Magnitude" estimate. The detailed estimate is produced once the project scope is developed. As described in 5.3.3, an important input for estimating the resource requirements is the list of activities and their attributes that results from the decomposition of the work packages, adopted from the lowest level of the Work Breakdown Structure (WBS). The activity list and the resource calendar, which specifies when and how long identified resources are available, are used to estimate the activity resource requirements. The activity resource requirements can be aggregated for each work package and provide the basis for estimating the requirement for each resource. Once the resource requirements are established, the activity durations are estimated using a variety of techniques, including the following:

- Expert judgment—Estimates are guided by historical information and estimators' experience.
- Analogous estimating—Parameters from previous, similar projects are used as a basis for estimating the same parameter for a future project.
- Parametric estimating—Statistical relationship between historical data and other variables are used to calculate estimates for activity durations.
- Three-point estimates—Three estimates are used to define an approximate range for an activity's duration to improve the accuracy of the estimate.
- Reserve analysis—Contingency reserves are included to account for schedule uncertainty.

The closer to the execution of the activity that the estimate is made, the more likely it is to be accurate. However, there is a natural trade-off between estimate accuracy, time, and cost. The earliest estimates require little time and effort but are less accurate. Highly accurate estimates require the assignment of resources and significant time. It is possible that a detailed estimate may arrive too late to be useful.

5.3.3 Scope

The scope management process ensures that all the work required—and only the work required—to complete the project is defined. Collecting requirements is the first step in the scope management process and provides the necessary information to define the project scope. The process of collecting requirements may be formal or informal and might include interviews, focus groups, surveys, and other forms of business analysis. Many sophisticated tools are available for documenting requirements for large projects. The baseline requirements must be unambiguous, traceable, complete, consistent, and acceptable to key stakeholders.

The development of project scope begins with the scope statement. The scope statement defines the project deliverables and the work required to create the deliverables. It is important that the scope statement identify what is included in the project as well as what is not included in the project. The detailed scope statement typically includes the following elements:

- Scope description
- Acceptance criteria
- Deliverables
- Exclusions
- Constraints
- Assumptions

The project scope statement is an important input for the process of subdividing the project deliverables and project work into smaller, more manageable components known as the *work breakdown structure (WBS)*.

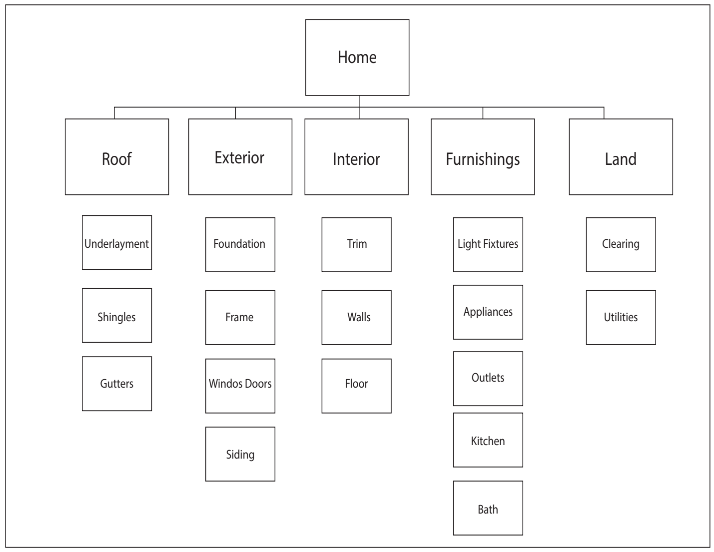
5.3.4 Work Breakdown Structure (WBS)

According to the *PMBOK® Guide*, the WBS is a "deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables" (p. 116). The deliverables at the lowest level of the WBS are called *work packages,* which is the level at which the durations and costs can be reliably estimated and reasonably managed. A WBS with major deliverables at the highest level of the structure is shown in Figure 5-4.

The WBS dictionary provides detailed information about the components in the WBS, such as description of work, responsible organization, milestones, resource requirements, acceptance criteria, and so forth. Work packages are decomposed into smaller components, often called activities, which define the tasks required to complete the work package. In many cases, it is not possible to define the activities required for many of the work packages until later in the project. This progressive elaboration planning is known as *rolling wave planning*. Activity attributes describe the detailed information about the activities and might include resource requirements, responsibilities, and predecessor and successor relationships.

The scope development process culminates in the scope baseline. The scope baseline includes the scope statement, the WBS, and the WBS dictionary.

Figure 5-4. Work Breakdown Structure (WBS). From *A Guide to the Project Management Body of Knowledge,* 6th ed., Newtown Square, PA: Project Management Institute.



5.3.5 From Scope to Schedule

Once the project scope is developed, the project team shifts emphasis to the development of the project schedule. The first step of schedule development begins with layering activities onto the project WBS. While the WBS outlines what is to be delivered by the project, the activities outline what must be done by the project in order to produce the required deliverables. The shift from deliverables to activities is important as it is the project activities rather than the deliverables that are included in the project schedule. Once the project activities are identified, the activities are then sequenced in logical order to determine the overall duration of the project. The sequencing and analysis of project activities is carried out using the network diagram.

5.3.6 Network Diagrams and Critical Path

Network diagrams are graphical representations of the work to be completed on a project. These diagrams are created during the planning phase and provide guidance for the execution of the work. They represent the sequence of the tasks or activities to be performed based on the information in the WBS and generally do not consider resource constraints. To create a network diagram, it is necessary to know the set of tasks for the project and the duration of the tasks, as well as the interdependencies of the tasks to be performed.

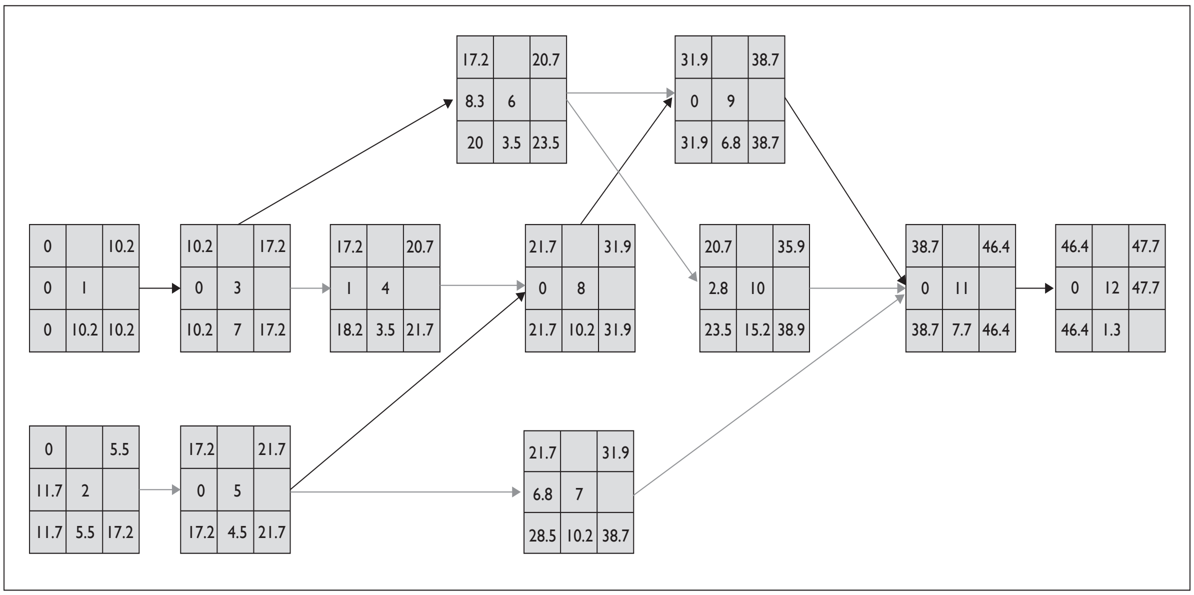
The network-diagramming process provides information about the earliest and latest start and finish dates for each of the tasks and the critical path for the project. The critical path represents the longest path through the network and includes all of the tasks that have zero slack. The term "zero slack" means that delays in these tasks on the critical path will result in the delay of the overall project.

Activity on node (AON), also known as precedence diagramming method (PDM), is used to illustrate the complex dependency relationships between elements in the WBS. The types of possible relationships in PDM include the following:

- Finish-to-Start (FS) – Successor task may begin when the predecessor task is finished.
- Finish-to-Finish (FF) – Successor task may finish when the predecessor task finishes.
- Start-to-Start (SS) – Successor task may begin when the predecessor task begins.
- Start-to-Finish (SF) – Successor task may finish when the predecessor task begins.

Because FS relationships are most common, the default relationship used by project-management software packages is FS. However, other types of relationships, such as FF, SS, and SF as well as lag and lead times, are possible. Figure 5-5 shows a simple PDM network diagram.

Figure 5-5. Precedence Diagramming Method (PDM). From *A Guide to the Project Management Body of Knowledge*, 6th ed., Newtown Square, PA: Project Management Institute.



A forward and backward pass through the network shows the Early Start (ES), Late Start (LS), Early Finish (EF), Late Finish (LF), and *slack* (amount of time a task can be delayed without delaying the project duration) for the project tasks. The tasks with zero slack, also called *float,* represent the critical path. Once the total float for a path is calculated, the free float, or amount of time a task can be delayed without impacting any successor activities, can be determined.

The use of the network diagram in determining project duration is known as CPM or the "critical path method." This method is used when the duration of each project activity is well understood. In cases where activity duration is uncertain, the Program Evaluation and Review Technique (PERT) is used. There are three time estimates, optimistic (t_O), pessimistic (t_P) and most likely (t_M) are used to calculate the expected time (t_E) using a weighted average according to the following equation:

$$t_E = \frac{t_O + 4t_M + t_P}{6}$$

The expected duration for the project is the sum of the weighted durations for the activities on the critical path. The variability of the activity time estimates can be approximated and used to estimate the probability of completing the project by a specific time.

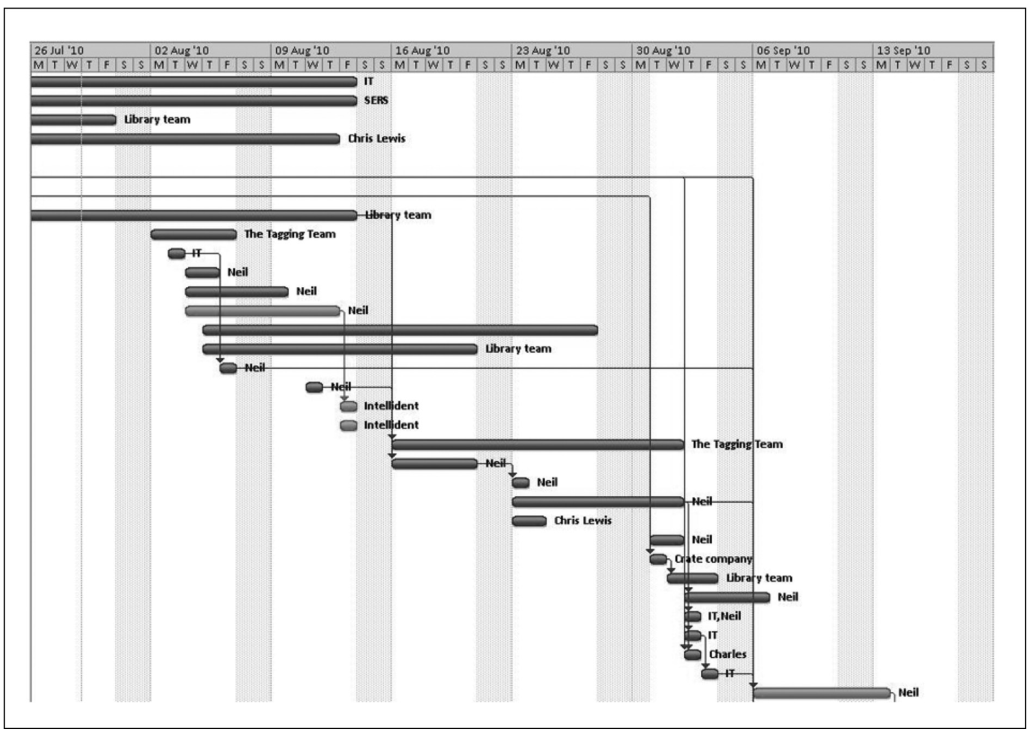
Three-point estimates are employed in the form of a weighted average using the PERT methodology. However, three-point estimates could also be employed in Monte Carlo analysis. Monte Carlo analysis simulates thousands of project duration "runs" by choosing one of the three-point estimate values at random for each project activity during each run of the schedule. Monte Carlo analysis results in a statistical distribution of project duration outcomes. An inspection of the distribution informs the project manager of the likelihood of achieving project completion duration scenarios.

The *critical chain method (CCPM)* is an emerging network analysis technique that emphasizes the importance of resource constraints and uses activity-time estimates that represent 50% likelihood of completion. The rationale behind this probability assignment is that individual tasks in the project will always vary. Despite individual task duration variation, the project manager seeks to ensure that the overall schedule is met despite some delays in individual activities. A new critical path is calculated using the 50% probability duration for each activity along with the known resource constraints associated with each activity. This new critical often differs from the original which does not consider limited resources and typically includes "padded" time estimates. The new critical path is called the critical chain. A project buffer, based on the uncertainty of the tasks on the critical chain, is added at the end of the critical chain to prevent project slippage. Feeding buffers are placed along paths that are not critical but that feed into the critical path to prevent the critical chain from being delayed. Once the buffers are inserted, all project activities are delayed to their latest possible planned start and finish dates. In theory, productivity will be increased as individuals try to meet tighter deadlines.

5.3.7 Presenting the Project Schedule

The analysis of project duration using the network diagram tool illustrates the logical order of events as well as the presence of serial and parallel activity paths. The network diagram however may be difficult for stakeholders to understand. Furthermore, network diagrams do not include milestones, cost information, and resource details. This information is entered into project management software, which generates the project schedule showing the planned dates for completing project activities. Gantt charts, which are bar charts that represent schedule-related information, are frequently used to illustrate project schedules. Figure 5-6 is an example of a planning Gantt chart generated using Microsoft Project™ 2010.

Figure 5-6. Gantt Chart Created Using MS Project™



5.3.8 Resources and Resource Constraints

Most projects are time-constrained and/or resource-constrained. Further, the assumptions made at the beginning of the project planning cycle fail to materialize as the project is executed. As a result, schedule development is often an iterative process. For example, re-planning considering unexpected events is required in most projects. The challenge is to produce the project deliverables within the original schedule and budget if possible. One way to do this is to attempt to reduce the project scope. Scope reduction requires negotiation when the project is producing for a single client. When the project is delivering to the market at large, reducing scope by eliminating features and functionality can be risky. When scope reduction is not possible, the project team may seek to reduce the schedule by providing more resources (and associated expense) to critical path activities. This strategy is referred to as project crashing. When crashing is attempted, project managers strive to obtain the greatest schedule compression with the least amount of additional cost. Fast tracking is a schedule compression technique in which activities that would normally be performed in sequence are performed in parallel. Project risks often increase when these strategies are used to reduce project duration. When the planned project and milestone schedules become firm, the schedule is saved as a baseline, which is a specific version of the schedule used to compare actual results to the planned schedule.

5.3.9 The Project Budget

Once the costs of all resources assigned to the project are aggregated by unit of time, a time-phased budget of the costs over the life of the project results is developed. The costs should be placed on the time-phased budget as they are expected to occur. Figure 5-7 shows an example of a time-phased budget.

Figure 5-7. Time-Phased Budget. From *Project Management: The Managerial Process*, 7th ed., 2017, New York: McGraw-Hill Irwin.

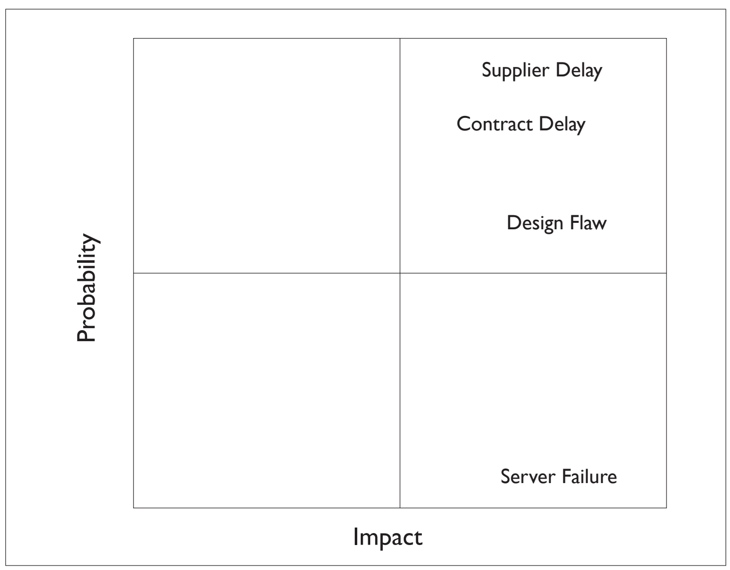
	July	August	September	October	November	December
Computer System Project						
Hardware						
Specifications	10,000.00	26,500.00	4,500.00			
Design			24,500.00	31,250.00	12,500.00	
Documentation						
Prototype						
Testing						
Assembly						
OS						
Kernel			4,750.00	8,225.00		
Drivers						
Parallel						
Serial						
Memory				3,750.00	4,800.00	10,500.00
Virtualization						
Network		10,250.00		24,375.00		
Documentation						
Utilities						
Specifications				8,500.00		
Routines				6,500.00	21,750.00	14,500.00
Shell						
Documentation					6,750.00	18,325.00
Integration						
Architecture	12,500.00	14,325.00				
Integration Part 1						
System Test						
Documentation						
Final Test						
Total	22,500.00	51,075.00	33,750.00	82,600.00	45,800.00	43,325.00

When finalized, the time-phased budget is saved as the project-cost baseline. Funding requirements are derived from the cost baseline. The project-cost baseline is used to measure, monitor, and control overall cost performance on the project.

5.3.10 Risk Identification, Assessment, Response Planning, and Risk Register

Risk is an uncertain future event or condition that, if it occurs, has a positive or negative effect on at least one project objective. Risk identification is the process of identifying the risks that may influence the project. Brainstorming is often used to identify risks. Brainstorming takes many forms including a SWOT (Strengths, Weaknesses, Opportunities, and Threats), nominal group technique, or scenario planning. The project team and all key stakeholders should be involved in the risk-identification process, which is an iterative process, because new risks may become apparent or anticipated risks may not occur throughout the project life cycle. Once the risks are identified, risk analysis is performed to assess the probability of the risk occurring and the impact of the risk should it occur. In some cases, sophisticated methods such as sensitivity analysis, modeling, and simulation are employed to predict the probability and impact of identified risks. A probability and impact matrix should be used to prioritize risks. As shown in Figure 5-8, the matrix specifies the combination of probability and impact, and rates the risks as low, medium, or high priority.

Figure 5-8. Probability and Impact Matrix. From *A Guide to the Project Management Body of Knowledge*, 6th ed., Newtown Square, PA: Project Management Institute.



The PMBOK® Guide includes risks that have the potential for both positive outcomes (opportunities) and negative outcomes (threats) in the risk-analysis process. Risk responses are developed to take advantage of the opportunities and reduce threats to the project objectives. The four most common responses for negative risks include the following:

- Avoid—Risk avoidance involves modifying the project to eliminate the threat entirely.
- Transfer—Risk transference involves shifting the negative impact and the responsibility for the risk response to a third party.
- Mitigate—Risk mitigation involves reducing the probability and/or impact of a risk to a tolerable level.
- Accept—Risk acceptance involves dealing with the negative impact of risk events as they occur without attempts to modify the project management plan in order to avoid, transfer, or mitigate risks.

The four most common responses for positive risks include the following:

- Exploit—In this strategy, the project team attempts to eliminate the uncertainty to ensure that the opportunity is realized.

- Share—In this strategy, some of the ownership and the gains resulting from the opportunity are transferred to a third party who is better able to capture the opportunity.
- Enhance—In this strategy, attempts are made to increase the probability and the positive impacts of the opportunity.
- Accept—In this strategy, the organization is willing to take advantage of the opportunity if the positive risk event occurs, but the opportunity is not actively pursued.

The risk register is the preferred tool for managing risks and documenting the characteristics of the risks for the project. The risk register should include the list of identified risks, risk category, risk owner, risk causes and triggers, probability of occurrence, impact, risk-response plans, and status. The risk register should be reviewed and updated on a regular basis throughout the project life cycle. As risk events occur, it may be necessary to create and submit formal change requests.

5.4 Executing

The executing process group includes all the processes necessary to complete the activities defined in the project management plan. This involves managing the resources, particularly human resources, to create the project deliverables as described in the scope statement. Typically, more expenditures occur during the execution phase than in any other phase, so all levels of management pay considerable attention to the project during project execution. Like the planning process group, execution is an iterative process and may include changes to the expected duration of activities and resource requirements, leading to change requests that might result in modifications to the project management plan. As the project progresses, identified risks might be realized, potential risks might not occur, and unanticipated risks might be identified. Each of these events will necessitate modifications to the risk management plan, which is an important subsidiary plan of the project management plan.

5.4.1 Project Team Management

The acquisition, development, and management of the project team are essential activities of project execution and are driven by the human resources plan. The human resource plan identifies and documents roles, responsibilities, and required skills and establishes staffing plans. A hierarchical-type or matrix-based chart defines the reporting relationships. A responsibility assignment matrix (RAM) is commonly used for illustrating the connections between work packages and project team members. An example of a RAM, known as a RACI (responsible, accountable, consult, inform) chart, is shown in Figure 5-9.

Figure 5-9. RACI Matrix. From *A Guide to the Project Management Body of Knowledge*, 6th ed., Newtown Square, PA: Project Management Institute.

	Role 1	Role 2	Role 3	Role 4
Task 1	R	A	C	I
Task 2	I	I	R	A
Task 3	C	A	R	I
Task 4	R/A	I	I	
Task 5	R	A	C	I
Task 6	C	C	R	A

The information included on the RACI is particularly important to help delineate responsibilities and accountabilities when external as well as internal resources are used on a project.

5.4.2 Models of Team Development

The staffing management plan details when and how human resource requirements will be met. Acquiring human resources is the process by which the appropriate people are identified to accomplish the work that must be completed on the project. Many questions must be answered, such as are the resources available internally, or will it be necessary to employ external resources? Can the team members work virtually, or must they be co-located? What are the costs of the required resources, and is training required? Developing the project team involves training of individuals to enhance the competencies of the project team members, as well as team-building activities to enhance the overall performance of the team. In 1965, Bruce Tuckman defined the four stages of team development. Later a fifth stage, Adjourning, was added: Forming—Individuals are oriented to the project and learn about their formal roles and responsibilities on the project.

- Forming—Individuals are oriented to the project and learn about their formal roles and responsibilities on the project.
- Storming—The team begins to address the project work and the technical decisions. Differing ideas and perspectives can lead to conflicts.
- Norming—Team members begin to trust one another and work together effectively. Behavior and work habits are adjusted to support the team.
- Performing—The team functions as a well-organized unit. Team members are interdependent and work through issues smoothly and effectively.
- Adjourning—The team completes the project work, and team members move on as the project closes.

It should be recognized however that the Tuckman model is but one model of team development. Gersick (1991) proposed the punctuated equilibrium model as an alternative. In this model, the team begins to gel, and performance develops as a step function once project time constraints are recognized. Either model may apply depending upon the circumstances associated with the team evolution. Models are imperfect attempts to describe reality—therefore—any given team may evolve somewhat differently in practice.

It is recommended that team ground rules be developed to establish clear expectations regarding acceptable behavior by project team members. As the project progresses, project team management assesses team performance in terms of technical success of project objectives, performance on project schedule, and budget. Desirable behavior should be recognized and rewarded when appropriate. Due to the high-intensity nature of projects, conflicts are a common occurrence. The following five techniques are used for resolving conflicts

- Avoiding—Retreating from an actual or potential conflict
- Accommodating—Emphasizing areas of agreement rather than areas of difference
- Compromising—Searching for solutions that bring some degree of satisfaction to all parties
- Forcing—Insisting on one party's viewpoint at the expense of others
- Collaborating—Incorporating multiple viewpoints from differing perspectives to lead to consensus and commitment. It is usually considered the preferred technique for conflict resolution.

Issues that arise during the course of a project should be documented and managed in a project-issues log. Effective communication is essential to successful project execution. Project managers spend the majority of their time generating, collecting, analyzing, and distributing project information. Effective communication creates a bridge between the project team and diverse stakeholders. It is important to remember that stakeholders include all individuals and organizations that are impacted by the project, both positively and negatively.

5.4.3 Project Procurement Management

Procurement management involves all aspects of acquiring products and services from external organizations. Procurement processes range from simple order placement to complex acquisitions that involve evaluation of formal competitive bids from prospective contractors. Typically, ordering standard parts and services is handled by a purchasing department. For more costly items, a make-or-buy analysis may be performed to determine whether work can best be accomplished by the project team or should be purchased from outside sources. When a buy decision is made for complex acquisitions, a Request for Proposal (RFP) is often issued in order to identify the vendor who can provide the best solution at the most competitive price. A bidder's conference is a meeting between the buyer and all perspective sellers that is intended to provide equal and fair access to information. Once proposals are received, a vendor evaluation is performed to select the vendor of choice. Next a procurement contract is awarded. The contract usually includes statement of work or deliverables, schedule, roles and responsibilities, pricing, payment terms, and acceptance criteria, among other things.

5.4.4 Project Contract Management

Contract management is an important function within procurement management and includes the establishment and administration of contracts related to the selling of the products or services that are produced by the project teams, as well as the contracts for products or services that are acquired by the project team. Most organizations have specialists in purchasing and/or contract law who will assist the project team in contract management. The type of contract affects the level of risk for the buyers and the sellers. Generally, the following three types of contracts are used:

- Firm-fixed price—Type of contract that establishes a fixed total price for the products and/or services to be purchased. Sellers are legally obligated to deliver the products or services regardless of the costs incurred to complete the work. Therefore, sellers assume greater risk for this type of contract.
- Cost-reimbursable—Type of contract that involves payments to sellers for all legitimate actual costs incurred for completed work plus fees representing seller profit. Cost-reimbursable contracts give greater flexibility to the project team when the scope cannot be precisely defined at the beginning of the project or the risks associated with the project are significant. Therefore, buyers assume greater risks for this type of contract.
- Time and materials—A hybrid type of contract that contains aspects of firm-fixed price contracts and cost-reimbursable contracts. This type of contract is often suitable when a precise statement of work might not be feasible. Unit labor or material rates may be clearly defined but the full value of the agreement or the exact quantity of products or services to be delivered might not be defined when the contract is established. Often, not-to-exceed values and time limits are included in these types of contracts.

Once contracts are established, the procurement relationships and contract performance must be managed to ensure that the sellers meet their contractual obligations. Due to the legal nature of a contractual relationship, the individual responsible for administering contracts may report to an organization outside of the project team. Administering procurement involves directing, managing, and reporting performance, performing quality and change control, and monitoring and controlling risks.

5.5 Monitoring and Controlling

Project performance can be defined as the extent to which a project met or has met the project requirements. Project performance in general terms is dependent on the level at which performance is measured (e.g., lowest level of the WBS) and at the moment at which performance is measured (e.g., at any moment during the execution phase, at the end of the project). Project performance is a complex construct conformed of different sets of project metrics that can be organized into two groups: technical and human project performance metrics. Different sets of metrics are used, depending on the nature of the project and/or of the needs of the stakeholders of the project. Projects that excel at both the human and the technical aspects of project performance are commonly labeled as high performance projects. Following are a common set of metrics used to assess project performance:

- **Technical project performance**—Cost performance, schedule performance, quality performance. These are commonly known as the triple constraints of project management. In addition, technical performance also includes the extent to which a project has met environmental constraints.
- **Human project performance**—Stakeholder satisfaction (e.g., members of the team, customer, project manager), learning, and the image of the project and of its organization.

Monitoring and controlling include those processes necessary to track, review, and regulate the progress of a project and to identify, initiate, and manage required changes. Project monitoring and controlling occurs throughout the project life cycle. An essential process within this process group is controlling the project scope, which ensures that all requested changes to the scope and recommended preventative or corrective actions are processed through the formal change-control system. If scope is not controlled properly, a phenomenon known as scope creep occurs. Scope creep refers to the tendency for project scope to expand over time due to small changes that are not formally processed through the change-control system but add up to significantly more work than the original scope baseline. If a scope change is deemed necessary, the impact on the project schedule, budget, and quality must be assessed to determine whether the change is justified. If it is determined that the change must be made, modifications to the scope, schedule, and budget baselines may be required.

However, baseline modifications are reserved for significant changes and should only be made when all project stakeholders approve. Other changes reflect the normal variations with projects and should be processed through the change-control system to ensure that all concerned parties understand the impact of the change.

Tracking Gantt charts are typically used to communicate project schedule status by comparing actual start and finish times to the baseline schedule. When the actual schedule differs from the planned schedule, corrective actions may be necessary, such as increasing the number of resources, requiring the project team to work additional hours, or completing tasks in parallel rather than sequentially. If critical chain scheduling is employed, the amount of buffer used is compared to the amount scheduled when evaluating schedule status. Tracking Gantt charts can be used to predict the time it will take to complete the project based on performance to date

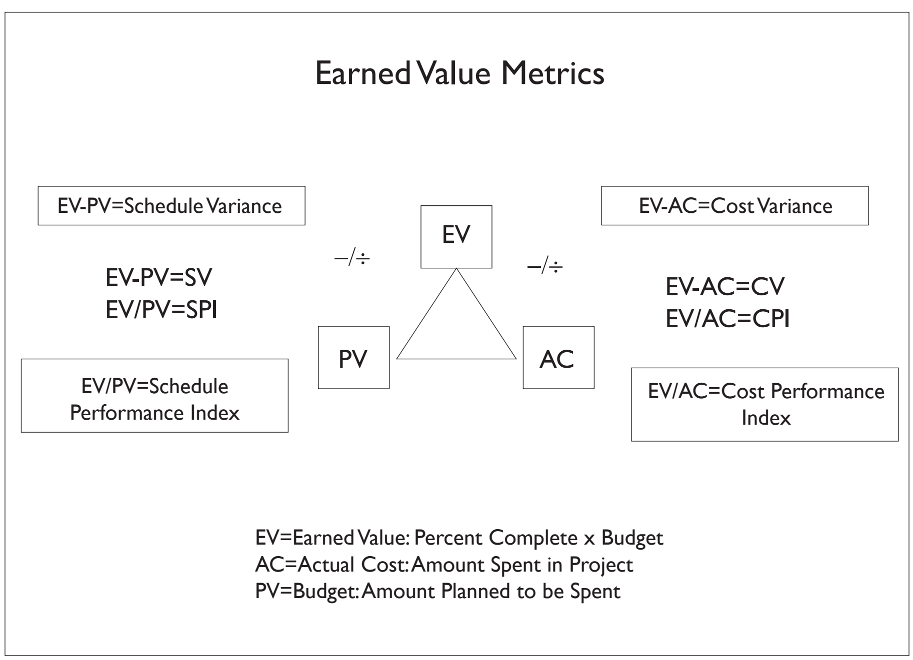
5.5.1 Earned Value Management

Actual project costs, as well as the value of the work performed, are compared to the cost baseline to monitor and control costs. For many projects, earned value management (EVM) is used to integrate the scope, time, and cost performance on the project. The three key dimensions of earned value follow:

- Planned value (PV)—The authorized budget for the work that is scheduled to be completed at a specific point in time.
- Earned value (EV)—The planned cost, in terms of the authorized budget, for the work that has actually been completed at a specific point in time.
- Actual cost (AC)—The total cost incurred for the work that has actually been completed (as opposed to the work that was planned to be completed) at a specific point in time.

Figure 5-10 shows typical earned value metrics used in projects.

Figure 5-10. Earned Value, Planned Value, Actual Costs, and Formulas. From *A Guide to the Project Management Body of Knowledge*, 6th ed., 2017, Project Management Institute.



In EVM, the following indices are used to indicate the variance of actual performance compared to the baseline schedule and budget:

- Schedule Variance (SV)—Difference between earned value (EV) and planned value (PV). An SV greater than zero indicates that the project is ahead of schedule and an SV less than zero indicates that the project is behind schedule.
- Cost Variance (CV)—Difference between earned value (EV) and actual costs (AC). A CV above zero indicates that the project spending is below budget and a CV less than zero indicates that the project is over budget.
- Schedule Performance Index (SPI)—Ratio of earned value (EV) to planned value (PV). A value above 1 indicates good project health with regard to the schedule and a value below 1 indicates poor project health with regard to the schedule.
- Cost Performance Index (CPI)—Ratio of earned value (EV) to Actual Cost (AC). A value above 1 indicates good project health with regard to the budget and a value below 1 indicates poor project health with regard to the budget.

EVM includes methods for estimating the total cost of the project at completion, referred to as estimate at completion (EAC). Ideally, the EAC is calculated as the sum of the actual costs (AC) to date and updated estimates of the cost for the work that remains to be completed on the project, known as estimate to completion (ETC). However, in some cases, it is not practical to re-estimate the remaining costs, so strategies for forecasting have been developed. The method for predicting EAC depends on whether the project is expected to progress as originally planned or as it has progressed thus far. Many believe that is prudent to assume that the project will continue to progress similarly to the way it has progressed thus far, particularly if the project is over budget. When doing so, EAC is calculated based on the budget at completion (BAC) and the cumulative cost performance index (CPI). The equation used is: EAC = BAC/Cumulative CPI. The ETC is calculated as the difference between the calculated EAC and the actual costs (AC) to date.

When variances are identified, project team members must provide explanations for the variances to the stakeholders and must develop preventative or corrective actions, which should be processed through the formal change-control system.

5.5.2 Project Quality Management

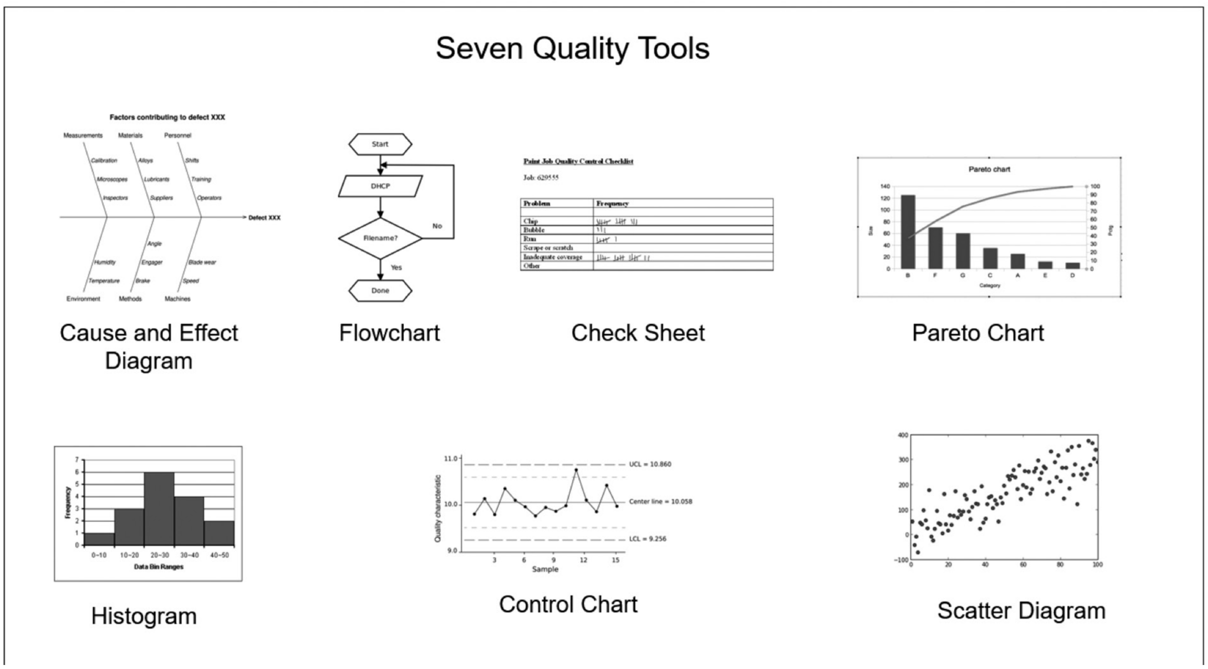
Quality assurance and quality control of the project management processes, as well as the project deliverables, are important considerations for all projects. During the planning stages of the project, the quality standards and the methods for ensuring that the standards are met must be defined so that project requirements are satisfied. Policies and procedures for continuous improvement must be established. The methods, policies, and procedures for project quality are compatible with the International Organization for Standardization (ISO) approach to quality. The tools and techniques for quality management include cost-benefit analysis, cost of quality, control charts, benchmarking, design of experiments, statistical sampling, and flow charting, among others. Quality metrics define a project or product attribute and how the quality-control process will measure it. The allowable variations, known as tolerances, must be established for all metrics. Quality assurance is the process of auditing the quality requirements and the data generated through the quality-control procedures to ensure proper quality standards are in place and continuous process-improvement strategies are employed. Quality control is the process of monitoring, documenting, and analyzing performance to detect poor process or product quality and to identify causes in order to recommend and/or take action to eliminate the causes. The seven basic quality tools, sometimes referred to as the 7QC Tools are illustrated in Figure 5-11. Some of the most frequently used tools are described as the following:

- Cause and effect diagrams (also called Ishikawa or fishbone diagrams) are used in root-cause analysis to help uncover factors that may be the source of problems.
- Control charts illustrate how a process behaves over time and help determine if variations are within acceptable limits. Variations from the schedule and cost baselines are often evaluated using control charts.

- Pareto charts are a specific type of histograms that are used to rank the causes of defects or problems related to a specific process and identify the defects or problems that occur most frequently. The Pareto Principle, also known as the 80/20 rule, suggests that, in many cases, relatively few causes (20%) produce a large percentage (80%) of the problems or defects. Project teams should address the causes creating the greatest number of defects first.
- Scatter diagrams show the relationship between two variables. Correlations of variables might help to explain undesired (or desired) variations.

Figure 5-11 summarizes the earned value management equations.

Figure 5-11. Seven Basic Quality Tools. From *A Guide to the Project Management Body of Knowledge*, 6th ed., Project Management Institute.



5.6 Closing

The closing process group includes the activities necessary to formally complete all aspects of the project or phase. For successful projects, the closing activities culminate in the single most important activity of the closing process, which is securing written acceptance of the deliverables from the customer. Administrative closure includes all actions and activities necessary to satisfy exit criteria and to transfer the products or services to the customer or the next phase of the project. Administrative closure also includes actions to collect records, audit project success or failure, gather lessons learned, and archive project information. To ensure that performance criteria are met, the project manager reviews all the information from previous phase closures. An important aspect of closing is the collection of lessons learned and best practices generated during the project in order to make them available to future projects.

Each contract applicable to the project or project phase must be addressed during project or phase closure. Often, contract terms and conditions prescribe specific procedures for contract closure. It is essential to verify that all work and deliverables are acceptable and that all open claims are finalized.

In some cases, projects are terminated prematurely, which requires investigation and documentation.

Early termination of a contract can occur by mutual agreement, due to the default of one party or for the convenience of the buyer, if provided for in the contract. Early terminations typically require special actions to be taken. When settlement cannot be achieved through negotiation, some form of alternative dispute resolution may be necessary, such as mitigation or arbitration. Unresolved open claims may be subject to litigation after closure.

As projects progress, personnel may be released when they complete the activities to which they were assigned or when their services are no longer required. It is important to gather information and update project documentation, such as lessons learned, before team members are released from the project.

Plans to facilitate a smooth transition from one project to another for all project personnel, whether at the end of a phase or at the end of the project, significantly improve morale.

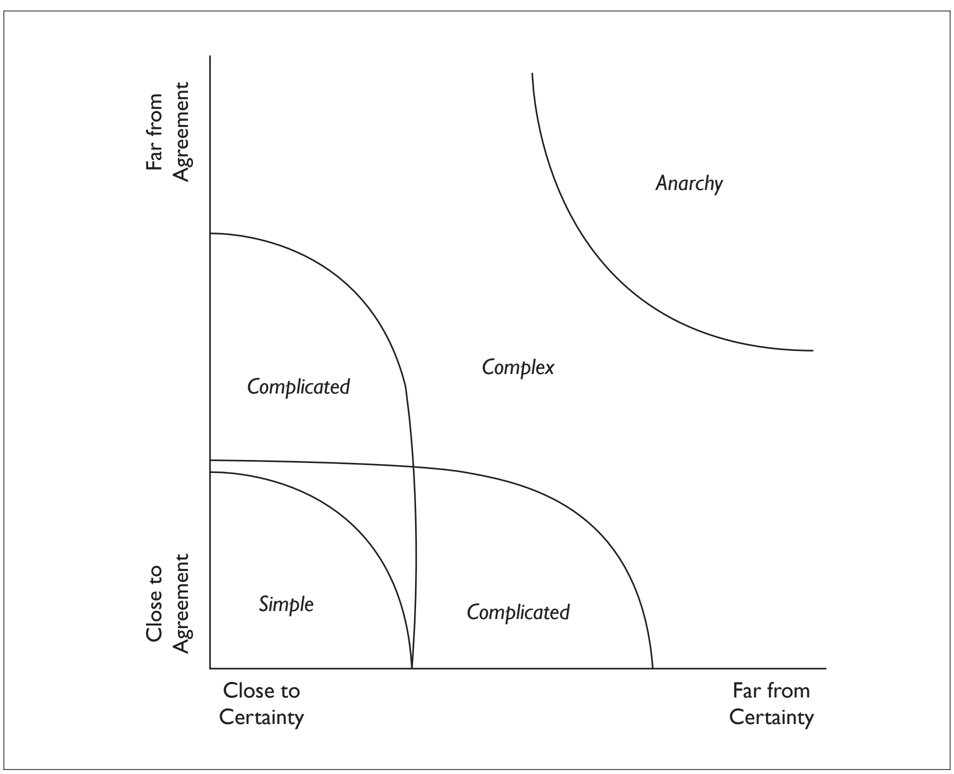
5.7 Introduction to Agile Project Management

Agile is the ability to successfully respond to changes, faster than the rate of change. This ability is suggested to come in the form of mental, physical, and interpersonal adaptability (Mueller-Hanson et al., 2005). Agile project management is a world view articulated through a framework that is intended to enable organizations, project teams, and managers to become more flexible and able to cope with the uncertainty of project environments. There are at least three important critical factors affected by uncertainty in the project environment: the uncertainty of the requirements of the project deliverables (i.e., what is to be produced), the uncertainty of the processes that are necessary to transform project resources into deliverables (i.e., how is to be produced), and the uncertainty of the capacity of the project to generate the project deliverables (i.e., what resources and infrastructure are needed and available to be used in the project).

5.7.1 The Stacey Matrix

The Stacey Matrix (Stacey, 1996), Figure 5-12, is a good starting point for assessing when traditional waterfall project management or agile project management approaches are more adequate to be used. The traditional waterfall model (Royce, 1970) implemented in traditional project management has failed to cope with the uncertainty of the project environment as it assumes predictability in the project environment and lacks iterative development (although Royce clearly stated in his work the need of iterative development). On the other hand, there are project management lifecycle processes that seek to tailor the traditional waterfall for iterative management. These include methods such as the incremental method and the spiral development to name but two beyond Agile methodology.

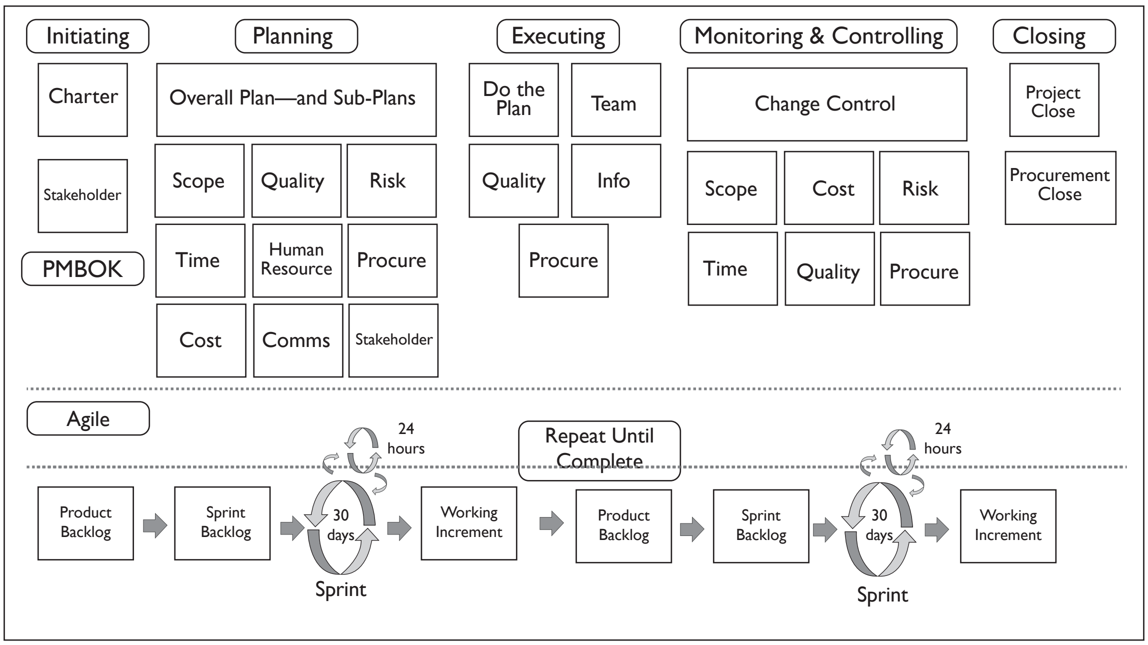
Figure 5-12. Modified Stacey Matrix (Stacey, 1996)



5.7.2 The Agile Process Framework

Agile project management shares common elements with the traditional approach to manage projects; however, it has some unique elements that enable a better response to uncertain environments when comparing it with traditional project management. A common element of agile project management with traditional project management is the overall approach to manage a project as proposed in the *PMBOK® Guide* and as shown in Figure 5-13. Agile project management, as in traditional project management, starts with an initial phase followed by multiple iterative phases.

Figure 5-13. *PMBOK© Guide* Model Compared with Agile



Agile project management builds upon a combination of a series of successful practices and techniques such as iterative incremental development; lean; just-in-time; empirical process control; continuous improvement; self-organizing teams; and cross-disciplinary integrated project teams among others, to define a set of 4 values and 12 principles (Beck et al., 2001) that guide agile decision-making and agile project actions. These values and principles seek to maximize flexibility and adaptability within a project while at the same time, minimizing process overhead.

The agile process framework is based on iterative incremental development. Iterations are full work cycles (from analysis, design, planning, execution, to testing) that produce value to the customer. These iterations create increments (small deliverables) of the total product or service being generated through the project that are assembled and integrated as the project progresses. In a project, these iterations are performed sequentially mimicking the phases of the *PMBOK® Guide* model (Slinger & Broderick, 2008).

There are at least three important aspects of iterations in agile project management: the level of the iteration, the duration of the iteration, and the number of iterations needed to produce the project requirements. These three aspects of iterations are defined in an agile project based on a combination of factors related to the customer (e.g., volatility of the industry, risk management, control need, financial resources), in addition to factors related to the product or service being generated (e.g., how soon can the design allow for producing value, technical constraints, uncertainty), as well as factors related to the capacity of the team (e.g., how fast the team can produce requirements). There are strategic, high-level, long-duration iterations called releases, and there are tactical, low-level, short-duration iterations called sprints (in Scrum) or just called iterations.

Releases are composed by a certain number of iterations and are defined in an agile project when the work to complete it is relatively extensive (i.e., the project cannot be completed in few iterations); thus, the need to group the work in major pieces of functions or value to the customer. Iterations, or sprints, are short, full work cycles (from analysis, design, planning, execution, testing, to review and delivery) that produce relatively small value increments to the customer. A project is composed by a certain number of releases, which are composed by a certain number of iterations (sprints) in which daily work is planned and tasks are completed to create incremental value in an iterative process.

Project level: The project-level work in an agile project starts with a planning phase and ends with a project retrospective. A project manager, customer, and team are defined at the project level. At the planning phase, the customer articulates the vision of the project to the team. The customer may come to the kick-off meeting with either a well-defined or a barely defined set of requirements; in any case, these requirements are clarified and refined in the product backlog as the project progresses. Figure 5-14 represents a vision task board that can be used in a project planning meeting. Project value is built during the inner phases. These inner phases can group the project requirements in different releases and compose these releases of different iterations. This is a common approach in large projects and organizations that would seek to group iterations in releases generating a product roadmap. Another approach is making the inner phases iterations, not using the release level in the project. This approach works well in short, small-scope projects. The project-level work ends with a project retrospective. A variable-price, variable-scope contract is a common contracting vehicle at the project level, as it defines the relationship between the customer and the project and can be supplemented by capped-price, variable-scope and fixed-price, and fixed-scope contracts. A product roadmap represents the releases against time and provides a visual artifact to plan and track project progress. The customer, with the assistance of the team, defines the product roadmap and the product backlog. Figure 5-15 represents a product roadmap.

Figure 5-14. Vision Task Board

Vision Statement: "Verb + Target + Outcome"			
Target group	Needs of Target Group	Product or Service or Ideas	Potential Competitors
Customers	Customer's needs End-users Market	Major functions Major constraints	Value of proposition of competitors Competitive advantage of product or service

Figure 5-15. Product Road Map Example

Date	1st Quarter/Year	2nd Quarter/Year	3rd Quarter/Year	4th Quarter/Year
Name	Version 1	Version 2	Version 3	Version 4
Features	Major Requirement A Major Requirement B Major Requirement C Major Requirement D	Major Requirement E Major Requirement F Major Requirement G	Major Requirement H Major Requirement D Major Requirement E Major Requirement F	To be defined by the market

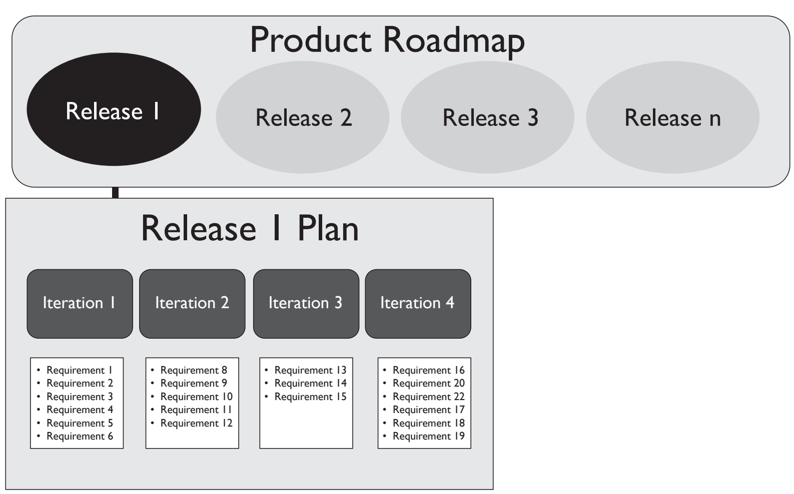
The product backlog is the list of requirements of the project. This list defines the scope of the project and is updated as needed by the customer. New requirements can be added, deleted, or changed at any point of time during the project. The customer ranks the requirements in terms of importance or priority, and the team assesses the amount of effort needed to produce the requirements. The product backlog is used in the planning of releases and iterations. The product backlog is a living document, as it represents the changing nature of the project scope. The product backlog is ready to be used in planning when the requirements are ranked in priority, have been estimated in size or amount of effort and, are relatively small, and the dependencies have been identified. However, to start planning, it is not necessary to have all of the requirements defined, just enough to plan the next release or iteration. The team, together with the customer, develops for each requirement its acceptance criteria (quality test that needs to be passed in order to be accepted by the customer) and the definition of when the requirement is completely done.

Estimating the size or effort of each requirement is a task performed only by the project team. In the estimation process, the team discusses what it will take to produce each requirement until it is completely done and passes its acceptance criteria. Requirements are first estimated by the team using abstract measures. A common method used for estimating is the planning poker in which relative size is used to assess how much team effort will be necessary to complete a given requirement. Abstract points are used to maximize the amount of work not done in the planning of the releases, as these requirements might be very vague and large (major requirements), making the accurate estimation of their size a potential waste of project time and resources, as these might only be completely understood after the customer and the team learn more about the project (i.e., the product/service, development processes, and the team capacity).

Release level: The release level of an agile project is defined by a release planning phase that is followed by a set of iterations (sprints) and ends with a release retrospective. At the release planning meeting, the team uses the timeline defined in the product roadmap for the release being planned to determine the duration and number of iterations (sprints) that will be needed to complete the release. An estimated team capacity or team velocity is a key input in the release planning. For example, a team of five that is fully dedicated to the project has an estimated velocity of 20 points per two months iteration, meaning that this team can produce 100 points in a release of five iterations. This is a strategic (release) velocity and will be updated at the end of each release, making it more accurate as the team remains together throughout the project and a series of projects. When the project has too much uncertainty (i.e., in the product or service being developed, and/or in the development process, and/or in the capacity of the team), it is recommended that buffers affecting (downgrading) the velocity of the team be applied. Another important input in the planning process is the selection of the top requirements of the product backlog and their interdependencies. These requirements should be small, for the major requirements must be decomposed in the product backlog to enable release planning. Selecting the top requirements from the product backlog makes the team focus on producing what has more value to the customer first. These relatively small requirements will be distributed in the different iterations until completing the capacity of the team. Figure 5-16 represents a release plan.

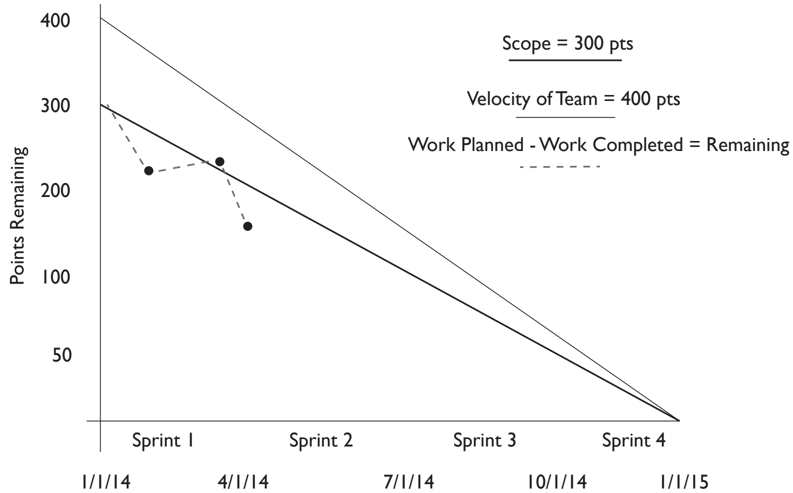
A revision of the product roadmap may be necessary at the end of the release planning meeting and/or at the end of the release, as the team and the customer learn more about the project. A release burndown chart will provide strategic transparency of the team commitment and performance at the release level. A high-level project contract can be supplemented with capped-price, variable-scope contracts for each release, which in turn can be supplemented with fixed-price, fixed-scope contracts for each iteration (sprint).

Figure 5-16. Example of a Release Plan



The release burndown chart represents the remaining work in abstract points across the different iterations (sprints) that are included in the release. It plots abstract points versus iterations. It provides a simple figure in which the plotted remaining work is expected to be zero by the end of the release. The release burndown chart is updated at the moment a requirement is demonstrated and accepted by the customer. Figure 5-17 represents an example of a release burndown chart that has completed its first iteration (sprint).

Figure 5-17. Example of a Release Burndown Chart



Iteration level: The iteration or sprint work of an agile project is defined by an iteration meeting, daily work, and a project review, demo, and retrospective. During iteration planning, the team uses the release plan to determine what requirements were expected to be produced in the iteration being planned and how long such iteration should take. This duration translates into a maximum team (velocity in time units; e.g., 400 hours per one-month iteration for a team of five members). This is the team's tactical (iteration) velocity. Because the iteration work is expected to start the day after iteration planning, project uncertainty is reduced, making iteration planning more accurate. At the iteration level, the team decomposes the requirements into tasks and measures the effort needed to complete these tasks in time units, usually hours. This information creates the iteration or sprint backlog. The team assigns an owner to each task (responsible person) and checks if the team velocity is enough to complete the planned requirements set in the release plan. The team prepares the iteration backlog, the iteration task board, and the iteration (sprint) burndown chart. The iteration backlog identifies the tasks, their estimated duration, their owner, and their priority. The iteration task board is a visual representation of the work planned (the iteration backlog) and the work in progress and completed per each requirement. Figure 5-18 represents an Iteration task board.

At the end of the iteration planning or at the end of the iteration work, there is an overall verification and potential update of the release plan, team velocity, and product roadmap based on the new understanding created during the iteration. A fixed-price, fixed-scope contract is a good contracting vehicle for the iteration, as no change will be expected in the set of requirements being worked during the iteration.

The daily meeting takes place during the daily work in the iteration. The team meets daily for 15 minutes maximum (i.e., that is why it is also called the daily standup meeting) to coordinate and strategize the work to be done during the day and to report on the work done the previous day. Additionally, the team identifies blocks that are necessary to be removed to ease or enable the work for the day. The project manager takes on these blocks, prioritizes them, and address them as fast as possible. This list of blocks is defined as the impediment backlog.

The iteration burndown chart represents the remaining work in hours across the time unit defined in the chart (e.g., days, weeks). It provides a simple representation in which the plotted remaining work is expected to be zero by the end of the iteration. The iteration burndown chart is updated at the moment a task is completed and/or daily.

The demo takes place at the end of the iteration. The goal of the demo is to showcase the results of the iteration and obtain approval from the customer. The demo is designed around the acceptance criteria (quality tests) identified by the team and the customer earlier in the project. The team, customer, project manager, and any other stakeholder is welcome to attend.

The review and retrospective is a key learning process in the agile project. It takes place at the project, release, and iteration levels. The goal is for the team to learn about what went right, what went wrong, and how it can be used in the next round of work ahead. The team collects facts and compares what was planned and what was achieved by the team, generating factual performance data. The retrospective formalizes learning in the agile project management process and enables continuous improvement.

The retrospective is the last process in an agile project, release, or iteration. Immediately after the completion of the retrospective, the team moves into planning the next iteration or release as needed by the customer and as stipulated in the contracts. A project can be extended indefinitely if the customer is interested in funding the project. Therefore, it is important that the team set a velocity that will allow a constant pace to be maintained indefinitely (Principle No. 8 of the agile manifesto) (Beck et al., 2001).

5.7.3 Agile versus Traditional Project Management Summary

While there are many differences in terminology between Agile and traditional project management, the overall intent of Agile is to commit to delivering functionality "a little bit at a time" rather than committing to a monolithic project all at once. Further, Agile maximizes face-to-face interaction and communication over extensive documentation and rigid processes. During a time in which standards and client requirements often change significantly, it makes sense for engineering managers to adopt a more flexible and common-sense approach to the project lifecycle. On the other hand, such an approach is not without its costs. When functionality is delivered "a piece at a time," there remains significant integration work to be done at multiple milestones. While Agile eliminates the final "big-bang" deliverable associated with traditional project management—it does tend to replace this with many smaller but no less difficult integration milestones. Finally, although process methodologies improve, likewise project complexity continues to grow. Project management, regardless of process framework adopted, PMI, IPMA, PRINCE2, Agile, or a combination, remains challenging.

Review

Upon completing the study of Domain 5: Project Management, you should be able to answer the following questions:

1. What are the five Process Groups and 10 knowledge areas defined by the Project Management Institute (PMI)? How does PMI map the knowledge areas to the process groups?
2. List the steps required to complete a work breakdown structure. Why is a work breakdown structure important?
3. Describe the significance of the critical path. How is the critical path determined?
4. What are some of the constraints that must be considered when developing a project schedule?
5. What are three-point estimates? What are the pros and cons of three-point estimates?
6. Discuss time-phased budgets. Why are they important?
7. Describe how risk is assessed as part of the project management process.
8. Explain the earned value management (EVM)/earned value analysis (EVA) technique. What are the three key dimensions, and how are the EVM variances and indices calculated?
9. Discuss how quality standards help improve the project management process.
10. What essential steps must be completed when closing a project?
11. Name project management frameworks in use throughout Asia, the Middle East, and Europe.

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6

Quality Management System

Domain 6 Champions

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6.1 Quality Management System

6.1.1 Quality Management Principles
6.1.2 Quality Management Tools and Techniques

6.2 Quality Engineering

6.2.1 Statistical Process Control
6.2.2 Measurement Systems Analysis
6.2.3 Process Capability
6.2.4 Cost of Quality
6.2.5 Quality Tools

Domain 6: Quality Management System

Key Words and Concepts

Total Quality Management	A management approach that focuses on continuous improvement to achieve customer satisfaction and long-term success of the organization.
Six Sigma	A customer-focused, continuous-improvement strategy and discipline that minimizes defects and variation in product design, production and service-delivery processes.
Continuous Improvement	Continuously improving processes to give customers what they want the first time and consistently every time.
Process Capability	The inherent uniformity of the process where the tolerance of the process is measured indirectly by one or more output variables. The ratio of tolerance to process variation is known as process capability.
Customer Satisfaction	Measure of how products and services meet or exceed customer expectation.
Quality Assurance	Establishes standards, procedures, and policies to manage quality within an organization.
Quality Control	Produces the specific data, measures, and values used by the organization to assess quality engineering and production.

6.1 Quality Management System

The ultimate success of any commercial organization depends upon its ability to determine and satisfy its customers' needs. Organizations focus on innovation, quality, speed, efficiency, and customer value to be globally competitive. The long-term sustainability of any organization depends on its commitment to continuous improvement. Quality must be consistent, long-term, and result in on-target performance of products and services with minimum variation. To satisfy customers, their needs must be considered throughout the entire planning, design, development, manufacturing, delivery, and service processes. Quality is critical for enhancing competitive performance and productivity, growing market share, and improving profitability. Three elements of profitability include (1) quality of products and services, (2) value or cost, and (3) timeliness of delivery. Total Quality Management (TQM) is a philosophy and culture with associated scientific tools, methods, and leadership actions. The quality management vision helps companies remain competitive in the face of customers' constantly changing and evolving expectations. The principles, practices, and techniques embodied within continuous improvement form a comprehensive organizational philosophy that strives to effectively fulfill customers' needs, and organizations implement such programs in order to be productive and create organizational knowledge with improved performance. The TQM imperatives consist of customer focus, worker empowerment and involvement (all the people, all the time), and continuous improvement. These imperatives create a culture of quality.

A Quality Management System (QMS) is documentation of the Quality Management in a given organization. The documentation includes all internal processes and if applicable the manufacturing processes as well. The formal documentation includes quality policy, quality manual, quality records etc. A formal documentation standardizes the processes and ensures consistency of outcomes enterprise wide.

6.1.1 Quality Management Principles

Quality must be defined for each product based on what the customer wants in the product through measurable characteristics and their limits of variability. According to Garvin (1987), quality has several dimensions, including but not limited to performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality.

The American Society for Quality (ASQ) defines quality as follows:

> "A subjective term for which each person has his or her own definition. In technical usage, quality can have two meanings: (1) the characteristics of a product or service that bear on its ability to satisfy stated or implied needs and (2) a product or service free of deficiencies" (http://asq.org/glossary/q.html).

Dr. Armand Feigenbaum defined quality as:

> "Quality is a *customer determination* which is based on the *customer's actual experience* with the product or service, *measured* against his or her *requirements—stated or unstated, conscious or merely sensed, technically operational or entirely subjective*—always representing a *moving target* in a competitive market." (Schoenfeldt, 2008, p. 152)

Continuous improvement focuses on continuously improving processes to give customers what they want the first time and consistently every time. The key principles of total quality can be summarized as follows:

- Every activity can be described as a process.
- Every process has inputs and outputs.
- Every individual process is part of a larger system of interconnected processes.
- Every process has customers and suppliers.
- The purpose of every process is to satisfy the customer.
- Satisfying the customer requires continuous improvement.

Continuous improvement and quality management was notably championed by pioneers such as W. Edwards Deming, Joseph M. Juran, Philip B. Crosby, and Kaoru Ishikawa. Deming defined quality as non-faulty systems; Juran, as fitness for use; Crosby, as conformance to requirements; and Ishikawa, from the perspective of the consumer.

Deming developed 14 points for management to ensure continuous quality management throughout an organization. Deming's 14 points are provided in Table 6-1.

Some of the elements of the Quality Management Principles are listed graphically in Figure 6-1.

Figure 6-1. Elements of QMS Principles (Reference: https://asq.org/quality-resources/quality-management-system)

Table 6-1. Deming's 14 Points for Management. From *Out of the Crisis,* by W. E. Deming, 1982, Cambridge, MA: MIT Center for Advance Engineering Study.

1	Create a constancy of purpose toward the improvement of product and service. Consistently aim to improve the design of your products. Innovation, money spent on research and education, and maintenance of equipment will pay off in the long run.
2	Adopt a new philosophy of rejecting defective products, poor workmanship, and inattentive service. Defective items are a terrible drain on a company; the total cost to produce and dispose of a defective item exceeds the cost to produce a good one, and defective items do not generate revenues.
3	Cease dependence on inspection to achieve quality. Do not depend on mass inspection because it is usually too late, too costly, and ineffective. Realize that quality does not come from inspection but from improvements on the process.
4	Do not award business on price tag alone, but consider quality as well. Price is only a meaningful criterion if it is set in relation to a measure of quality. The strategy of awarding work to the lowest bidder has the tendency to drive good vendors and good service out of business. Preference should be given to reliable suppliers that use modern methods of statistical quality control to assess the quality of their production.
5	Constantly improve the system of production and service. Involve workers in this process, but also use statistical experts who can separate special causes of poor quality from common ones.
6	Institute modern training methods. Instructions to employees must be clear and precise. Workers should be well trained.
7	Institute modern methods of supervision. Supervision should not be viewed as passive "surveillance," but as active participation aimed at helping the employee make a better product.
8	Drive out fear. Great economic loss is usually associated with fear when workers are afraid to ask a question or to take a position. A secure worker will report equipment out of order, will ask for clarifying instructions, and will point to conditions that impair quality and production.
9	Break down the barriers between functional areas. Teamwork among the different departments is needed.
10	Eliminate numerical goals for your work force. Eliminate targets and slogans. Setting the goals for other people without providing a plan on how to reach these goals is often counterproductive. It is far better to explain what management is doing to improve the system.
11	Eliminate work standards and numerical quotas. Work standards are usually without reference to produced quality. Work standards, piece work, and quotas are manifestations of the inability to understand and provide supervision. Quality must be built in.
12	Remove barriers that discourage the hourly worker from doing his or her job. Management should listen to hourly workers and try to understand their complaints, comments, and suggestions. Management should treat their workers as important participants in the production process and not as opponents across a bargaining table.
13	Institute a vigorous program of training and education. Education in simple but powerful statistical techniques should be required of all employees. Statistical quality-control charts should be made routinely, and they should be displayed in a place where everyone can see them. Such charts document the quality of a process over time. Employees who are aware of the current level of quality are more likely to investigate the reasons for poor quality and find ways of improving the process. Ultimately, such investigations result in better products.
14	Create a structure in top management that will vigorously advocate these 13 points.

In addition, Juran developed 10 steps to quality improvement, provided in Table 6-2.

Table 6-2. Juran's 10 Steps. From *Juran on Planning for Quality*, by J. M. Juran, 1988, New York, NY: The Free Press.

1. Build awareness of the need and opportunity for improvement.
2. Set goals for improvement.
3. Organize to reach the goals (have a plan and an organizational structure).
4. Provide training.
5. Carry out projects to solve problems.
6. Report progress.
7. Give recognition.
8. Communicate results.
9. Keep score.
10. Maintain momentum by making annual improvement part of the regular systems and process of the organization.

Finally, Crosby developed 14 steps to continuous improvement, provided in Table 6-3.

Table 6-3. Crosby's 14 Steps to Continuous Improvement. From *Quality Is Free: The Art of Making Quality Certain*, by P. Crosby, 1979, New York, NY: McGraw-Hill.

1. Make it clear that management is committed to quality.
2. Form quality-improvement teams with representatives from each department.
3. Determine how to measure where current and potential quality problems lie.
4. Evaluate the cost of quality and explain its use as a management tool.
5. Raise the quality awareness and personal concern of all employees.
6. Take formal actions to correct problems identified through previous steps.
7. Establish a committee for the zero-defects program.
8. Train all employees to actively carry out their part of the quality-improvement program.
9. Hold a "zero defects day" to let all employees realize that there has been a change.
10. Encourage individuals to establish improvement goals for themselves and their groups.
11. Encourage employees to communicate to management the obstacles they face in attaining their improvement goals.
12. Recognize and appreciate those who participate.
13. Establish quality councils to communicate on a regular basis.
14. Do it all over again to emphasize that the quality-improvement program never ends.

Ishikawa's quality philosophy was defined by quality first rather than short-term profit. His philosophy focused on consumer orientation—not producer orientation—by thinking from the standpoint of the other party. The next process is your customer, which breaks down the barrier of sectionalism. Ishikawa used statistical methods and stressed using facts and data to make presentations. His philosophy incorporated the organizational culture, with respect for humanity as a management philosophy through full participatory management and cross-functional management.

6.1.2 Quality Management Tools and Techniques

Quality has evolved over time from a philosophy of inspecting products and removing defects to continuous improvement of products, processes, and services. A variety of process-management tools, quality management systems, and quality standards have been developed to ensure consistency in product and service performance.

6.1.2.1 Quality Management Tools

A process is a step or sequence of steps that uses inputs and produces a product or service as an output. Quality management tools have been developed to assist with data collection and analysis, identification, planning, and problem solving. Table 6-4 provides brief descriptions of the seven management and planning tools.

Table 6-4. Seven Management and Planning Tools

Activity Network Diagram	A tool used to illustrate a sequence of events or activities, represented as nodes, and their interconnectivity. This tool is useful to monitor, schedule, modify, and review activities and critical milestones for a project.
Affinity Diagram	A tool used to organize large amounts of data, concepts, and ideas based on their natural relationship to each other. It is useful when grouping large amounts of information.
Interrelationship Diagram	A tool used to identify cause-and-effect relationships between factors in a complex situation. It is useful when relationships are difficult to determine.
Matrix Diagram	A tool used to show relationships between two groups of data and the importance between objectives and elements, cause and effect, people and tasks. It is useful in determining responsibility of elements in an implementation plan.
Prioritization Matrix	A tool used to decide among several options by ranking each option according to specific criteria. It is useful when not all benefits are of equal value.
Process Decision Program Chart	A tool used to graphically illustrate problems (all events that can go wrong) and appropriate countermeasures.
Tree Diagram	A tool used to break a general topic into activities using a hierarchy of tasks and subtasks necessary to complete an objective.

6.1.2.2 Quality Management Systems

A variety of standards addresses quality. Some are mandated based on industry while others are voluntary and might vary based on location.

1. Quality Standards

Some of the organizations that establish quality standards for industry include:

- ANSI: The American National Standards Institute – an organization that "oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector" ("About ANSI Overview," available at https://www.ansi.org/about_ansi/overview/overview?menuid=1).
- ISO: The International Organization for Standardization – an international organization that has developed standards for international business use. ISO 9001:2015 addresses quality management, ISO 14000 addresses environmental management, and ISO 13485 addresses the medical device industry.
- NIST: The National Institute of Standards and Technology – an agency of the U.S. Department of Commerce with the mission "to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life" ("NIST General Information," available at https://www.nist.gov/director/pao/nist-general-information). NIST manages the Malcolm Baldrige Award process.

Quality Management System standards are available from ISO and are widely used world wide. The most widely used Quality Management System standard is ISO 9001:2015. It is applicable to organizations of all sizes and is generic in nature applicable to all sectors. A company following this standard assures its customers that the products and services it provides meet customer and regulatory requirements while maintaining continuous improvement activities to continuously enhance their products.

ISO 14001:2015 standard is used to define Environmental Management Systems. ISO/IEC 27001:2013 is related to Information technology — Security techniques and Information security management systems.

ISO 13485 is related to medical device manufacturing. It is a regulated standard is often used in conjunction with ISO 9001:2015. Compared to non medical device manufacturing, the 13485 standard is more specific and has stricter requirements. A process validation would include – IQ, OQ, PQ, Process validation protocol and verification. IQ refers to Installation qualification and relates to ensuring the equipment is installed properly, calibration has been conducted, spare parts list is available, safety features are in place etc. OQ refers to operational qualification and is used to demonstrate the process has been challenged under worst case conditions and proper DOE has been conducted to optimize the process parameters. PQ refers to Performance Qualification and is used to demonstrate that the process will consistently produce acceptable products under the given operating conditions. The stability and reliability of the process is determined here. Once this is done, the Process validation protocol will be documented describing the validation process and lists the test parameters and describing the limits of acceptability of the quality of the product. The final step is to ensure the verification is completed and is documented by providing objective evidence that the specified requirements have been met.

While ISO 9001:2015 is generic and widely used, some industry specific standards have been developed. The IEEE computer society maintains a set of software standards. These standards are often used as a checklist for ensuring quality for software processes. Some of the IEEE software and systems engineering standards are: 730-2014 Software Quality Assurance Processes, 828-2012- configuration Management in systems and software engineering, 829-2008 software and system test documentation.

2. The Malcolm Baldrige Award

The Malcolm Baldrige National Quality Award was developed in 1987 to promote total quality management. This award is given annually by the President of the United States to organizations that exemplify the best quality practices in the following areas:

- Leadership
- Strategic planning
- Customer focus
- Measurement, analysis, and knowledge management
- Workforce focus
- Process management
- Results

6.2 Quality Engineering

Engineers and engineering managers are not only tasked with designing and developing processes and products, but also with creating and managing systems that yield quality results. Quality engineering consists of two branches that support reliability and customer satisfaction: quality assurance and quality control.

Quality assurance (QA) establishes standards, procedures, and policies to manage quality within an organization. QA standards include ANSI, ISO, and NIST as described in Section 6.1.2.2.1. Recipients of the Malcolm Baldrige award adhere to a set of best practices in quality management. Quality assurance is measured by audits that assess whether the company is doing what it says it will do. This is the essence of an ISO audit, for example, in ensuring that documented quality practices are implemented across the organization.

Quality control (QC), on the other hand, produces the specific data, measures, and values used by the organization to assess quality engineering and production. Many of the metrics used in QC are standardized across industries and are built from seven basic quality tools:

The seven basic quality tools include:

- Check sheets
- Flow charts
- Histograms
- Pareto charts
- Cause-and-effect diagrams
- Scatter charts
- Control charts

Some of these tools are primarily used for data gathering (e.g., check sheets) while others are utilized more for analysis (e.g., Pareto charts). **Control charts**, in particular, are used to monitor the quality output of continuous processes. Engineers and engineering managers make decisions based upon statistical data analysis in a control chart. Control charts are developed and utilized through statistical process control.

6.2.1 Statistical Process Control (SPC)

Statistical process control (SPC) dates to the early 1930s and the work of Dr. Walter Shewart, a mentor to W. Edwards Deming. Shewart identified that all processes create data and when that data is analyzed via statistical methods, it can be determined whether the process is within statistical control or if it is being impacted by a special cause. Statistical data analysis then leads to identification, correction, and elimination of special cause variations that reduce quality. Natural variation, also known as common cause variation, is inherent in any process and cannot be eliminated without re-design or re-engineering of the process itself. With only natural variation, a process is said to be within statistical control if the output is stable within $\pm 3\sigma$ limits.

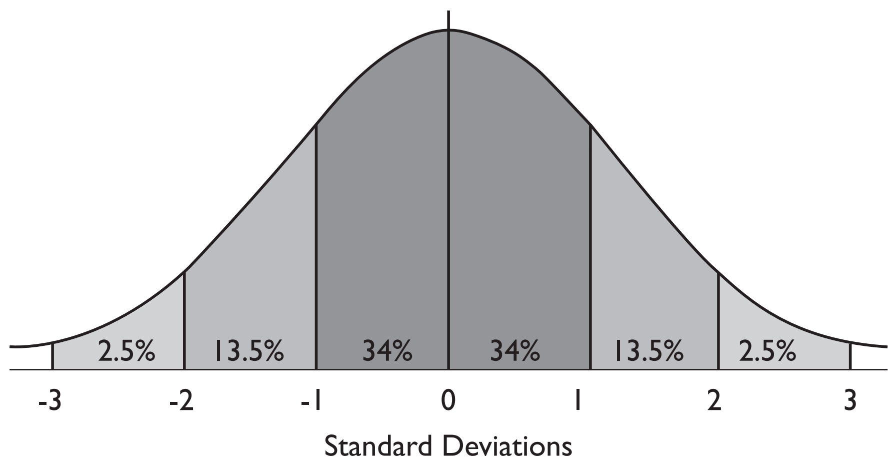
Goetsch and Davis (2016) defined statistical process control as “a statistical method of separating variation resulting from special causes from variation resulting from natural causes in order to eliminate the special causes in to establish and maintain consistency in the process, enabling process improvement.”

Variation

The output of a process that is properly operating is graphed as a bell-curve as shown in Figure 6-2. In a normally distributed dataset ("bell-curve"), the data set average (mean) is coincident with the mode and median, and data is evenly distributed and symmetrical on either side of the average. The x-axis represents a measurement of the process common such as weight, composition, or strength. The y-axis represents the frequency count of the measurements. When enough measurements are counted, the curve is smooth rather than showing discrete interval counts as in a histogram.

Note that the target measurement value is at the center of the curve. Variation in measurements displaces the curve to the right or left. When there are no special cause variations impacting the process, 99.73% of the output measurements will fall within ±3σ limits (standard deviations). The resultant degree of variation is related solely to natural causes. Keep in mind that the ±3σ limits are not the same as specification limits, which may be tighter than the statistical process control limits.

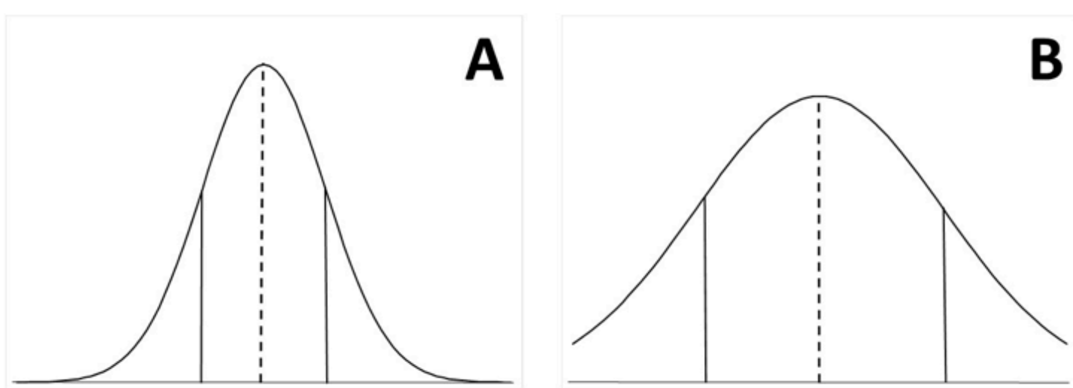
Figure 6-2. Example of Normally Distributed Data ("Bell-Curve")



When the data set is spread farther from the mean, as in Figure 6-3B, the measurement is less precise or repeatable. When the frequency distribution curve is narrower, the data is more repeatable (Figure 6-3A).

In order to apply hypothesis testing, as in a Six Sigma quality improvement project, a normal distribution of the data is often required. There are several tests to verify that the quality control data is normally distributed. Most statistical analysis software packages include simple commands and tests to validate that the data set is normally distributed.

Figure 6-3. Differences in Normal Distribution Curves



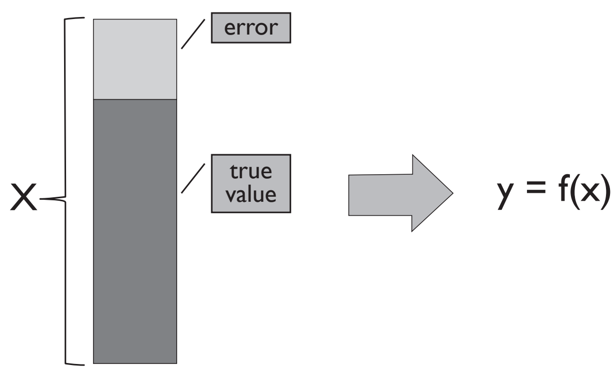
6.2.2 Measurement System Analysis (MSA)

While statistical process control is used to identify, correct, and eliminate special cause variation in a process, it is critical that the data quality is sufficient to analyze further. Data must be reliable before an engineer or engineering manager uses it to make a decision. **Measurement system analysis** (MSA) is a systematic methodology to identify and analyze the variation of components in the measurement itself. For example, if all components of an assembled part are manufactured at the maximum allowable tolerance, the overall quality of the part may be negatively impacted.

Figure 6-4. Measurement System Analysis

A measurement system is simply a process used to gather data (see Figure 6-4). As indicated, *y* is the output of the measurement system and consists of the observed values in the process. The input to the measurement system is represented by *x* and includes both a true value and a measurement error. In quality improvement projects, engineers and engineering managers seek to minimize the measurement error so as to influence the observed value leading to an improved quality output (see Figure 6-5).

Figure 6-5. Measurement Error

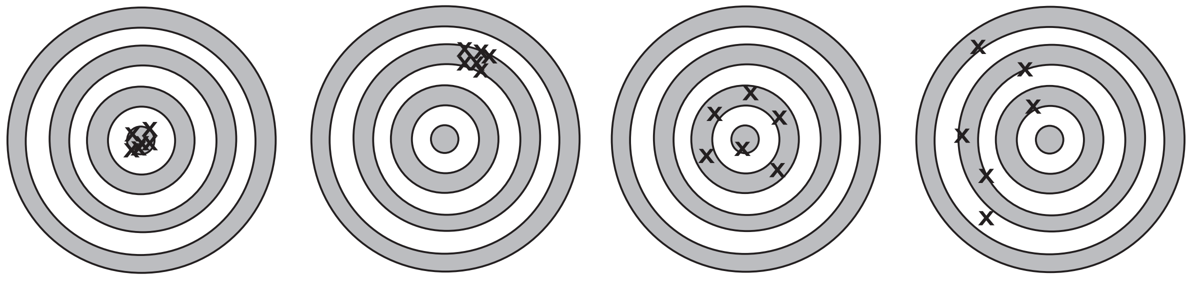


We use a *variable measurement system* for values that are continuous and an *attribute* MSA for discrete measurements. Examples of continuous measurements include height, weight, and temperature; whereas, discrete measures include color (red, blue, yellow), true/false, and Likert rating scales (1-5).

There are many potential sources of measurement error. These include human error, environmental conditions, equipment, sample contamination, materials, and methods. A cause-and-effect diagram can help a quality team brainstorm potential factors that affect the measurement system. Regardless of the source of error(s), the more errors introduced via the measurement system, the less reliable are the observed output values. A valid measurement system is both *accurate* and *precise*.

Accuracy describes how well the observed value reflects the true value. An accurate measurement is one in which the average observed value is very close to the true value. **Precision**, on the other hand, indicates the consistency of repeated measurements. A data set that has a lot of spread is not precise, while a data set that delivers the same values under the same circumstances is highly precise. If a data set meets the conditions of accuracy and precision, then the data can be used for decision analysis. If the measurement system is not accurate, not precise, or not accurate or precise, the measurement system requires calibration to create an accurate and precise measurement.

Figure 6-6. Accuracy and Precision in a Measurement System



Another element to consider when evaluating a measurement system is repeatability and reproducibility, commonly known as "gauge R&R." **Repeatability** evaluates whether the *same appraiser* obtains the same value when measuring the same object using the same equipment under the same environmental conditions. **Reproducibility** evaluates whether *different appraisers* can obtain the same value in measuring the same object independently. This refers to the level of agreement between different appraisers. Note that gauge R&R only addresses the precision of a measurement system.

6.2.3 Process Capability

Process capability is a measure of the inherent uniformity of the process. While it is not normally feasible to directly measure the process itself, the tolerance of the process is measured indirectly by one or more output variables. Frequently, these output measurements involve the uniformity of the product(s) produced by the given process. A process is considered stable when there are no special cause variations, the process is in statistical control, the future performance of the process is predictable within limits, changes happening in the process are due to random variations, and there are no special trends or patterns in the process control chart. **Statistical process control** (SPC) is the term used for the measurement and control of production variability.

Most production processes included product tolerance or specification limits to satisfy customer quality expectations. Process variation should fall within process tolerance limits to maintain quality production and to meet customer needs. The ratio of tolerance to process variation is called the process capability and is shown in the following equation.

$$C_p = \frac{\textit{Tolerance Width (T)}}{3\sigma \textit{ Limit of Process}}$$

A process capability of one (1), therefore, will generate approximately 0.15% out-of-tolerance products at either extreme (low or high limit). Meanwhile C_p=1.33 theoretically provides 100% yield.

The values of C_p assume that the center of the specification coincides with the process mean. An alternate index allows for the common case where this assumption does not hold. In the following equation, k is a calculated value based on the process design, process mean, and tolerance width. The value of k is available in a variety of references (Goetch & Davis, 2016).

$$C_{pk}=(1-k)\ C_p$$

When the capability index (C_{pk}) is equal to 1.0, the specification limits and average are coincident with process ±3σ limits and the process average. This means that any upset in the process will result in off-specification production. A capability index (C_{pk}) of less than one (<1) indicates that the specification limits are tighter than the process spread. Such a process is not capable and will yield a defect rate greater than three (3) parts per 1,000. Finally, when C_{pk} is greater than one (>1), the process is considered capable because the spread of the process is tighter than the specification tolerance. The defect rate is less than three (3) parts per 1,000 in this case.

6.2.3.1 $\overline{X}$ and R Charts

When a process is both capable and stable, a control chart can be used to distinguish special cause from common cause variation. Data on a control chart are plotted over time and, without any special cause variation, stay within the upper control limit (UCL) and lower control limit (LCL) parameters. When a special cause variation occurs, a data point will fall outside the UCL or LCL, or there will be a "run" of several points in a trend above or below the average line or increasing and decreasing for a significant time. Common control charts use the R-chart and the $\overline{X}$-chart ("X-bar") to determine statistical process control. If the data do not conform to the R-chart, then the special cause variation must be corrected. Once the R-chart is stable, the $\overline{X}$-chart is used to maintain process control.

The R-chart represents the variation in the sample ranges while the $\overline{X}$-chart plots the average of samples over time. To create these control charts, used for continuous data, the steps are as follows (Goetch & Davis, 2016).

1. Determine the sampling procedure. Sample measurements are taken in subgroups of a specific size (n=3 to 10). Initially, there will be 25 or more subgroup data sets collected.
2. Collect data of about 100 individual data points within k subgroups of n measurements. There should be no adjustments to the process during data collection.
3. Calculate the mean of the data in each subgroup.
4. Calculate the data range, R, for each subgroup. This is the difference between the maximum and minimum value for each subgroup.
5. Calculate the *process average* and plot this as the center line on the $\overline{X}$-chart. The process average is the average of the subgroup averages.
6. Calculate the average of the subgroup ranges. This is the center line for the R-chart.
7. Calculate the process UCL and LCL using the process average, the subgroup range average, and a reference table of factors based on the number of data points in each subgroup.
8. Draw the control charts using the calculated values.
9. Plot and monitor data on the control chart over time.

The **p-chart** is similar to the $\overline{X}$ and R control charts but is used for attribute (discrete) data. Points plotted on a p-chart are the fraction of defective pieces found in a sample of n pieces. The p-chart is also used for counted data when the concern is associated with the number of defects. A *defective* piece may have multiple *defects* within it. For example, a defective part may fail quality inspection due to a number of defects (scratches, loose screws, poor adhesion, and so forth).

6.2.3.2 Detecting Variation in a Control Chart

Normally, when the data points fall within the UCL and LCL boundaries on a control chart, the process is considered stable and in statistical control despite falling within the $\pm 3\sigma$ limits. There are, however, several patterns and trends in the data that indicates the process may be out of control. Engineers will investigate the special cause variation to eliminate quality issues and bring the system back within control. In some cases, the process control may have improved, and the statistical process control chart variables need to be recalculated to reflect tighter quality bands. Some of these out-of-ordinary run or trend situations include the following (Speegle, 2010):

- Nine (9) points in a row on one side of the centerline,
- Six (6) points in a row steadily increasing or decreasing,
- Fourteen (14) points in a row alternating up and down,
- Two of three (2 of 3) points outside the 2σ limits on one side of the centerline,
- Four of five (4 of 5) points outside the 1σ limit on one side of the centerline,
- Fifteen (15) points in a row inside of the 1σ limit, or
- Eight (8) points in a row on both sides of the central line with no points within the 1σ limit.

6.2.4 Cost of Quality

Delivering quality products, services, and processes is not free; however, failing to deliver quality to customers is very expensive. During project planning and development, engineers must account for the **Cost of Quality** (CoQ). Maintaining and improving quality is an ongoing operational expense and spans R&D, production, marketing, and sales.

There are two primary elements that make up the CoQ: the cost of conformance and the cost of nonconformance. The CoQ is lowest and remediation efforts have the most impact when the organization avoids errors and rework. The CoQ is highest for external failures, including rework and repairs after a product has reached the customer.

Cost of conformance is associated with quality programs to avoid or detect failures. In the first case, quality is designed and built into systems, processes, and procedures. These prevention costs include training, standard operating procedures, documentation, properly sized and maintained equipment, and allowing staff time to perform tasks and activities accurately. Appraisal costs are also categorized as a cost of conformance. In assessing quality, inspectors will test a sample of finished products. Some of these evaluations include losses due to destructive testing, which has a cost associated with producing the part and then the added cost to analyze it after-the-fact for quality control. Inspection is also a cost of quality aligned with conformance.

The **cost of nonconformance** is typically greater than the cost of conformance but is also more visible and traceable to specific failure events. The cost of nonconformance is split between internal and external failure costs. Internal failure costs are associated with rework and scrap. For example, inspection may reveal a batch or run of defective parts or materials. If possible, the organization will reprocess the parts and materials to salvage the raw material investment, but in many cases, failures lead to scrap. In the worst-case scenarios, scrapped parts and materials also incur storage and environmental disposal fees.

External failures are a cost of quality associated with completed parts, materials, or equipment that has already been delivered to a customer. Not only are the financial costs high for external failures, the reputational and marketing impacts can also be very expensive for an organization. External failure costs include warranty work, liability payments, and potential lost business.

6.2.4.1 Sampling

It is typically undesirable and impractical to inspect each and every product from an assembly line or production run. **Sampling** is a quality control tool that allows engineers a way to inspect and test product quality that is both feasible and representative of the entire production run. Organizations seek to minimize the number of samples collected and analyzed due to the cost associated with gathering and analyzing such samples. On the other hand, an adequate number of samples must be tested to assure quality standards are met.

A **sampling plan** establishes guidelines for obtaining samples as well as decision criteria to release a production lot to customers. Often, if the representative or random sample passes the QC criteria, then the entire lot is accepted. Such acceptance sampling is a statistical method since any random part selected for inspection has an equal chance of being selected and inspected. If the sample has an unacceptable number of defects, then the lot will be rejected.

In a *single-sample attribute plan* a single representative sample is evaluated with a discrete decision: defective or not defective. The following factors and variables are necessary for a single-sample attribute plan:

- N = lot size,
- n = sample size,
- c = acceptable number of defective items in the sample, and
- d = actual number of defective items in the sample.

Each of the n items is selected randomly from the lot and inspected. If the sample has $d \leq c$ defective items, then the whole lot will be accepted. If, however $d > c$, the entire lot is rejected.

Engineering management must specify the levels of *c* and *d* since an organization would not want to unnecessarily reject good products or to pass on defective products to customers. The **acceptable quality level** (AQL) is thus a negotiated quality level that creates high customer satisfaction at the lowest cost for the organization.

The **producer's risk** is described by α and is the probability of committing a Type I error. In statistics, a Type I error represents a *false positive*, meaning that a failure was detected when there was no defect present. Type I errors in a statistical process control system result in common cause variation being treated as a special cause variation, thus resulting in wasted resources. Many organizations use α=0.05, setting the producer's risk of a false positive at the 5% level.

The consumer's risk, or β, represents a Type II error, meaning that a production lot was inadvertently accepted when the number of defective items exceeded the AQL. A Type II error is considered a false negative and mistakenly evaluates special cause process variation as a common cause variation. Because external failure costs are the most expensive CoQ, Type II errors neglect the need to investigate changes in the stability of the process using SPC. In many organizations, β=0.10, so that the consumer's risk is set at the 10% level.

In *double-sampling* and *multiple-sampling plans*, the sample size is typically smaller than in a single-simple plan; therefore, the cost is also less. A double-sampling plan uses a small sample size and if the quality is very high, the lot is accepted. Likewise, if the quality is very poor, the lot is rejected. If the sample is not conclusive regarding a decision to accept or to reject, then a second sample (of small size) is collected. The lot is either accepted or rejected based on the combined results of the two samples. Because the double-sampling plan uses a decision metric for very good production lots or very bad ones, a smaller, less costly sample normally suffices. The primary benefit of this method is to avoid a large, expensive sample.

A multiple-sampling plan, or *sequential sampling plan*, typically utilizes the smallest sample size and hence can be the most cost-effective method. The steps in a multi-sampling plan are similar to those of the double-sampling plan in which a small sample is pulled initially. This sample may be as small as a single production unit. If the defectives in the sample are less than a prespecified lower limit, the lot is accepted. If the defectives are greater than a specified upper limit, the lot is rejected. If the sample value falls between the lower and upper limits, a second sample is collected and analyzed. The cumulative defects are compared with an adjusted lower and upper limit, accepting or rejecting the entire lot. If the second sample also proves inconclusive, then the procedure repeats collecting a third and subsequent samples as necessary.

A variation of the sampling plan is to collect only two samples—one at the beginning of the production run and one at the end of the batch. If both samples pass the required quality control tests, then the entire lot is accepted. The goal of sampling is to balance quality and economics in a structured trade-off. When collecting the sample is very expensive or when the product involves life-safety features, it may be more cost-effective for the organization to collect larger samples in a single-sampling plan. If the cost of sample collection is low compared to inspection and evaluation costs, double- or multiple-sampling plans may be more reasonable for the organization. Destructive testing, for example, can involve significant cost since both raw materials in production costs are sacrificed.

6.2.5 Quality Tools

Three additional tools help engineering managers assess product and process quality to identify continuous improvement opportunities. Failure mode and effects analysis (FMEA) tries to identify and prioritize all possible failure modes according to risk. Design of experiments (DOE) is a sophisticated method of testing processes to optimize operational results. Quality function deployment (QFD) is a tool that matches customer needs to product design specifications.

6.2.5.1 FMEA

Failure mode and effects analysis (FMEA) is considered an analytical quality tool and is used to identify potential product issues. FMEA prioritizes potential failures according to risk and drives the organization to reduce or eliminate the probability of these risks to occur. "*Failure modes*" are used to identify all possible types of failures before they occur in the product or process. The potential consequences of these failures are studied as the "*effects analysis.*" Severity of the risk consequence may be ranked according to (Goetch & Davis, 2016) the following:

- Severity of the failure from the customer's viewpoint (S)
- Probability or likelihood of occurrence (O)
- Probability of detecting the failure internally (D)

Each of the risk assessment factors is assigned a score ranging from one (1) to ten (10), with ten (10) representing maximum severity, certainty of occurrence, and impossible to detect. An overall *risk priority number* (RPN) is calculated by multiplying the FMEA factors (RPN=S x O x D). Thus, an RPN score of one (1) means there is virtually no risk while a score of 1000 indicates an immediate and extreme risk.

Management will work with the quality engineering teams to determine a cutoff score for the RPN. Product or process redesign is often required to reduce the RPN by changing parameters to reduce severity of impact, probability of occurrence, and or probability of detection.

FMEA can be used to build quality into a process during the design or redesign of the process; when improvements are initiated for a product, service, or process; in situations that deploy existing technologies to new applications; in incident investigations; or when health, safety, and the environment are critical elements. Once a team understands the basic mechanisms of assessing S, 0, and D scores, FMEA is an easy-to-apply quality tool spurring important organizational quality discussions and decisions.

6.2.5.2 Design of Experiments (DOE)

Traditional experiments vary one factor while holding all others constant. In evaluating even the simplest processes, this type of experimentation can lead to hundreds of experimental runs. **Design of experiments** (DOE) is a modern, sophisticated approach to optimizing processes with targeted experimentation. Using DOE instead of a traditional approach to experimentation can reduce the number of individual runs by an order of magnitude (e.g., tens instead of hundreds).

Rather than adjusting just one variable at a time, DOE shortens experimentation procedures by simultaneously testing multiple factors in each experimental run. This type of experimentation also reveals interactions among factors. Moreover, DOE can be used to determine the impact of testing on the cost of quality and relationships among variables. Results of DOE testing also illustrate which factors are most critical—and which ones are not—so that a quality engineer can establish control charts for the system.

DOE is a seven-step process (Vaidyanathan, 2013).

1. Understand the process inputs and outputs.
2. Quantitatively measure responses.
3. Develop a *factor matrix*.
4. Define levels for each factor (e.g., high, medium, and low).
5. Complete the *random* test runs.
6. Calculate the overall effects for each factor.
7. Confirm and verify results.

Traditional sampling of three factors would lead to nine tests. For example, testing the battery life of a cell phone with three different batteries (A, B, C) would require testing individual battery life on three different devices (I, II, III) while holding all other variables constant. This results in the factor matrix in Table 6-5.

Table 6-5. Factor Matrix for Traditional Sampling

A	B	C
--	--	--
--	--	--
--	--	--

However, using randomization of testing, DOE yields a factor matrix that allows simultaneous experimentation of the battery and device, along with another factor of storage capability (1, 2, 3) as in Table 6-6.

Table 6-6. Factor Matrix for DOE Sampling

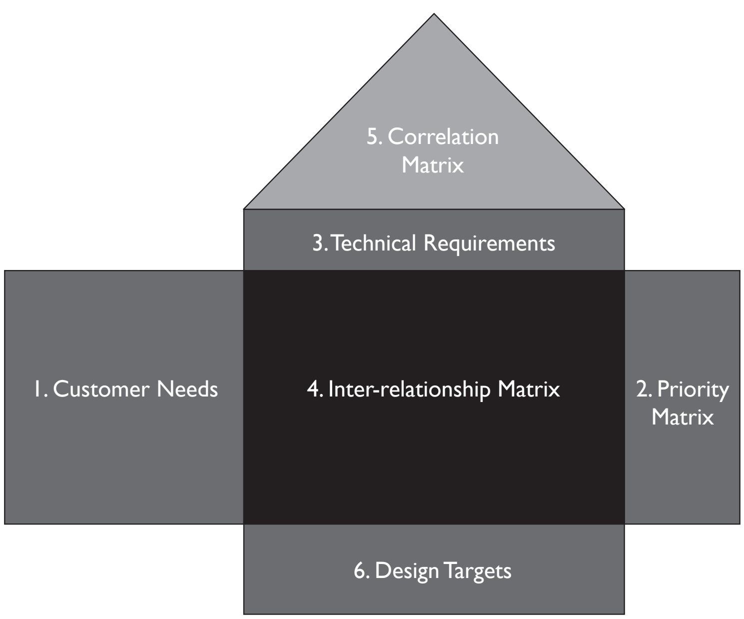
	I	II	III
1	C	A	B
2	B	C	A
3	A	B	C

This testing design assumes there are no interactions among the variables (battery life, device, and storage capacity) so that the number of experimental runs is minimized while collecting data that yields the best optimization for the cell phone design. A statistical analysis of the test runs will validate the assumption of no interactions among factors.

6.2.5.3 Quality Function Deployment (QFD)

The ultimate definition of quality is for products and services to meet customer expectations and to deliver customer satisfaction. Engineers ensure quality by translating the **voice of customer** into product design specifications. **Quality function deployment** (QFD) is a formal methodology that translates customer needs and wants into design objectives. The main artifact of QFD is the **House of Quality** (HOQ) as shown in Figure 6-7.

Figure 6-7. House of Quality (HOQ)



Customer requirements are collected, categorized, and ranked for priority in Section 1 (Customer Needs) of the HOQ. Customers will rank the importance of each characteristic so that the most critical product attributes are noted from the voice of the customer.

Next, the quality, marketing, and engineering design teams conduct a *competitive assessment* as in Section 2 of the HOQ (Priority Matrix). Here, the organization's current product offering is compared to competitor offerings and each customer requirement is ranked. When the organization's product or service offering scores high in the competitive assessment, there is no further need to improve those product attributes. However, for customer requirements in which the organization scores low compared to competitors, especially for highly-ranked requirements, there is significant opportunity for improvement.

At this point in the process, the team has only identified "what" is important to customers. It is the job of the engineering design team to translate the "whats" into "hows." These design characteristics are documented in Section 3 of the HOQ (Technical Requirements). Each customer requirement and each design characteristic are then evaluated for interaction. Interactions are rated as strongly positive, positive, neutral, negative, or strongly negative. A symbol for each interaction is entered into Section 4 of the HOQ, called the Inter-relationship Matrix.

However, some design characteristics may influence one another. For example, pressure and temperature interact in petrochemical processes and cannot be treated as independent variables. These relationships among design characteristics are documented in the "roof" of the HOQ (Section 5, Correlation Matrix). Again, symbols are commonly used to indicate the strength of the relationship (strongly positive, positive, neutral, negative, or strongly negative). Section 5 of the HOQ is also known as the "trade-off" matrix.

Finally, the target values for each design characteristic are noted in Section 6 of the HOQ (Design Targets). At this point, development cost and profit potential are also considered in the design targets. The estimated impact or benefit to the customer for each design characteristic improvement is compared to the cost and the list of target values is prioritized. The product design team may select only a few of these design elements to change in order to balance the needs of the customer while providing an improved, cost-effective product design.

At first, QFD appears to be a complicated analysis. However, QFD is a valuable tool to combine a quality strategy with value engineering. It is also an important communication device, drawing on cross-functional team member participation to balance customer needs with product design specifications.

Review

Upon completing the study of Domain 6: Quality Management System, you should be able to answer the following questions:

1. What are the common themes among the philosophies of Deming, Juran, Crosby, and Ishikawa?
2. Describe the seven management and planning tools and provide an example of where you could implement each tool in your organization.
3. Discuss how quality standards improve processes and products.
4. List some of the elements of Quality Management System Principles.
5. What is a normal distribution?
6. Explain Statistical Process Control and Process Capability.
7. How can FMEA be used for improving quality of a product?
8. What are the 7 steps to conduct a DOE?
9. How can QFD help design better products?

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7

Operations and Supply Chain Management

Domain 7 Champions

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Domain 7: Operations and Supply Chain Management

Key Words and Concepts

Supply Chains	A supply chain is made up of all the players in business activities related to a product or service, such as the customers, the manufacturer (or service provider), and the suppliers, along with information and product flows between the players.
Bullwhip Effect	The bullwhip effect is said to occur in a supply chain when product orders get inflated due to lack of information exchange across the different layers of a supply chain.
Interaction Matrix	The matrix that measures the number of trips between a given pair of departments/offices/machines in a layout.
Value-Added	Activities or tasks that convert a product or service to add worth from the customer's perspective.
Core Competencies	Tasks that an organization is better at performing than any of its competitors.

7.1 Process Improvement

Customers continually want more reliable, durable products and services in a timely manner. In order to remain competitive, all organizations must become more responsive to customers and operate at industry benchmarked standards. A process is a step or a series of steps that uses inputs and produces a product or service as an output. Table 7-1 provides brief descriptions of several key process metrics.

Table 7-1. Process Metrics

Cycle Time	Average time for a particular step to complete one item
Setup Time	Time required to convert from producing the last good product of A to the first good product of B
Takt Time	Rate of customer demand
Throughput	Number of items output from a process in a given period of time
Touch Time	Time the material is actually being processed
Value-Added Time	Time used for activities for which a customer is willing to pay
Work In Progress (WIP)	Material in the process at various stages
Work In Queue (WIQ)	Material waiting to be processed; part of WIP, used to identify bottlenecks

7.1.1 Knowledge of Process Improvement

Lean Manufacturing and Six Sigma are both powerful tools for improving quality, productivity, profitability, and market competitiveness. Six Sigma is focused on reducing variation using a problem-solving approach and statistical tools. It is a customer-focused continuous-improvement strategy and discipline that minimizes defects and variation.

Lean focuses on eliminating waste and improving flow using various Lean principles and their respective approaches. It focuses on the customer by addressing what is value-added and what is non-value-added. It results in reduction in throughput time and elimination of all non-value-added activities.

A comparison of Lean and Six Sigma is given in Table 7-2. By combining Lean and Six Sigma, a system can be implemented to reap optimal benefits.

Table 7-2. Lean vs. Six Sigma

	Lean	Six Sigma
Goal	Create flow Eliminate waste	Reduce variation Improve process capability
Business Scope	Project-oriented Operations level	Strategic
Culture	Operations level (at minimum)	Corporate culture
Application	Mainly manufacturing processes	All business processes
Approach	Lean technique-specific Basic principles and best practices	Generic problem-solving approach using statistics
Project Selection	Driven by value stream mapping	Various approaches
Length of Projects	Short-term focus	Long-term cyclical improvement
Infrastructure	Ad-hoc – kaizen-based	Dedicated resources
Tools	Value stream mapping, Single Minute Exchange of Dies (SMED), Poka-Yoke (mistake proofing)	Pareto Chart, SIPOC, Gage R&R, Process Capability, Design of Experiments (DOE), Root Cause Analysis (RCA), Control Charts

7.1.2 Six Sigma

Six Sigma is a customer-focused, continuous-improvement strategy and discipline that minimizes defects and variation with a goal of 3.4 or less defects per million opportunities in product design, production, and service-delivery processes. It is a methodology, culture, and a metric. Six Sigma is focused on reducing process variation using problem-solving and statistical tools, with standard deviation as the key metric of variation. Six Sigma methods were first introduced by the Motorola Company and deployed by Jack Welch while he was the CEO of General Electric. The key goals of Six Sigma aim to accomplish the following:

- Develop a world-class culture.
- Develop leaders.
- Support long-range objectives.

The benefits of implementing a Six Sigma program include the following:

- Stronger knowledge of products and processes
- Reduced variation and defects
- Increased customer satisfaction—generates business growth and improves profitability
- Increased communication and teamwork
- Common set of tools

Within Six Sigma, there are several key roles, including Master Black Belt, Black Belt, Green Belt, Champion, and extended team members. All of these roles involve being a catalyst for change throughout the organization. A Master Black Belt drives major projects, trains and mentors Black Belts, and works with champions to select projects. There is typically one Master Black Belt per business unit or site (1 per 1,000 employees). A Black Belt leads major projects; mentors, consults, and trains Green Belts; promotes out-of-the-box and critical thinking; and challenges the old ways of doing business. In an organization, Black Belts are approximately 1-2% of the population (10-20 per 1,000 employees). A Green Belt uses the fundamental Six Sigma tools and uses only the specific tools that relate to his or her project. A Champion provides top-down commitment to the Six Sigma goals, works with the Master Black Belt to select and monitor projects, and delivers support. A Black Belt also guides the Green Belts in the use of advanced statistical tools, such as DOE.

The Six Sigma methodology is based around the five-phase methodology of Define-Measure-Analyze-Improve-Control (DMAIC). Figure 7-1 displays the overall structure of the Six Sigma methodology.

Figure 7-1. Six Sigma Methodology

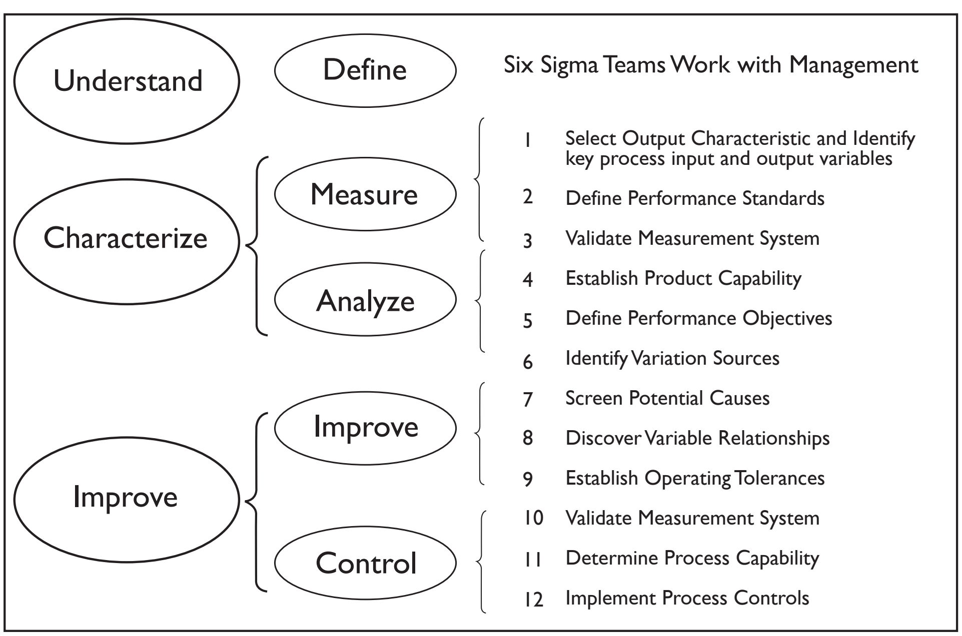

Table 7-3 addresses the key questions in each phase of the DMAIC methodology.

Table 7-3. DMAIC Phases

DEFINE PHASE
- What processes are involved?
- Who is the process owner?
- Who are the team members?
- Which processes are the highest priority to improve?
- What data supports the decision? (Metric)
- How is the process performed?
- How is the process performance measured?

MEASURE PHASE
- What are the customer-driven specifications for the performance measures?
- What are the improvement goals?
- What are the sources of variation in the process?
- Is your measurement system accurate and precise?
- What sources of variability are controlled and how?

ANALYZE PHASE
- What are the key variables affecting the average and variation of the performance measures?
- What are the relationships between the key variables and the process output?
- Is there interaction between any of the key variables?

IMPROVE PHASE
- What are the key variable settings that optimize the performance measures?
- At the optimal setting for the key variables, what variability is in the performance measure?

CONTROL PHASE
- How much improvement has the process shown?
- How much time and/or money was saved?
- How will you sustain the gains achieved by developing control systems?

7.1.3 Lean

Lean is a broad term that encompasses many different techniques. The term refers to more than just a set of techniques; it is a philosophy or attitude that promotes continual efforts to reduce and ideally eliminate waste in an organization. The primary focus of Lean is on the customer, to address value-added and non-value-added tasks (Womack & Jones, 2003). Value-added tasks are the only operations for which the customer is ready to pay. *Lean production* is the popular name of the Toyota Production System (TPS). The TPS is based on the writings of Henry Ford and was further developed by Toyota following World War II. Lean emphasizes eliminating waste and creating flow within an enterprise. Ideally, this is *single-piece flow*, or *one-piece flow*, which is when a product moves through the steps of the process with no interruptions or waiting between steps (Mann, 2015). The idea in creating flow in Lean is to deliver products and services just-in-time, in the right amounts, and at the right quality levels at the right place. This necessitates that products and services are produced and delivered only when a pull is exerted by the customer through a signal in the form of a purchase (Womack, Jones, & Roos, 2007). A well-designed Lean system allows for an immediate and effective response to fluctuating customer demands and requirements.

Lean strives for constant, continuous improvement. The improvement activities are usually accomplished through Kaizen events which are of varying duration from one day to one week during which a team focuses all its efforts in applying Lean tools to improve the process. In Japanese, Kaizen means "change for the better."

7.1.4 Lean Tools

The Lean tools that are most commonly used to eliminate waste and achieve flow are value stream mapping, Single Minute Exchange of Dies (SMED), one-piece flow, Kanban, 5S housekeeping, visual management, cellular manufacturing, heijunka, poke-yoke, and standard work.

7.1.4.1 Value Stream Mapping

Value stream mapping is the first building block to determine the current state of the process. The purpose of value stream mapping is to understand the big picture. The current value stream consists of all activities, including value-added and non-value-added (Rother & Shook, 2003) in the process. Value stream mapping must be conducted first to provide an effective blueprint for implementing an improvement strategy. The current value stream map shows the inventory between each process in terms of cycle time for the process. Lean manufacturing focuses on TAKT time, which is the rate of customer demand. The TAKT time calculation is given in the equation:

$$\text{TAKT Time} = \frac{\text{available working time per shift}}{\text{customer demand rate per shift}}$$

While the current value stream map helps identify the areas of opportunity to eliminate waste, the future state value stream map shows the ideal value stream when all waste has been eliminated.

7.1.4.2 Single Minute Exchange of Dies (SMED)

Single Minute Exchange of Dies (*SMED*) is a system of setup reduction and quick changeovers. The method is used to efficiently respond to fluctuations in product demand. SMED reduces downtime by improving the setup and changeover process. In SMED, the objective is to convert internal setup activities to external setup activities. Internal activities are defined as those that are done when the machine is stopped for changeover. External setup activities, on the other hand, are those that can be done while the machine is running. SMED also enables the implementation of a one-piece flow and shorter lead times.

7.1.4.3 One-Piece Flow

One-piece flow is a Lean tool based on producing one unit at a time and passing on to the next process. One-piece flow focuses on eliminating wait time, transportation, and inventory. Implementing one-piece flow also improves and creates flow. Other advantages of one-piece flow include reducing lead times of production, identification of defects earlier in production processes, flexibility, and reduced material and inventory costs. Handling time is substantially reduced in one-piece flow systems.

7.1.4.4 Kanban

Kanban is a Japanese term meaning “signboard” and is a production signaling tool that aids the use of single-piece flow or small lot sizes. It reduces the dependence of a manufacturing system on production estimates. It is generally an indicator, often physical, that a particular workstation in a production line needs a component from a workstation upstream. Since this technique allows each station to produce only what is required by the station immediately downstream, it makes single-piece flow practical by reducing or eliminating inventory on the line and preventing line overproduction.

7.1.4.5 5S Housekeeping

5S Housekeeping is a Lean tool that focuses on effective workplace organization and standardized work procedures through eliminating waste. The 5S terms are derived from the Japanese terms *seiri, seiton, seiso, seiketsu,* and *shitsuke*. The English language terms are *sort, straighten, sweep, standardize,* and *sustain*. The benefits of implementing 5S include elimination of unnecessary steps, reduced waste, improved efficiency, improved safety, and a cleaner work environment.

7.1.4.6 Visual Management

Visual Management, also known as Visual Factory, visualizes a shop floor in an attempt to make the shop an orderly environment in which the disorderly stands out and can thus be addressed. This technique effectively makes every employee a workplace inspector and decreases the chance of mistakes, defects, and lost employee labor hours associated with a chaotic workplace. Display charts are used to communicate in a clear visual way.

7.1.4.7 Cellular Manufacturing

Cellular Manufacturing is a tool to organize departments around a product or a family of products with similar processing sequence. Typical cell configuration in cellular manufacturing is u-shaped. Cellular manufacturing aligns processes and equipment in sequence. Benefits include faster production cycles, reduced inventory, and improved product quality.

7.1.4.8 Heijunka

Heijunka, or production leveling, matches the production schedule to the demand of the customer. In other words, products are manufactured in the leveled order—that is, in the order in which they are required. For example, if a customer requires six red widgets and two blue widgets, a leveled order might be Red-Red-Blue-Red-Red-Blue-Red-Red. This technique allows supplier and customer who use only a certain type of product to function continuously with smaller inventories. This is generally implemented after the use of the SMED tool has reduced setup change times.

7.1.4.9 Poka-Yoke

Poka-yoke is the Japanese term for "mistake-proofing." These are devices, such as a keyed connector, that physically or procedurally do not allow mistakes to happen. It is a structured approach to ensuring quality throughout a process. The focus is eliminating the root cause(s) of defects to product high-quality products and service.

7.1.4.10 Standard Work

Standard Work is a Lean tool that defines and documents the interaction between people and their environment. It provides a routine for consistency of an operation and a basis for improvement by detailing the motion of the operator and the sequence of action. Standard work consists of three elements: TAKT time, standard work sequence, and standard work in process. The current process is documented to provide a basis, or standard, and continuous improvement. After improvements, standard work should be revised to incorporate the improvements. Used as a tool, standard work establishes a routine for repetitive tasks, makes managing resource allocation and scheduling easier, establishes a relationship between the person and the environment, provides a basis for improvement by defining the normal process and highlighting areas for improvement, and prohibits backsliding. Standard work creates a clear standard operation for completing a process. Any deviation from standard work indicates an abnormality. In turn, abnormalities indicate an opportunity for improvement.

7.2 Operations Management

Operations management is the science underlying operating efficient and effective systems. Examples of such systems include assembly plants, such as an automotive factory; processing plants, such as chemical plants and refineries; retail stores; hospitals; airports; airlines; and courier delivery services, etc. An operations manager is one who is "a realistic, make-it-work, get-it-done person" (Russell & Taylor, 2013). The science of operations management covers a broad spectrum of areas that include the following:

- Operations strategy
- Product development
- Forecasting demand

- Facilities management
- Supply chains and inventory management
- Scheduling
- Project management
- Human resources development
- Quality management

Techniques and tools used in operations management belong to a field called *Operations Research* (*OR*).

7.2.1 Operations Strategy

Customer-satisfaction measurement, analysis, and implementation is so critical that ISO 9000 standards and management-model best practices (for example, the Malcolm Baldridge Award, EFQM, and others) now require companies to assess customer satisfaction. Fortunately, companies are left to determine on their own the assessment process. Figure 7-4 (Allen, 2004, used by permission) details customer loyalty and response to company-initiated change. Working from the concepts of branding and brand loyalty, companies can predict customer behaviors by focusing on satisfaction with relationships and transactions.

Developing an operations strategy is perhaps the most important function of a manager. It involves formulating a long-term strategic plan that can help the firm to grow and be competitive. Developing a strategic plan involves numerous tasks, some of which are enumerated:

- *Developing a mission*: Every business has a mission, such as an area of business in which it operates or a market it serves. This has to be defined and redefined if necessary on a regular basis for the firm to remain competitive. The mission is an integral part of the so-called "business model" of a company. In general, the mission tends to have a broad scope—for example, The mission of a company is to produce gears used in automobiles.
- *Identifying core competencies*: These are operations that an organization is better at performing than any of its competitors. Excellent after-sales service, producing products of the highest quality, and delivering on time are examples of core competencies. Products and technologies are usually not regarded as core competencies since their advantages are often short-lived and cannot sustain themselves over a long period of time. Usually, core competencies tend to be processes.
- *Recognizing measures of competitiveness*: These are product features that allow the product to be competitive in the market. Examples are cost, quality, innovative design, and so forth. These are usually the features that compel a customer to choose that product in the market.

7.2.2 Product Development

Every organization needs to design and re-design its products and services to satisfy its customer base.

This requires innovative designers who can ensure that the firm retains its competitive edge in the market. Part of product development is also related to the speed with which a new product is introduced into the market. Some important features of product development include the following:

- *Product design*: Selection of material, tolerances, and customer specifications
- *Feasibility studies*: Studies and surveys conducted, usually by marketing managers, to identify the need for a product in the market
- *Quality Function Deployment* (*QFD*): Using customer requirements in designing and re-designing the product

7.2.3 Forecasting

Forecasting is the science of predicting demand for the product produced by a firm or the service provided over a given time horizon. Forecasting is essential for making decisions regarding the following:

- Machine capacity
- Raw material ordering
- Hiring personnel

Forecasting involves collecting historical sales data for the products sold by the organization and then making a prediction for the sales over the next quarter or year (or the time horizon specified). Some commonly used methods for forecasting follow:

- Regression
- Exponential Smoothing
- Time-series (Box-Jenkins) methods
- Delphi Method

Forecasting methods are usually required to take into account factors such as seasonality, condition of the economy, and other product-specific features, such as the current age of the product in its life cycle. Forecasting invariably involves errors, and the challenge is to develop a forecast with minimal error. It is not uncommon to combine forecasts from different methods to generate a more reliable estimate. Clearly, an incorrect forecast can lead to numerous problems; a forecast that overestimates demand increases risk of overproduction while one that underestimates leads to potential loss of revenue. As production systems move from push to pull, the impact of forecasting error on risks of overproduction is becoming less pronounced. Nonetheless, accurate forecasting remains to this day a critical function of the operations manager.

7.2.4 Scheduling

Scheduling of jobs on machines is an important task that is typically assigned to the production planner (Askin & Goldberg, 2002). Essentially, scheduling means determining the sequence in which products are processed on the machines in a shop. Scheduling rules tend to depend on whether the shop is a flow shop or a job shop. In a flow shop, every job has the same routing while in a job shop, that is not the case. In general, in a job shop, most jobs tend to have their own routings. As such, in a flow shop, one can use the same sequence for each machine. In a job shop, scheduling is more complicated. Most scheduling rules tend to minimize measures such as the total tardiness of jobs, the total amount of inventory in the system, or the completion time of the last job in the system. We will discuss some of these measures now.

Lateness of a job is computed as follows. One assumes that time starts at 0 in the time horizon. Then, lateness of the i-th job is given by

$$L(i)=C(i)-D(i),$$

where $C(i)$ denotes the completion time of the i-th job and $D(i)$ denotes the due date of the i-th job. (The due date is converted into the amount of time permitted for the job in the system.) Another metric that is related is the so-called tardiness of the job:

$$T(i)=\max[0,C(i)-D(i)].$$

Thus, if a job is completed before its due date, its lateness is negative and its tardiness is 0. Therefore, it is useful in many companies, especially those that work on make to order (MTO), to develop a schedule that minimizes the total tardiness of all jobs that need to be scheduled. A number of rules, such as EDD (Earliest Due Date First), can be used to heuristically minimize the total amount of tardiness in job shops. In EDD, jobs are arranged in the ascending order of their due dates. The sequence that results is used as a schedule in the flow shop.

In make to stock (MTS) systems, it is often common to use the SPT (Shortest Processing Time) first rule. In SPT, the job that has the shortest processing time is given the highest priority. Jobs are arranged in the ascending order of the sum of their processing times on all machines. It can be shown that a rule like SPT can reduce the total amount of inventory in the system. A number of other metrics are used in scheduling:

- Weighted tardiness
- Number of tardy jobs
- Weighted flow time

In "weighted" criteria, one uses a different weight—that is, a measure of importance—for each job in computing the metric. These weights can be calculated on the basis of the revenue generated by the job, how loyal the customer is, and so forth. Some of the rules other than SPT and EDD that are also popular are WSPT (weighted SPT), WEDD (weighted EDD), and AU (Apparent Urgency) (Askin & Goldberg, 2002).

Another important criterion in flow shops is the makespan, which is the time between the start of production and the completion of the last job in the schedule on its last machine. For two-machine flow shops, the celebrated Johnson's rule provides an optimal schedule to minimize the makespan. For n-machine flow shops, the P-heuristic has been widely used in the literature.

In job shops, one also seeks to minimize the makespan or some variant of the makespan. However, in job shops, computing the makespan requires drawing a Gantt chart. Every scheduling rule leads to a unique Gantt chart. Because of the complexity of the problem, this has generated voluminous theoretical literature. In the industry, however, one typically finds that simple dispatching rules are commonly used. These rules determine the priority of a job at any given time depending on which jobs are currently available to be scheduled on a given machine. Thus, when jobs are available at a machine for scheduling, one uses dispatching rules to generate priorities. The job with the highest priority starts production, and this process repeats when the machine becomes free again. Some popular dispatching rules are based on the following:

- SPT
- LWR (Least Work Remaining)
- FCFS (First Come, First Served)
- FISFS (First in Shop, First Served)
- EDD
- SLK (Select job with Least Slack)

Scheduling in continuous manufacturing plants like refineries or chemical plants are focused on running the process for extended periods of time, with intensive downtime periods for scheduled maintenance and/or upgrades. While these are continuous processes, there are often blends or grades of products that must be forecasted and scheduled in the production plan.

7.3 Inventory Management and Supply Chains

Inventory management and supply chain management have significant overlap. In most industries, the supply-chain manager is also responsible for inventory management within the firm. Hence, we discuss these topics within the same section.

7.3.1 Inventory Management

We begin with a definition of inventory. Inventory can be found to belong to five different classes:

- Raw-materials inventory
- Work-In-Process (or progress) (WIP) inventory
- Finished-goods inventory
- Transit inventory (inventory that is in transit between a location outside the factory and the factory)
- Consignment Inventory (unsold inventory stored at customers location)

The cost of carrying all of this inventory can be significant and is called Working Capital. For many companies this can tie-up a significant amount of cash that could be used for other purposes, like capital investment. Costs include the cost of the inventory itself, the facilities to store it, and taxes. Excess inventory can be considered a waste, so companies try to optimize the amount of inventory they hold to assure customer service levels while minimizing working capital.

Storing excessive amounts of finished-goods inventory is also risky, because inventory can get obsolete in a rapidly changing market and might never sell if that happens. The materials manager is usually responsible for making sure that raw materials are available for production when an order arrives and that the finished goods reach the customer on time.

An important task in inventory management is to track inventory so that orders can be placed at the right time and customer deadlines are met. MRP (Materials Requirement Planning) systems, usually computerized, can be of great help in all of these tasks if they are used properly. The inventory manager not only seeks to minimize the total inventory cost but also to increase the probability of on-time delivery and a minimization of the overall lead time.

Some key concepts in ordering raw material follow:

- Continuous and periodic review
- Newsboy models
- EOQ (Economic Order Quantities)
- Quantity discounts

In continuous review, the inventory situation is continually monitored, and as soon as the inventory of a raw material falls below a pre-specified threshold, an order is placed for it. In periodic review, the inventory is monitored on a periodic basis, such as after one week or a month, and orders are placed as needed. The EOQ model is a popular model from the 1900s that is used to determine the exact amount to be ordered and is based on balancing inventory and inventory carrying costs. The newsboy model is another model for determining order quantities. The EOQ and the newsboy models or some of their variants are still widely used in the industry for determining order quantities.

Another important aspect related to inventory management is the use of a pull or push system. There are significant differences in these two systems.

- **Pull**: In such a system, a customer order(s) drives the system. In other words, one does not initiate production of a job until an order is placed for it.
- **Push**: In such a system, jobs are produced according to the forecast and master production schedule, based on the assumption that whatever is produced will eventually be sold.

In many industries, hybrid systems that combine aspects of push and pull are used. For some products, it may be more attractive to use pull, but for some products that have a more reliable demand, it may be easier to use push. Push systems are also called make-to-stock (MTS) while pull systems are also called make-to-order (MTO).

Pull systems are also closely related to JIT (Just-in-Time) systems. The philosophy of JIT is to start producing a job after the order is received in the minimum possible time (lead time) without increasing the number of resources needed beyond what is affordable. JIT systems also use Kanbans (or cards) to regulate the amount of inventory in the system.

7.3.2 Supply Chains

Any manufacturing enterprise involves suppliers (vendors), manufacturers, and customers. Likewise, a service enterprise involves the service provider and the customers. A supply chain is made up of all of these entities and players, as well as the flow of products and services, along with the associated information flows. Clearly, product or service flows are associated with the transportation networks and logistics. Information flows are associated with the communication that occurs across the different players in the supply chain: the orders placed by the customers, the orders placed to the suppliers, inventory information at the different stages in a supply chain, point-of-sale data, and so forth. Information of this nature has to be exchanged in a supply chain for it to be effective.

Often, one speaks of the supply chain of a product or service. This involves the supply chain for that specific product or service. Supply chain management focuses on the management of goods, services, and information to synchronize the operations of all its players such that the overall costs of running the system are lowered (Russell & Taylor, 2013). Thus, overall supply-chain managers supervise the business processes and activities associated with all the players.

7.3.2.1 Information Flows

Information flows across the different levels of a supply chain are usually facilitated through electronic transfer of data and documents. Modern computer technologies can be used effectively to ensure that information can be transmitted smoothly and immediately across the different layers of a supply chain. Locating the sales and movement of every item in a supply chain is critical to the retail industry. E-business, electronic data interchange (computer-to-computer exchange of data via connected databases), e-procurement or e-purchase, the Internet, and bar codes (that generate point-of-sale data) are important features of supply chains. These features are called enablers because without them, it is unclear if supply chains could be managed as effectively as has been achieved in the last decade. The *bullwhip effect* is an undesirable supply chain phenomenon that occurs when information is not exchanged properly. Small fluctuations in demand at the point of sale cause progressively larger fluctuations in demand throughout the supply chain (wholesaler, distributor, manufacturer, suppliers) because each player exaggerates his or her demand based on past experience of a shortage or fear of shortage of inventory. The bullwhip effect can make the chain unstable, leading to excess inventory at the various levels in the chain. Optimal information exchange can minimize occurrences of the bullwhip effect.

7.3.2.2 Distribution Network Design

The distribution network that transports goods between suppliers, warehouses, distribution centers, manufacturing plants, and customers is made up of the infrastructure provided by rail, road (trucking), air, water, and pipelines (oil transport). Maintaining a strong infrastructure of rail and roads is usually a task undertaken by the government. Sustaining it is important for the success of all supply chains. Water transport on oceans is a cheap model of transport that is also relatively slow. It is often the only mechanism to transport material internationally when the countries have a separating ocean(s).

7.3.2.3 Supplier Selection

Selecting the right supplier is a critical component of an effective supply-chain-management strategy. Suppliers that are located nearby may produce less risk in terms of delivery time but may be more expensive. On the other hand, suppliers who are very distant might be cheaper, but getting the product on time from them may be riskier. Quality is also an important issue that is not related to distance between suppliers and buyers.

7.3.2.4 Global Supply Chain

Lifting of barriers on international trade in recent years has allowed the entire globe to become a market place—that is, there are suppliers and customers all over the world. Hence, a firm in one part of the world can place orders to a firm in another part. As a result, we now have global supply chains for many products. Of course, managing a global supply chain requires skill because it is full of risks—and of course, opportunities. Firstly, one must move goods across land, air, and oceans. Secondly, one must take into account duties, tariffs, and exchange rates in the international setting. Thirdly, upon relocating to another country for manufacturing, the firm must account for renting costs, labor costs, and the transportation infrastructure of that nation. Cultural issues also play a role. Despite these hurdles, many firms have successfully navigated the different control layers of global supply chains. Europe is a major market, along with the U.S. Japan has had an export-driven economy for years, while Asian countries like China and South American countries like Brazil have now emerged as major manufacturers. Singapore and Hong Kong have played the role of trading centers. Global supply chains can be used to improve profits by optimizing the tariffs paid by a multinational. For example, a Japanese automaker may decide to sell made-in-Japan cars in the U.S. due to lower U.S. tariffs on cars. The same automaker might then export the same type of car made in the U.S. to Canada and Mexico to take advantage of NAFTA, which lowers the tariff paid for exports from U.S. to Mexico.

7.4 Facilities Management

The area of facilities management is an important one for the engineering manager. It usually revolves around designing the layout of facilities such as factories in the production-systems setting (Heragu, 2008) and facilities such as hospitals, fire stations, and airports in the service-systems setting. We will focus on the production-systems setting.

7.4.1 Goals

The main goals of layout planning follow:
- Minimizing the total material-handling cost and the total distance traveled while carrying material
- Minimizing the material-handling portion of the product's lead time
- Ensuring safety within the facility

7.4.2 Layout Design

The main steps in designing the layout of a production facility follow:
- Step 1: Determining the area needed for the factory and the warehouses
- Step 2: Determining the best arrangement of machines and offices needed in a factory

Step 1: This step usually entails determining how many machines are needed of each type by the factory. Production of past years and demand forecasts are used to determine the production volumes needed for each product. This is called product analysis. Product-analysis data are then used along with individual production rates of machines to determine the number of machines of each type needed. The following model is popular:
- P: the production rate, the number of finished products to be produced in one day
- E: the efficiency of the machine in question
- T: the time (in hours) for which machine is available in one day
- t: time (in hours) needed for producing one part on the machine
- NM: the number of machines needed.

The following formula is often used to compute NM:

$$NM = Pt/ET,$$

where NM is rounded up to the next higher integer.

Each machine needed has its own area requirements. One adds a clearance of usually at least 10 feet to each side of the machine to obtain the total area needed for the machine. The surrounding area is used to store tools needed for the machine and for the space operators need to perform their functions and to move material to and from the machine. Safety is an important criterion in determining how much space needs to be allocated between machines and for the material-handling movers to move.

Step 2: After the total area needed is determined, one must design the arrangement of the different machines and the other entities, such as managers' offices and restrooms, within the layout. In order to determine the best arrangement, one typically constructs the interaction matrix and the distance matrix.
- Interaction matrix: The interaction matrix measures the total amount of material handling that occurs between any two entities (e.g., machines, offices, and departments) in a given time period, such as one day. Thus if $I(i,j)$ denotes the element in the i-th row and j-th column of the matrix I, the interaction matrix, then $I(i,j)$ denotes the number of trips that occur between i and j in the given time period.
- Distance matrix: The distance traveled from the i-th machine (or office) to the j-th machine is represented in the so-called distance matrix, D, where $D(i,j)$ denotes the distance between the i-th machine and the j-th machine.

Clearly, both *I* and *D* are symmetric matrices. The total amount of material handling that occurs is given by the following formula:

$$MH = \sum_{i=1} \sum_{j=1} D(i,j)I(i,j),$$

where the summation is over all *(i,j)* pairs, *N* denotes the number of machines, and *MH* denotes the total distance over which material is carried (Material Handling) in the given time period.

The overall goal of the layout-designing process is to minimize the total amount of material handling that occurs. Clearly, every layout has a unique *D* matrix associated with it that depends on the exact locations of the different areas (machines and offices) within the layout. Designing the best arrangement is hence a combinatorial problem of finding the best combination such that the product *MH* is minimized. When the cost of moving material from the *i*-th machine to the *j*-th machine is known, one can introduce the costs into the material-handling equation as follows:

$$MHC = \sum_{i=1} \sum_{j=1} C(i,j)D(i,j)I(i,j),$$

where *C(i,j)* denotes the cost of moving material from *i* to *j, MHC* is the total material-handling cost incurred in the time period associated, and the summation is carried out over all *(i,j)* pairs. Usually, the cost term, *C(i,j)*, is measured on a dollars-per-foot basis and can be estimated from the operational and capital costs of the material-handling equipment used.

A number of algorithms have been developed to assign the entities (machines or offices) in order to minimize MHC. A prominent algorithm is CORELAP. A number of commercial software packages design layouts when they are provided with the interaction matrix or some other indicators of how frequently two machines (or offices) interact.

7.4.3 Types of Layouts

Usually, the layout of a manufacturing factory depends on the volume-variety ratio in the production mix. Industries that tend to produce a few products in large volumes are typically flow shops, where machines are laid out in lines where each line belongs to a given product and within each line, the general flow is according to the sequence of movements of the product associated with that line. Such a layout is also called a product layout.

When there is a very large variety of products being produced, one has a job shop, for which a process layout is preferred. In a process layout, machines belonging to the same family, such as turning, are usually located within one area. When the production shop is neither a flow shop nor a job shop, but something in between, a group technology or cellular layout is preferred. In a cellular layout, one combines similar parts and machines into so-called cells such that within each cell, one has a shop that resembles a flow shop. When very heavy products are involved, such as in airplane assembly or ship building, one uses a fixed position layout, in which the product is rarely moved but the machines move around it.

7.4.4 Material-Handling Equipment

Material handling is performed with push carts, conveyors, forklifts, Automated Guided Vehicles (AGVs), and robots. Other types of equipment include overhead cranes and hoists. Push carts are trolleys pushed by human beings while forklifts are like mini-trucks. Push carts and forklifts are used in all types of production shops but are necessary in job shops. Conveyors are automated material-handling equipment that require little human supervision but ensure smooth flow within a flow shop if used properly. The reason conveyors are useful in flow shops is that in flow shops routes of jobs are fixed and do not vary much. Automated-guided vehicles are expensive material-handling units that can be used within flow shops for moving material in an automated fashion from one machine to another. The vehicles are programmed to move from one spot to another in the factory. Robots are usually used to move material over short distances and typically perform functions of a human arm in hazardous environments, such as welding, or for tasks that require strength and the ability to perform repetitively without making errors. Robots are especially useful in assembly environments. All types of material-handling equipment, with the possible exception of push carts, need a great deal of maintenance, and their downtimes add to the overall lead time.

7.5 Measuring Supply Chain Performance

A very simple approach to measure the supply chain's performance is to determine whether the firm makes profits. However, such a simplistic approach rarely works in practice. This is because simply measuring profits annually does not help improve the performance of the firm over a longer time period, such as 10 years, nor does it help diagnose problems in the firm. As a result, a very large number of metrics and frameworks have been proposed for measuring supply-chain performance that can be used throughout the year in managing the operations of the firm. It is important to know that the popularity of a metric changes from industry to industry. Some of the main metrics follow:

- *Lead times*: The lead time is usually the time elapsed between the order placed by the customer and the receipt of the finished product by the customer.
- *Order fill rates*: The proportion of orders that are satisfied. These are important in both Make-to-Order (MTO) and Make-to-Stock (MTS) production systems and in service industry, such as retail.
- *On-time deliveries*: The proportion of orders that are delivered on time (important in MTO).
- *Inventory turns*: Ratio of the cost of goods sold and the average inventory in the system.
- *Inventory-holding costs*: Total cost of holding inventory in a given time horizon (e.g., one month).
- *Forecasting errors*: The MSE (mean-squared error) of the forecast and actual sales over all products.

  This is a very important measure in MTS production systems and in the retail industry.
- *Product quality*: The quality of the outgoing product, such as proportion of shipped-out product that is defective (and returned as a result). This is perhaps the most critical metric in the production industry.
- *Product availability*: The proportion of time that raw materials are available when production is started.
- *Order-entry accuracy*: Proportion of documentation that is accurate.
- *Warehouse-picking accuracy*: Proportion of times items are picked up correctly from warehouses in MTS production environments.
- *Customer-inquiry service*: Proportion of customers who receive response in a timely and courteous manner.
- *Invoice accuracy*: Orders correctly billed.
- *Payment accuracy*: Payments made correctly.

It is a common practice in industry to use some formal system such as Balanced Score Card, the SCOR model (Supply Chain Council), and ABC (Activity-Based Costing) to measure the performance of the supply chain. These systems are often a part of the MRP (Materials Requirement Planning) software used and typically quantify and rank the performance of the supply chain using the metrics discussed earlier.

There are a number of other metrics that are also important from a strategic standpoint and are frequently used in the industry. Some of these can be quantified easily, while some have a qualitative nature:

- *Return on investment* (*ROI*): The amount of time (e.g., in number of days) required for converting cash invested in assets into cash received from customers. This is a very popular measure of top-level, supply chain managers in industry.
- *Supplier effectiveness*: Rating or ranking the quality and on-time performance of the suppliers to the firm.
- *Flexibility*: Flexibility of the supply chain in managing deadlines. This involves several metrics, one of which is slackness in meeting deadlines (which might be strategically important).
- *Variability*: Variability has become a very important metric in SCM in recent years. One approach to measure the variability is to compute the variance in some of the metrics discussed earlier, such as on-time deliveries, product quality, and lead time.

- *Non-value-adding activities*: The proportion of lead time spent in non-value-adding activities. With the advent of Six Sigma and Lean, this has also become a very critical component in measuring a supply chain's performance. This is a metric that one seeks to minimize.
- *Ratio of distribution costs to total costs*: This ratio can be used to compare different products within the same firm. Clearly, the smaller this ratio, the better off the firm. Distribution costs can be minimized but cannot be eliminated. One can use smart routing strategies to reduce costs of distribution.
- *Ratio of information processing cost to total cost*: The following activities related to information processing cost money: order entry, order follow-up and updating, discounts, and invoicing. The total cost of these activities might exceed manufacturing and distribution costs.
- *Human resource productivity*: One or more metrics used to rate the productivity of a human. This task is often more difficult to quantify in comparison to others but if ignored might indirectly lead to numerous problems, including disruptive turnover and losing productive employees.
- *Energy usage*: As we become more environmentally conscious, growing emphasis is being placed on minimizing our energy usage.
- *Product development*: The time taken to develop or launch a new product is critical in electronics and automotive industries, where innovativeness of the product and the annual improvement of features are critical.
- *Capacity utilization*: Usually, capacity is measured by machines and space. Typically, important in MTS than in MTO, capacity utilization is a measure of how much of the capacity in a factory is being used and whether the capital is spent on purchasing capacity.

Review

Upon completing the study of Domain 7: Operations and Supply Chain Management, you should be able to answer the following questions:

1. Discuss the features of Lean and Six Sigma. What contributions have these approaches made to supply chain management?
2. Define what is meant by a supply chain of a product. What is meant by the bullwhip effect?
3. Name the essential tasks involved in operations strategy?
4. Discuss some important mechanisms used for inventory management in a supply chain.
5. What is a global supply chain?
6. Name some important metrics used to measure the effectiveness of a supply chain.
7. Name the different types of layouts one sees in a production environment.
8. Discuss how a given layout in a production environment can be evaluated.

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8

Management of Technology, Research, and Development

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Domain 8: Management of Technology, Research, and Development

Key Words and Concepts

Boston Matrix	Model used to describe a product in relationship to its levels in market share and market growth.
Development	The systematic use of scientific and technical knowledge to meet specific objectives or requirements.
Innovation	An invention that has produced economic value in the marketplace. An innovation can include new products, processes, services, or new ways of doing business.
Product Portfolio	The range of products a company has in development or available for consumers at any one time.
Research	The search for knowledge (systematic investigation) with no preconceptions to establish facts, solve new or existing problems, prove new ideas, or develop new theories.
Research and Development	The creative work undertaken on a systematic basis to increase the stock of knowledge, including knowledge of man, culture, and society, and the use of this stock of knowledge to devise new applications.
Technology	The creation, use, and knowledge of tools, machines, techniques, crafts, systems, or methods of organization to solve a problem or perform a specific function.
Technology Assessment	An assessment process used to determine the capabilities of any given technology, including its specifications and performance, as well as its applicability to a planned project.

8.1 Overview

8.1.1 R&D Management

Many engineers or engineering managers will have the opportunity to work as part of a Research and Development organization at some point in their career. Research and Development, commonly referred to as R&D, spans a range of activities that extends from early research of a domain to specific development of commercial applications. Definitions used by the National Science Foundation (2015) help distinguish among these activities: "Basic research is the pursuit of new scientific knowledge or understanding that does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest. Applied research applies the findings of basic research or other existing knowledge toward discovering new scientific knowledge that has specific commercial objectives with respect to new products, services, processes, or methods. Development is the systematic use of the knowledge or understanding gained from research or practical experience directed toward the production or significant improvement of useful products, services, processes, or methods, including the design and development of prototypes, materials, devices, and systems."

Activities classified as R&D differ from company to company although there are three primary organizational models used in most firms. The first organizational model is a divisional-functional-organization structure that has an R&D department typically staffed with engineers who are responsible for new product or services development. Engineers in this type of department may also be part of broader cross-functional teams with overall product- or service-delivery responsibilities, utilizing existing technology or creating new technology as required. The second organizational model for R&D is like a corporate central R&D laboratory structure where industrial scientists and engineers are doing applied research in scientific or technological fields which might enable future product development. These teams will have connections to the divisional R&D teams to facilitate technology transfer from the laboratory when ready. The third model of an R&D organization is best described as a think-tank structure where researchers are doing basic research in technology areas that have some source of external funding. For both the second and third organizational models, these activities are generally not expected to yield quick profits and generally carry greater risk and uncertainty regarding return on investment.

8.1.2 Technology Management

Technology clearly plays a key role in the R&D process. There is a wide variety of different perspectives on the definition of technology. A simple definition is that technology is the knowledge, products, processes, tools, and systems used in the creation of goods or in the provision of services (White & Bruton, 2011). This definition is well aligned with the use or creation of technology in R&D. Technology management, though often referenced as a parallel career path to R&D management for technical individuals, is a very similar set of systemic and strategic activities. One of the most commonly cited definitions of technology management is that it is the linking of different disciplines to plan, develop, implement, monitor, and control technological capabilities to shape and accomplish the strategic objectives of an organization (White & Bruton, 2011).

According to the Product Development Management Association (PDMA), the goal of technology management is "to prioritize and focus research and development efforts on technology opportunities today that will have a positive effect on corporate revenues in the future" (Kahn, Castellion, & Griffin, 2005). With the increasing pace of product development, the need for planning—both strategic (to ensure organizational objectives are met) and tactical (to ensure product-development objectives are met)—has become even more important. Once the decision to move forward on new products is made, there are a few recommendations: "to accomplish their goals, corporations should invest in tools, processes and structure that support the identification of technological opportunities to fuel product innovation and product-to-market excellence" (Kahn et al., 2005).

Whether you identify more closely with R&D Management or Technology Management is largely a reflection on the structure of your company and how it approaches the development of new products and services that create value for customers. In either case, the integration of technology as part of a systematic development process to deliver customer value serves as a foundation for either discipline.

8.2 Role of Innovation

Innovation arises out of a critical expectation of both R&D and Technology Management, the generation of new ideas to solve problems. Innovation is more than the generation of new or creative ideas; it is the implementation of those ideas into a new device, application, or process. Innovation requires combining a creative idea with the right resources and expertise to develop something useful for the business. In many industries, technological innovation is now the most important driver of a firm's competitive success. Businesses in a wide range of industries rely on products developed within the past five years for one-third or more of their sales and profits (Schilling, 2013). In fact, according to Boston Consulting Group's 2013 survey on innovation, respondents ranked the importance of innovation higher than ever, building on a trend of the past five years (The Boston Consulting Group, 2013).

The pace of innovation has been impacted by advances in digital technologies. Companies are increasingly using big data analytics to help identify new areas for innovation exploration as well as make informed investment decisions. Computer-aided design tools have made it easier and faster for firms to design new products. Digital manufacturing technologies have made shorter production runs more economical and have reduced the importance of production economies of scale (Schilling, 2013). Manufacturers of automobiles, cell phones, and other consumer electronics create broad product portfolios to meet almost every market niche possible. Although the production of multiple product variations was historically expensive and time consuming, today's flexible manufacturing technologies enable companies to easily transition from one product model to the next, adjusting production demand with real-time inventory data. Investment in platform architectures allows for the use of common components across product variations, which helps reduce production costs.

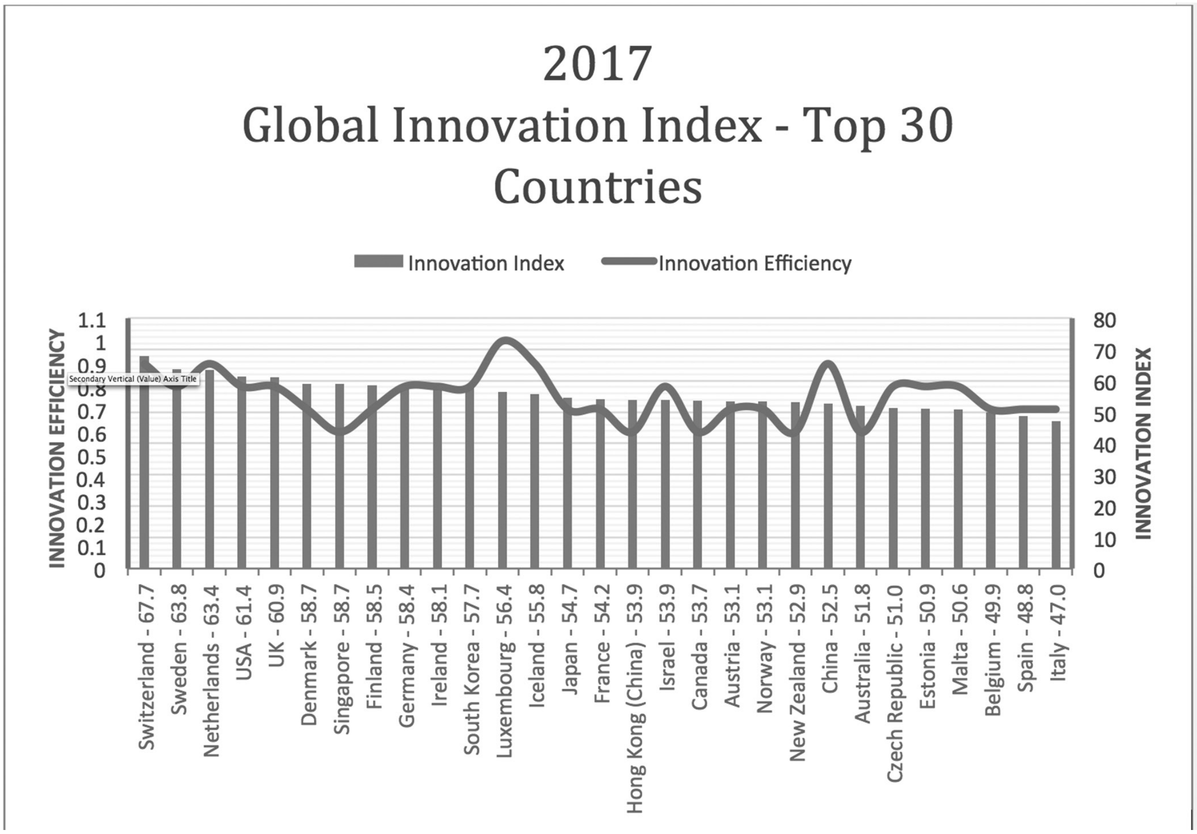
The adoption of new technologies to increase the pace of innovation enables the shortening of development cycles and allows more rapid new-product introductions. This leads to shorter product life cycles, which spurs firms to innovate more quickly. Ultimately, firms discover that innovation must be a strategic imperative, or they will find themselves in the unfortunate position of seeing their revenues and profit margins decline.

8.2.1 Globalization

Globalization of world markets is having a significant impact on the importance of investing in innovation. Worldwide competition has put pressure on domestic firms to ramp up their innovation to produce differentiated products and services. The world's economically mature countries, such as the United States, Japan, and Germany, have been the leaders in innovation for decades, but countries such as Brazil, India, and China are quickly closing the gap. The percent increase in economic growth in these countries dwarfs that of mature economies. This growth implies more customers, more revenues, and ultimately a greater ability to invest in innovation. To augment this strong economic growth, these countries often have supportive government policies to further enable investment in innovation. Some policies have a specific focus and an immediate effect, such as large R&D tax credits. Other policies have a less direct impact but can translate into big benefits over time, such as building a highly capable workforce through education programs. The net effect is that these rapidly growing countries are committed to innovation and are investing heavily to build their innovation competitiveness (The Boston Consulting Group, 2010).

For the past 10 years, the Global Innovation Index has provided a window into how counties are performing relative to innovation. A set of measures are collected that assess factors that enable innovations within a country as well as the results of the innovation activities. An innovation efficiency ratio is calculated to show how much innovation output a given country is getting for its inputs. Data from the Global Innovation Index 2017 report is shown in Figure 8-1. Notable in the Global Innovation Index is the rise of Asian countries, now occupying five of the top 25 positions.

Figure 8-1. 2017 Global Innovation Index (https://www.globalinnovationindex.org/userfiles/file/reportpdf/gii-full-report-2017.pdf)



Digital technologies are not only contributing to the increased pace of innovation, but also driving innovation in successful global companies. Each year Boston Consulting Group identifies the year's Global Challengers (Boston Consulting Group, 2018). These companies are chosen using a combination of quantitative and qualitative criteria. Some of the criteria includes having at least $1 billion in annual revenue, 1,000 or more employees, have a strong international presence, and having growth rates that outpace their home market GDP or industry average. These companies are using digital technologies to innovate in technology sectors that help address problems in emerging world markets. Some examples include:

- Industrial goods and manufacturing: Digital technologies are being used to mitigate rising wages in emerging market manufacturing factories.
- Consumer: E-commerce sales and distribution can compensate for lack of modern trade channels in many cities.
- Energy: Renewable energy sources address pollution problems in emerging market cities.
- Health care: Digital health care delivery helps deal with limited hospital capacity.

Many of these Global Challengers are world-wide leaders in digital technologies and are leapfrogging their counterparts in established markets and will continue to be a driving force in the global economy and delivery of new innovations

8.3 Strategic Management of Innovation

As the race to innovate accelerates with increasing global competitive pressures, businesses continue to look for ways to accelerate their new-product-development process. Sometimes firms don't have a clear strategy, a strong portfolio-management process, or even a rigorous project-management approach. This lack of discipline leads to starting more projects than can be adequately supported, choosing projects that are a poor fit with business objectives or engineering skillset, delayed development cycles, and high project-failure rates. While some people argue that innovation should not be constrained by process, Boston Consulting Group's research shows that firms who are strong in innovation performance are far more likely to follow a standardized process, and they recognize that a strong process requires being effective at governance, portfolio management, and project management (Boston Consulting Group, 2013).

Creating a well-defined technology innovation strategy will not guarantee business success, but it can improve its innovation success rate. It is critical that innovation projects are aligned both with a firm's key business objectives and core competencies, as well as its resources. It is important that the organizational structure and reward systems encourage the generation of innovative ideas and also recognize the need to take risks and accept some failures. The product-development process should effectively manage risk to maximize technical and market success. There are many models that can be used to provide a foundation for strategic management of innovation. White and Bruton (2011) offered a Cyclical Innovation Process Model that moves through technology forecasting, acquiring technology, implementing technology, integrating technology, and exploiting technology. Schilling (2013) offered the Strategic Management of Technological Innovation Model, which examines the industry dynamics of innovation, formulates the innovation strategy, and implements the innovation strategy. Both models provide a systematic approach to the management of innovation that can potentially improve a business's innovation success rate.

The subsequent sections will examine the key elements of the Schilling model to provide some additional background to aid in creating an approach to the strategic management of innovation.

8.3.1 Understanding Industry Dynamics

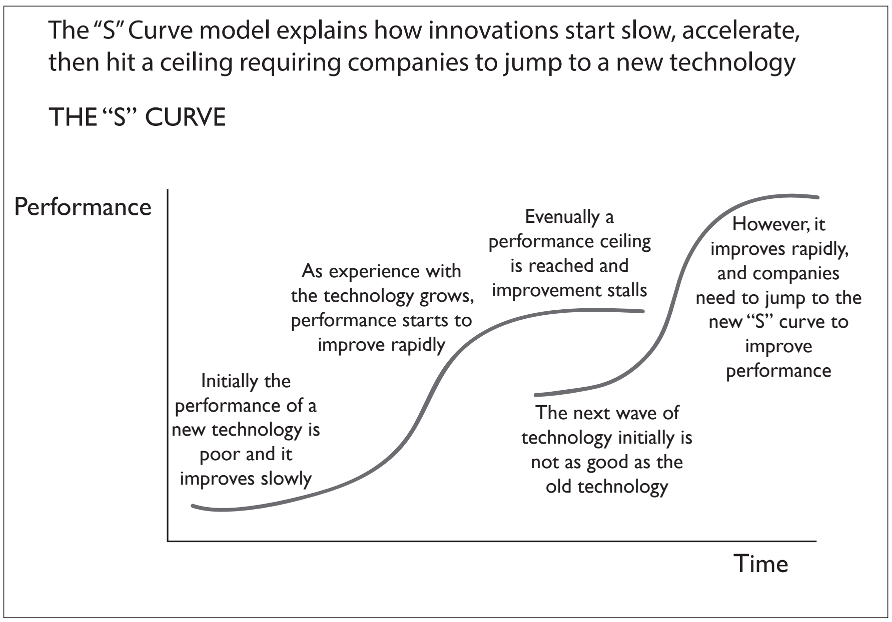
It is important to gain an understanding of how and why innovation occurs in an industry to help lay the foundation for creating an innovation strategy. Two important elements of industry dynamics include source and type of innovation. There are many different sources of innovation in a firm, including individuals or teams who are part of an R&D organization, research laboratories, universities, government laboratories, or even nonprofit organizations. Perhaps an even more important source of innovation is the result of linkages among the various sources, or collaborative networks. There is growing awareness around the importance of collaborative networks in the generation of ongoing innovation. Example collaborative networks could include joint ventures, licensing agreements, research associations, and even informal networks. These types of collaborations are particularly important in technology sectors where it is sometimes difficult for a single organization to have all the capabilities necessary to bring an innovation to market.

Technological innovations are often categorized into different types, much as projects may be categorized as part of an overall portfolio-planning process. Two common dimensions often used to categorize innovations are described next.

- Product Innovation versus Process Innovation: Product innovations are reflected in the products or services delivered by an organization while process innovations are generally focused on improving the effectiveness or efficiency of an organization through how work is done. Though product innovations are generally more visible, process innovations are often necessary for an organization to compete successfully. It is important to note that product and process innovations can go hand in hand. For example, a new-product concept might require a new manufacturing process innovation to bring the product to market.
- Radical Innovation versus Incremental Innovation: Radical innovation describes something that is new and different from existing products and processes. Radical innovations can have a high element of risk technologically but also from the perspective of customer acceptance. Introduction of wireless technology is an example of a radical innovation. Certainly, there were technical risks, but initial customer acceptance carried a high risk as well. Incremental innovation makes a minor change to existing products or services but is viewed as providing some type of additional value to the customer or business. Migration of cell-phone service plans from fixed to unlimited minutes represents an incremental innovation in cell-phone services.

One additional important topic related to the industry dynamics of technology innovation is the s-curve. Both the rate of a technology's performance improvement and the rate at which the technology is adopted in the market conform to an s-shape curve. When a technology's performance is plotted against the amount of effort invested in the technology, it typically shows slow improvement that accelerates over time and then finally diminishes. (See Figure 8.2.) Performance improvement early on is slow because the technology might not be clearly understood, or even customer-performance requirements are not yet clear. Performance will improve quickly with focus on the parameters that will have the greatest impact. At some point, there is diminishing return to continue investing in additional technology improvements. A new technology innovation will emerge and eventually take the place of the existing technology. That transition can be orderly, with a clear path for easily migrating to the new technology both from a development and customer-usage perspective. Often, though, the jump to the second s-curve is caused by a new, discontinuous innovation that makes the first technology obsolete. Incumbent firms using the first technology are then faced with the decision of trying to extend the life of their technology and products versus switching to the new technology as well.

Figure 8-2. Technology S-Curve (http://strategictoolkits.com/strategic-concepts/s-curve/)



8.3.2 Formulating an Innovation Strategy

Formulating an innovation strategy will integrate tools and knowledge from other EMBOK domains to create a cohesive approach. The first step is to assess the business's current technology position and define its future strategy. Key tools to use in these steps include a Strengths Weaknesses Opportunities and Threats (SWOT) analysis, Porter's Five-Force Model, and core-competency analysis. These are all described more fully in Domain 3, Strategic Planning. The SWOT analysis is an important tool to help answer questions regarding the current position of the firm, where it has strengths to be leveraged and where there are weaknesses and threats to be considered. To address a firm's current market position, it is useful to consider Porter's Five-Force Model. This model will help analyze the external environment that a firm is facing and help shape its strategic objectives. A key element of an innovation strategy is having a clear understanding of the firm's core competencies. Core competencies are typically considered to be those that differentiate it strategically and include more than core technology. A core competency emerges from the ability to combine multiple capabilities into something that is difficult for competitors to imitate.

With a clear view of a firm's current technology and competitive position, an innovation strategy can be created. A firm's purpose is to create value for its customers, generate returns for shareholders, and foster a good environment for the employees. A firm's strategic intent will provide a compelling view of how the firm will deliver on the stated purpose over time. A strategic intent can often be a single-page document that includes a statement of the firm's mission, vision, and key long-term objectives. For example, key long-term objectives may include a focus on technology, process, market development, and employee training. Within each area, there will likely be 3-5 strategies to support the objectives. Another way to focus key objectives is to use the Balanced Scorecard as a model, described in Domain 4. The key long-term objectives would be focused in four areas: financial, customer, internal business processes, and employee learning and growth. Thinking about objectives using the Balanced Scorecard model approach (Kaplan & Norton, 1996) ensures that there is enough thought given to critical-success factors and critical metrics to gauge progress. Without the metrics to evaluate a given strategy, it is impossible to access progress and make needed adjustments until it is often too late.

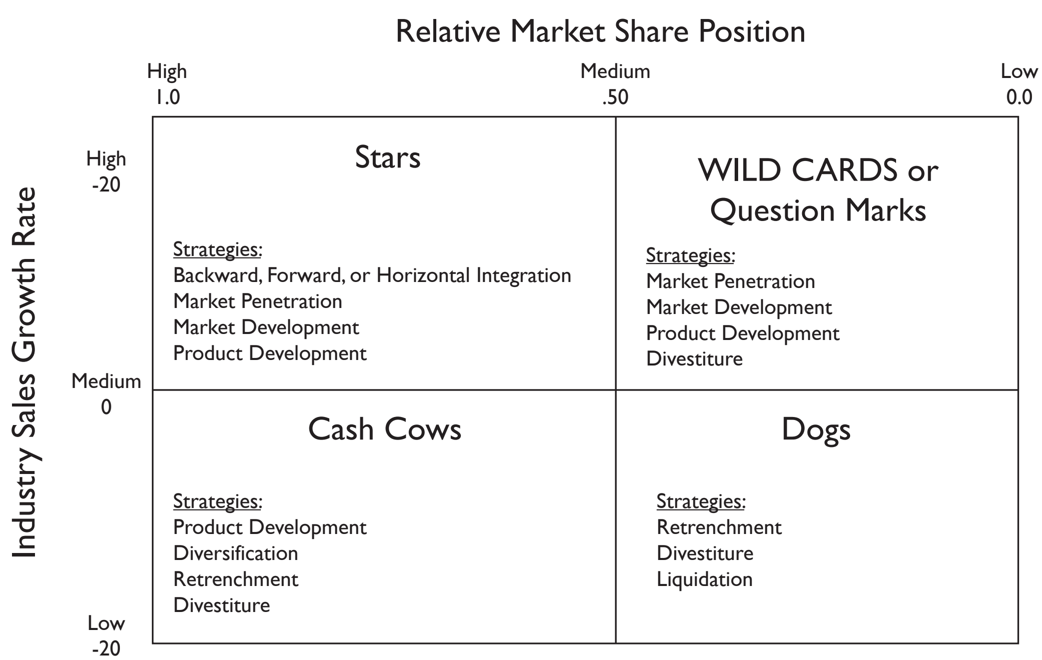
8.3.2.1 Product Portfolio Analysis

The strategic intent will serve as the basis for the innovation strategy. The next step is to carefully evaluate and select the right technology projects to invest in. An engineering manager may be in the position of having to make difficult choices about which projects to invest in to effectively balance delivering the necessary value to the business within resource constraints. Having a well-thought-out and rigorous product portfolio process will support engineering managers in making the best choices. An assessment of the current product portfolio serves as the input for the product-portfolio process.

1. Analyzing a Current Product Portfolio

Products in a portfolio can be classified in many ways. In 1968, Boston Consulting Group developed a tool for portfolio analysis, now commonly known as the Boston Matrix. A simple and effective tool, it categorizes products into one of four quadrants based on market share and market growth (see Figure 8-3).

Figure 8-3. Boston Matrix



The four categories of the Boston Matrix are:

- Stars are high growth products compared with the competition. They often need investment to sustain growth. As growth slows, and assuming they maintain their market share, Stars evolve to Cash Cows.
- Cash Cows are low growth products with a high market share. These are mature products with little need for investment. They need to be managed for continued profit to deliver cash flows needed for investment in Stars.
- Question Marks are products with low market share in high-growth markets. They may have potential but may need investment to grow market share.
- Dogs are products with low market share in low-growth markets. They may generate enough cash to break-even but are generally not worth investing in.

Creating a current portfolio view for a business entails identifying which category of the Boston Matrix each existing product belongs in. Each product is then mapped onto the matrix. Larger symbols (generally circles) are used to represent products that represent a larger portion of the business (market share, revenues, etc.) and smaller symbols to represent more "minor" products. The goal is to have a reasonably balanced portfolio with products at different categories in the matrix. It is normal to have some Stars, a few Cash Cows, and a few Dogs that are either products in trouble and in need of retooling or at the end of their natural life cycle.

Unbalanced portfolios are indicators of an immediate need for strategic reassessment of current business practices. These portfolios can result from the following:

- Over-investing in low-growth segments
- Under-investing in high-growth segments
- Misjudging segment growth
- Not achieving market share
- Losing cost effectiveness
- Not uncovering emerging high-growth segments
- Unbalanced business mix

2. Evaluating and Selecting New Projects for the Portfolio

Both qualitative and quantitative methods can be used for evaluating and selecting new projects to be included in the business product portfolio. Discounted cash-flow analysis is one approach that can be used to evaluate projects. Discounted cash flows assess whether the anticipated future benefits are great enough to justify the expense. The two most commonly used financial metrics in discounted cash-flow analysis are net present value and internal rate of return. Both metrics provide concrete financial estimates that facilitate trade-off decisions among projects.

Many product development projects require the evaluation of qualitative information as part of a trade-off discussion. A typical approach will include creating a screening model that includes the qualitative factors. Each factor will be assessed on a defined scale by key stakeholders for each project. A project prioritization will emerge. Oftentimes, the factors used in a screening model will be weighted such that those with a higher priority will carry greater influence in the assessment. Assignment of the weighting factors requires alignment among the stakeholders and is a critical element of the screening-model approach.

Product portfolio planning is a process that can be practiced on a very small scale, within a project team, or on a very large corporate scale. In either case, it is critical to have a clear statement of strategic intent as the foundation for the process. It is important to have key stakeholder alignment on the qualitative and/or quantitative factors that will be used to evaluate projects. Screening models, as a part of this process, are simple tools that can be used very effectively when the evaluation factors are weighted appropriately. Finally, the outcome of this process can be used to align project resources to the highest-priority projects and provide visibility to potential resource gaps.

To be effective, product-portfolio management is a critical business process that needs to be executed on a regular cadence. Using a tool such as the Boston Matrix is useful but only provides a snapshot of the current business position. New project proposals need to be evaluated along with the current portfolio on a regular basis to allow for appropriate investment trade-offs to support the business needs. Engineering managers need to have the discipline to make difficult decisions to cancel current products or projects in development that do not support a balanced product-portfolio.

8.3.3 Implementing an Innovation Strategy

In many industries, the ability to integrate innovations into new products quickly, efficiently, and with high quality often are driving factors to a firm's success. Unfortunately, a high percentage of projects do not deliver on expectations regarding cost, budget, or quality. There are three key objectives for the new product development process: delivering the right customer requirements, minimizing development time, and controlling costs. Fortunately, there are numerous tools and methodologies that can be used to enable an effective and efficient product development process. Sections 8.5 and 8.6 details examples product development processes that can be used to deliver innovations to market.

8.4 Innovation Best Practices

The innovation process across differing industries takes many forms, and there is no single right approach. Research in this area (Boston Consulting Group, 2013), though, has identified five key attributes that emerge as innovation best practices:

- Leadership commitment: Leaders in an organization must be committed to a culture of creativity, change, and risk taking. They must be clear on their strategy and have a laser-sharp focus on growth to ensure that their organization does not get complacent.
- Leverage Intellectual Property (IP): Historically, protecting IP rights has been a defensive strategy by companies to protect their innovations and technologies. Today, companies are using IP to establish competitive advantage.
- Manage the portfolio: With the ongoing tension of limited resources and too many projects, effective innovators learn how to keep the high-potential projects moving forward. Resources are invested in the high-priority projects, and the leaders are not afraid to cancel projects as part of a rigorous stage-gate process.
- Focus on the customer: Strong innovators find ways to involve customers in their idea-generation process, get customer feedback throughout development, and focus on customer satisfaction as a post-product-release metric.
- Establish strong processes: Strong innovation performers have clear governance and decision-making processes that are a key part of a standardized development process. They view governance, portfolio management, and project management as distinct elements of their process but know they must be effective at all three. They emphasize teamwork and foster communication and collaboration.

8.5 Integrating Research and Technology into New Products—Concept to Realization

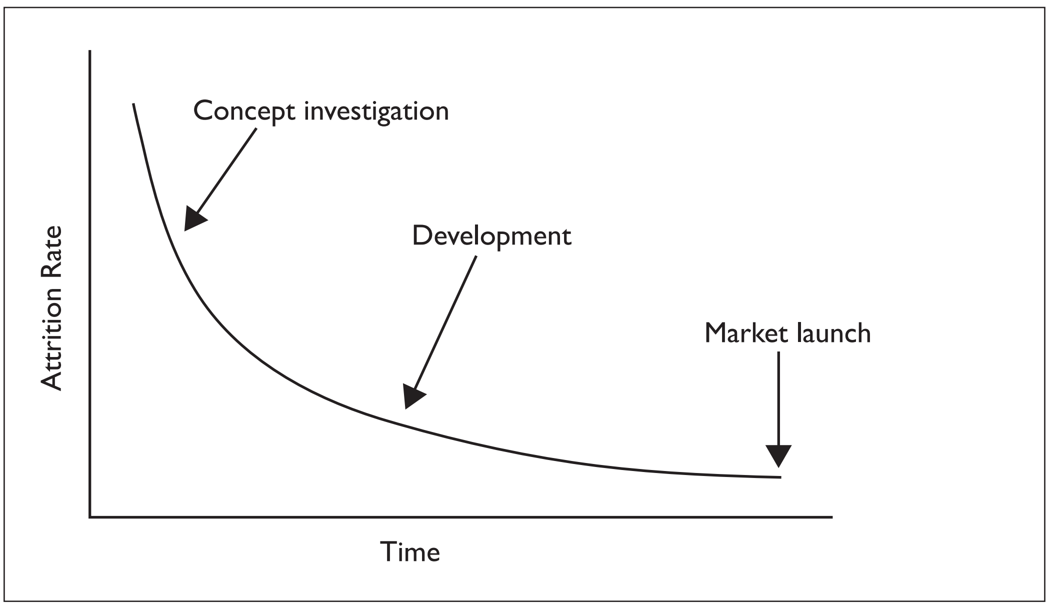
8.5.1 Product Realization Process

There are a wide variety of corporate strategies for product development. The product realization process is the term used to describe the work that the organization goes through to develop, manufacture, and deliver finished goods or services. Some firms focus on established markets and compete by producing a product at the lowest cost. Other firms find their niche by focusing on new products to satisfy a market need or even to create a market. Yet, product success does not come from technological development alone. Companies must integrate innovation with creative marketing, finance, and social insights to create a successful market launch.

Everyone thinks of Apple as the icon for developing successful new technologies such as the Smartphone. However, the company is successful because it focuses on all elements of the product realization process, not just the product design and manufacture. The first Smartphones were developed in the 1990s by IBM, Nokia, AT&T, Ericsson, and others. What made Apple so successful when it launched the iPhone in 2007 was its ability to combine keen insights of marketing, finance, and usability along with product design and manufacture. Engineering managers are typically responsible for the latter aspects but must work with managers in the other areas if a product is to be successful.

There is a common saying, "Fail fast and fail cheap." The product realization process is expensive and as time progresses, the company invests more time and money into an idea. Bringing a product to market only to have it fail is an expensive endeavor. The key to successful product development is to identify those ideas that are less likely to succeed and cancel them before too much investment is made. Even then, there is no guarantee the product will be a success in the marketplace. Studies show that only about 1 in 60 product ideas ever make it in the marketplace (Cooper, 2011). Figure 8-4 shows this attrition, with most product ideas failing during the initial investigation at the company. More fail during development, as technical challenges prove too difficult or expensive to overcome. The rest fail during launch due to poor market response.

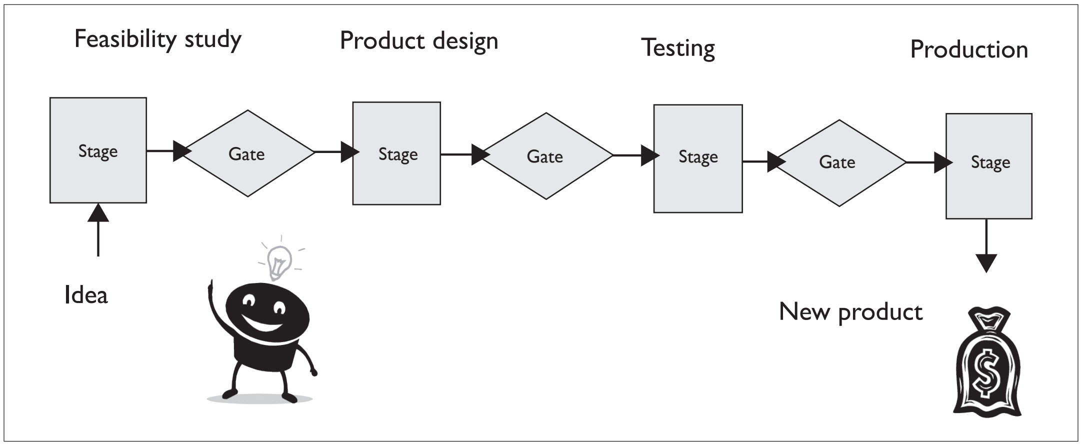
Figure 8-4. The Attrition Rate of New Products Over Time



Developing new products in R&D is typically managed through a stage-gate process. The purpose of this process is to manage the risk associated with bringing a product to market. Since the goal is to develop research into a usable product that provides a return on the investment, careful attention to design detail, following a disciplined process, and asking difficult questions can increase the likelihood that only the best ideas are pursued.

A typical stage-gate process is shown in Figure 8-5. The goal is to intensely review the project at each gate with a bias toward canceling the project unless it continues to show promise.

Figure 8-5. Typical Product-Realization Process



The process described in Figure 8-5 may also be referred to as a traditional project management life cycle, or waterfall life cycle. It is sequential in nature where the team can only proceed to the next step if the criteria for passing through a gate have been met. This life cycle works well when the product goal, requirements, and solution are clear (Wysocki, 2014). There are other project management life cycles that work better when there is more uncertainly in the solution or product being developed. An Agile project management life cycle is the product-realization process often used for software R&D. This will be introduced briefly in Section 8.6.

8.5.2 Knowledge of Integrated Product-Design-and-Development Methods

The steps of hardware product design are often described as follows:

- Product definition
- Conceptual design
- Detail design
- Prototyping and testing

Traditionally, product design was a time-consuming, sequential process that required one department to complete its portion of the design process before the next department could begin its part. With the advent of computer-based design applications, this sequential process has been replaced with a simultaneous, integrated design approach. The same steps are completed but in a more iterative, concurrent way. This approach shortens the design process considerably. The technology now exists to use computers to turn a sketch into a detailed design. Users no longer operate in silos but, instead, are members of multifunctional teams that draw on each other's strengths to develop the product.

1. Product Definition

In a traditional project management life cycle, establishing a concise set of customer requirements and resulting product definition prior to moving into design is critical. Quality function deployment (QFD) is one method used to integrate the voice of the customer into the design and development process (Bossert, 1991). QFD is a technique to elicit the wants and needs of the customer, prioritize them, and translate them into product specifications and characteristics. The multifunctional project team uses customer requirements, marketing information, and technical data to develop a prioritized list of engineering targets that the new design must meet. When developing targets, consider the following questions:

- What are the customers' requirements?
- What is the relative importance of each requirement to the customer?
- What is the customer-satisfaction level with existing products?
- What is the satisfaction level the product-design team hopes to achieve?

8.5.3 Conceptual Design

1. Basics

Conceptual design can be described in multiple ways. If taking an existing product and making modifications, conceptual design can be described as developing a new prototype. For a new product idea, conceptual design can be imagining the possible. In most applications, it is something in between.

In general, conceptual design describes the activities to find a solution to the product requirements identified during the product definition step. If done properly, the product definition step will identify specific target values for these requirements. For example, in designing a printer, the design team will identify product requirements such as printing 15 pages per minute or the ability for a paper tray to hold an entire ream of paper. During conceptual design, the team identifies initial ideas for a product that can achieve these product requirements at the specified target values. There are an infinite number of ideas the design team may have. In our example, the design team might pursue an ink-based printer or one based on electrophotography. Once these types of decisions are made and their associated technologies identified, the set of possible solutions begins to narrow.

2. Concept Changes

It is important not to agree on a concept too quickly. There can be many approaches for achieving the product requirements and break-through solutions can only be found by exploring different concepts. Some approaches to conceptual design (Pahl et al., 2007) go to great length to keep a product concept as functional as possible while considering alternative approaches. In this way the design team does not focus on the first solution and continues to explore approaches.

Design decisions are relatively easy and inexpensive to change early in the product development process. This is the time to explore new technologies and new applications to create a product that is distinctive from the competition. During the next step of detail design, extensive company resources will be committed and detailed product specifications will be agreed upon. The opportunities for change become more limited. The cost to make changes is relatively high therefore, it is best to make changes during conceptual design when the concept is still flexible.

3. Representation

At the end of the conceptual design step, a representation of the concept must be developed. This representation is usually in the form of a written description, sketch, or solid model. Sometimes, a physical model is made. The key is to provide a representation so that everyone on the design team has the same understanding of what the product is. This is also an opportunity to get customer input through activities such as focus groups where the concept representation is shared and feedback gathered.

8.5.4 Detail Design

Simulation models can be used to determine the effects of a product or process change without the expense of an actual full-scale trial. While prototyping can help debug the manufacturing process and product design, it can be time consuming and costly. Computer simulation provides a useful and cost-effective alternative to such traditional testing methods. The rapid development of computer technology has made computer simulation affordable and doable for the majority of manufacturing and design projects.

Computerized simulation models can be used to determine the effect of a single change or of multiple, simultaneous changes to a product or process. Many computer-driven design programs that include 3D design capabilities also include 3D modeling and simulation abilities. If a part is designed in three dimensions, surfaces of the solid model are defined using 3D modeling, and machining simulations are conducted using the software's simulation capabilities.

When a part is designed using computer-aided design and manufacturing (CAD/CAM) technologies, software can be used to identify manufacturability issues such as inappropriate tool clearance, sequencing problems, or unacceptable wear rates. A virtual tool can be "test driven" over the part to check for clearance and other manufacturability issues. It is much more efficient to learn at the desk that a cutting tool will bind or break at the same point on each part than it is to bind or break the tools on the production floor. The desktop is also the best place to learn that a design simply cannot be produced as specified. Consider the equipment and tooling costs associated with a production trial that results in no ability to produce the product as originally designed. It is much better to change the design in the virtual stage than to attempt to reverse-engineer a process that is not capable of producing the desired result and might, in fact, never be capable of production.

Simulation models can also be used to determine the performance of equipment used to build parts. These simulation models can help to identify when a piece of equipment can be reused, when it needs modifications for most efficient operation, and when it will need to be replaced.

In addition to design and manufacturing simulations, the flow of a product throughout an entire facility can be simulated. Materials availability, transportation issues, bottlenecks, and the location of each part as it progresses through the facility can be recreated in computer models. The broad bandwidth capabilities and large data-storage capacity of today's computers allows for the use of increasingly sophisticated simulations that can conduct a wide variety of simulations simultaneously, rather than evaluating changes to one variable at a time, as was done in the past. Following the use of simulation methodologies, review the proposed project to determine product feasibility. Consider the following questions:

- Is it feasible to build the product?
- Does the production facility currently possess enough types and quantities of equipment to produce the product, or will new equipment need to be purchased?
- Can it be built safely and efficiently?
- Does a sustainable market exist for the product?
- If a sustainable market does not currently exist, can a market niche be created that will generate enough sales to justify production of the product?
- Will the cost to the end user be acceptable?
- Is funding available to implement the project?
- What will be the source(s) of project funding?
- Are suitable resources available for allocation to the project? Do suitable human resources exist? Will additional staff be required? Does the production facility have the capacity to schedule additional tasks of the type required to produce the product?
- Are there increased training needs associated with the project?
- Are there any regulations that must be considered in the manufacture, distribution, and sale of the end product?
- Will customers develop alternative uses for the product, potentially creating liability issues for the manufacturer?
- Can the project be brought to market within a timeframe that will allow capture of significant market share?
- Will the project be profitable, or could resources be better used elsewhere?

1. Designing Experiments

A well-designed experiment varies several factors at once to account for the possibility of interactions among them, as opposed to an experiment that allows only one factor to vary at a time in a tightly controlled environment.

Use designed experiments to accomplish the following:

- Provide an estimate of the effect of various conditions or equipment.
- Determine the sources of variation in a process.
- Optimize a process.

Guidelines for conducting designed experiments follow:

- Be there—it is important to actively participate in the experiment to ensure that the data is collected as planned. However, this does not mean that the engineering manager should operate the process

and/or collect the data. To best simulate the actual process and to avoid bias in the data collection, actual production personnel should operate the process and collect the data.
- Randomize trials across the entire design.
- Runs should be independent and not influenced by prior conditions.
- Ensure that the product or process design is fully capable of withstanding some level of user abuse.

A practical application of how designed experiments can be used is described in the following example. A heavy equipment manufacturer was experiencing an unusual failure in the tower section of its mid-sized end-loaders. (The tower is the portion of the machine where the operator enclosure rests and the part where the bucket/lift arm assemblies attach.) Although the design was believed to be quite robust, towers were developing cracks, which was an unexpected failure for this piece of equipment. Because of the seriousness of the failures and the possibility of injury to the equipment operator, further investigation was conducted.

The investigation revealed that these cracked towers were only occurring on vehicles owned by a specific customer. When that customer's equipment use techniques were assessed, investigators found that rather than use explosives to remove rock from the face of the quarry for pick-up by the end loader, the owner's operating personnel were driving the end-loader into the quarry walls with the bucket being used as a ram to remove the rock—not quite the use for which the equipment had been designed. Operators were instructed on the correct use of the equipment. When warranty claims were denied due to product abuse, the owner decided to pursue an alternative method of rock removal.

2. Robust Design

Depending on project goals, there are numerous approaches to design and testing that engineering managers find useful, including robust design. To ensure, early in the process, that the design is able to fully address the project definition, robust design employs certain concepts:
- Understanding the relationships between design parameters and the project definition
- Variation causes quality loss
- Two-step optimization
- Orthogonal arrays for matrix experiments
- Introducing "noise" into the experiment, including, but not limited to the following:
- Parameter variations
- Environmental changes
- Operating conditions
- Manufacturing variations
- Data analysis and prediction
- Identification and confirmation of interactions

In projects not employing robust-design techniques, quality efforts are traditionally made in the testing and/or production ramp-up phases of a project, when it is often too late to make significant changes.

8.5.5 Prototyping and Testing

Pilot production, while difficult and costly in and of itself, can be used to tweak products and processes to make them more efficient prior to project rollout. Field tests of pilot models often provide the opportunity to identify potential problems and make corrections before a large volume of product has been released to the public.

1. Pilot Builds

Design, unfortunately, does not always consider the physical requirements of the manufacturing environment. Sometimes it is not physically possible to manufacture the product in a safe or efficient manner without the development of special tools and fixtures to position and create parts. A pilot build allows manufacturing inefficiencies to surface.

Ideally, feedback from the pilot build should be solicited from all groups involved in the production process, not just engineering. This includes personnel in materials acquisition, scheduling, production operation, safety, tooling, and transportation, as well as anyone else involved in production. Collect feedback from designated representatives from each of these groups daily and use it to improve the processes and designs prior to production ramp-up.

It should be noted that feedback received from the production floor is invaluable to the pilot process. The employee who turns the wrench to build the product often has the most practical solution to problems encountered during the pilot build. Be sure to solicit, value, and use this person's input. In many instances, machine operators, technicians, and the like have just as much insight as those who hold an engineering degree and might even possess a greater amount of practical knowledge. Use that knowledge base whenever and wherever it is discovered.

Most industries and major companies have acceptance standards for how products should perform and be tested. Products from the pilot run are subjected to these standards to ensure success before full production.

2. Feedback Challenges

Feedback from suppliers, manufacturing personnel, and customers will help in the assessment of any new product pilot. Their combined input will help to ensure the best, most cost-effective product development and implementation. Incorporating the feedback obtained from the individuals involved in a pilot production will help smooth the way for improved performance in the future.

Ideally, the engineers and others involved in the design should be readily available during pilot production so that they can develop solutions based on field conditions. For global companies, some engineers involved in the design of a product are, in many instances, half a world away from the pilot-production facility. Thanks, however, to a wealth of advanced communication tools, web-based design, and increasingly sophisticated simulation utilities, it is now possible for engineering teams almost anywhere on the globe to interact in real time. For those companies that cannot realistically take advantage of such technologies, it is best to have at minimum a representative of the virtual-engineering team available on-site to address complications as they arise. Often, new designs or processes will be evaluated by building a prototype. Prototypes are not always constructed in the manner that will be used during full production, but the construction of prototypes does allow designs to be tweaked along the way. The next prototype to be built will be based upon knowledge gained during the design and development of the prior prototype. It is not always known if a new design will work. Prototypes serve as the test for design functionality and illustrations of ideas and can be used to gather early customer feedback.

The larger and more complex the design or product, the more advantageous it is to develop prototypes. Various designs can be assessed for manufacturability, cost, ability to meet the needs of the customer, and life expectancy. Large-equipment manufacturers build prototype models and send them to top customers for trial and feedback. Product designs are then improved through testing before full production begins.

When evaluating the manufacturability of a product, consider the following:

- Can the new design be constructed with existing tooling, or will new tooling (and increased costs) need to be a part of the design considerations?
- Are materials readily available?
- Do production personnel possess the knowledge, skills, and abilities to implement the new design; or will training need to be provided?
- Can the process required to complete production be controlled so that scrap and rework can be avoided?
- Are there any transportation issues involved, either within the production facility or outside? Is the product so large that it cannot be moved throughout the production facility? Will it need to be built in modules and then assembled on-site?
- If the product will be built in modules, how will functionality of the product be tested? Don't assume that if the parts are functional, the assembly will be functional.

- Does the new product need a special environment for construction, such as a clean room or a temperature-controlled environment?
- What alternatives are available for adaptation that will make the manufacturing process more efficient?

In order to evaluate the manufacturability of one product or a group of products, develop an assessment instrument to record all comments, problems, difficulties, and needed changes. It is also a good idea to record the decisions and activities that were effective so that they aren't inadvertently changed during redesign. Evaluation of alternative products requires that all alternatives be scored against the same criteria in order to determine which product is the best fit. The assessment instrument used can be as simple as a chart that is completed by hand or as complex as a custom computerized assessment.

8.5.6 Design Revisions

1. Basics

As an idea evolves into a design, revisions become common and even expected. Revisions help refine the work and help everyone become better designers by stretching the comfort zone and causing a re-evaluation of what is considered right. Designers have come to expect the inevitability of revisions—the real question is often how many revisions and when to say "enough." Designers inescapably have to deal with clients who have tried to obtain endless design revisions. However, as professionals, a clearly defined boundary for the frequency and number of revisions is needed.

How are these boundaries for design revisions defined? A contract is a great place to begin. Every job needs a contract that is approved and signed by all parties involved. The contract should contain a clearly defined process for revisions related to the specific project. No project or client is exactly alike, and every contract should reflect that. A solid knowledge of the clients and their needs is required. Generally speaking, there is no recognized number of revisions that make a design successful. The actual number required should be assessed on a per-client, per-project basis.

A key element in this process is to be clear when outlining what the contract covers. Clients need to be guided through their specific contract line-by-line so that there is complete understanding of what is in the contract and the implications of signing it. If necessary, schedule a specific time for a complete review of the contract. This will permit a thorough scrutinizing of the contract and its details. By taking the time to carefully review the contract with the client, his or her level of confidence and trust will increase and there will be less chance of persistent revisions and problems.

2. Progress Reports

Keeping the client base updated can work to the advantage of the organization by reducing the work load and ensuring fewer revisions. If the client is aware of what was originally agreed upon—including timelines and contractual specifics—there are less questions and problems related to the project. When the client is aware, he or she feels as if he or she is part of the project, and in some cases, even responsible for the outcome. With this sharing of responsibility, the client truly becomes a partner in the project. Confidence is built within the client toward the project. Clients are less likely to be critical of a project that they have helped to build and have confidence in.

3. Design Evaluation

Changes to the product or process generally result in changes to the bottom-line costs associated with the product or process. Computerized-simulation models have the ability to identify the effects of changing project variables. As new technologies are implemented, it is often most advantageous to adopt and test each new technology in a pilot or laboratory application prior to instituting a full-scale test. However, when evaluating the results of these controlled processes, it is wise to understand the wide range of variables that will be present when the product or process is released for general use. Under no circumstance, assume that the carefully controlled conditions of the lab will bear any resemblance to the actual conditions of use in the "real world."

Each new technology, product, or process will need to be evaluated for the following:

- Cost
- Feasibility
- Life expectancy
- Environmental impact
- Marketability
- Alternative uses

When evaluating several alternatives, it is best to evaluate each alternative against the same set of criteria. Encourage all project stakeholders to participate in the evaluation.

8.5.7 Life-Cycle Design

Another way that current practice differs from traditional product design is that of life-cycle engineering. Traditionally, engineers only concerned themselves with product performance—that is, does the product function in such a way so as to satisfy the user's needs, can it be manufactured within budget, and so forth. Today, in order to be competitive, the engineer must consider the various life-cycle issues associated with the product. This would include topics such as manufacture and assembly, packaging, shipping, usability, maintenance, service, recycling, and so forth.

Several life-cycle issues are listed next.

1. Design for Manufacture and Assembly

Design for manufacturability is a process to develop products efficiently and economically. The physical capabilities of the manufacturing environment should have a direct impact on the design of the product, as should the assembly and disassembly procedures that accompany manufacturing.

Engineers must understand that the "ultimate" design may not be able to be produced in the manufacturing environment and the design expectations might need to be adjusted to reflect the realities of the manufacturing facility.

When designing for manufacturability, consider the following:

- Tool capability
- Materials availability
- Worker safety
- Need for retooling
- Product flow throughout the production facility

2. Assembly/Disassembly Procedures

Assembly or disassembly procedures provide the guidelines, usually in a step-by-step format, for each step of the assembly or disassembly process. Procedures include the following:

- Parts and tools required
- Order of assembly or disassembly
- Assembly or disassembly criteria (such as torque, wait time, temperature requirements, fluid fill levels, etc.)
- Inspection criteria
- Packaging instructions
- Shipping procedures
- Documentation

Review and revise assembly/disassembly procedures to develop a consistent method of product assembly. During the review phase, the project team should carefully evaluate each step of the assembly/disassembly procedure to fully understand what assembly/disassembly involves. In an environment where a part cannot be reused due to safety concerns, assembly/disassembly procedures that require that part to be assembled, and then disassembled, and then reassembled require three times the number of that part than the final product actually uses. For example, if a bolt can only be torqued to the specified torque one time before it needs to be replaced, plan to make that bolt part of a sub-assembly that will not require removal of the bolt, or include the extra bolts required to disassemble and reassemble the product in the assembly/disassembly procedures.

3. Design for the Environment

Design for the environment takes into consideration, and works hard to minimize, the risks that the product or process would pose to human health and the environment. It also develops practices that take environmental-impact concerns into consideration.

4. Design for Maintenance

Design for maintenance takes special care to ensure that product maintenance can be completed using safe, easy methods. Parts that require routine maintenance and replacement should be accessible to most individuals and not require Herculean effort to service. Engine-oil dipsticks, for example, should not be placed in locations that mechanics have trouble reaching.

5. Design for Reliability

Design for reliability is an approach to make products and processes at desired levels of reliability while maintaining reasonable life-cycle costs. If the product and/or production process is not reliable, product performance will be undesirable and production costs will ruin profits. However, reliability doesn't just happen; it has to be achieved. Knowing how to calculate reliability is important but more so is the ability to actually make the product more reliable. Design tools, such as Failure Mode and Effects Analysis (FMEA), are a part of designing a reliable product, but they are only a start. Testing and control plans, Fault Tree Analysis, and other techniques can ensure that a desired level of reliability can be achieved.

6. Design for Reusability

Design for reusability acknowledges that just because a specific part of a product fails, it may not be necessary to discard the entire product. It may, in fact, be perfectly acceptable from both a cost and environmental impact perspective to divert usable parts of the product from the waste stream and reuse them to create other parts. For example, many automotive parts have been remanufactured for years. Consumer electronics are also often recycled for reuse.

7. Design for Service

Design for service develops products or processes that are easy to maintain and service. Disassembly procedures are provided so that service is easier to undertake and successfully complete (Doka, 2000).

8. Design for Disposal

Design for disposal views the design process from an often-overlooked angle. When the product's useful life is over, what are the disposal requirements? For some products, such as nuclear reactor fuel, the considerations are quite complex. For others, considerations are less intricate, such as the design for a packing carton that is left unwaxed and undyed in order to ensure the most efficient breakdown when the product enters the waste stream.

9. Design for Intellectual Property Issues

Intellectual property refers to types of creativity for which exclusive rights are granted by national laws. Of most interest to product designers are trade secrets and patents. In general, designers have two main concerns regarding these types of intellectual property. One is that their innovation is protected and that no one else can use it or take advantage of it. The other concern is that they do not violate the intellectual property rights of others.

8.6 Agile Development

Section 8.5 details approaches that can be used for product development. However, there isn't a single development model that is best for all projects. Some firms use a more adaptive or iterative approach known as Agile development. Whether managing projects to develop products or services, these methodologies are designed to accommodate change in requirements more readily and deliver working solutions as quickly as possible. For software development the most common iterative methodology is referred to as Agile software development. It describes a of collection values and principles that were written by a group of software practitioners in 2001 and are described as the Manifesto for Agile Software Development.

Agile software development methodologies have slight variations in the way phases of software development are defined although a full life cycle generally includes a concept phase, inception and scoping, iteration, release, production, and retirement.

- Concept phase—Projects are identified and prioritized as part of an overall project portfolio planning process.
- Inception and scoping—Team members are identified, funding is secured, and initial requirements are identified with the customer. At this point, the project is broken down at a high level into a series of iterations that last generally from two to four weeks.
- Iteration—The development team works to deliver working software based on iteration requirements and customer feedback. Each iteration will follow a set steps which include planning the details of the requirements to be delivered in the iteration, developing the software that delivers on the specified requirements, testing the software, demonstrating the software for the customer, accepting any customer or stakeholder feedback, and closing the iteration to identify any work that needs to move to the next iteration.
- Release—At the completion of the required number of iterations to deliver on the necessary requirements, any final testing is completed, necessary training and documentation are developed, and the final release of the software is delivered into production.
- Retirement—Includes any end-of-life activities including notification of customers or migrating them to new solutions.

The Agile development life cycle is dominated by the work that takes place during the iterations. Since each iteration is relatively short and a fixed completion time, teams develop a methodical approach for scoping the work they can complete in the time allotted. Key to a successful Agile process is the full engagement of the customer throughout the life cycle. This can be quite different from a traditional life cycle where the customer may be engaged early on to define requirements and at the end of the process if customer acceptance is needed.

8.7 Entrepreneurship

Entrepreneurship is often described as the process of developing, launching, and running a new business, which is often a small business to start. A key element of this definition is that the person developing this business (the entrepreneur) often carries the financial risk for the success or failure of the business. Entrepreneurs have an idea for an innovation or technology that they want to bring to market. At an early stage, the entrepreneur should develop a business plan, or pitch, which focuses on a mission statement and a market analysis that describes the customer problem being addressed by this solution. A fundamental challenge for nearly all entrepreneurs is funding. In the case of a complex start-up business that requires significant investment before any sales start, a more extensive business plan may be needed up front to secure financing from banks, investors, or both.

Like the discussion in Section 8.4, entrepreneurs needs to identify their strategic options and clarify their go-to-market strategy as they move their idea from development to launch. Gans, Scott, and Stern

(*Harvard Business Review*, May-June 2018) shared a framework, the entrepreneurial strategy compass, which allows start-up business founders to approach their strategy choices in a methodical way. They propose that the opportunities for new businesses can be categorized along two dimensions: attitude toward incumbents already in a similar business and attitude toward the innovation. This matrix identifies four strategies that can be considered in decision making that are described next:

- Be an idea factory. Maintain control of the innovation and figure out how to create value within an existing marketplace.
- Execute quickly. Focus on creating value for partners in an existing value chain.
- Protect intellectual property. Create and control a new value chain, often by developing a new proprietary architectural platform.
- Take incumbents by surprise. Go after existing markets.

Although start-ups want to move quickly, using some type of framework to test hypothesis regarding the new business proposal can yield insights into the feasibility of the technology, capabilities of the founders and whether they have the right skills to bring an idea to market, or requirements for funding needed. Analysis of these insights can help the entrepreneur chose the strategy that best aligns with the mission statement they started with to help motivate both them and other early stakeholders.

Review

Upon completing the study of Domain 8: Management of Technology, Research, and Development, you should be able to answer the following questions:

1. Describe the different types of R&D activities.
2. Identify the 3 types of R&D organization models.
3. How does technology management differ from R&D management?
4. Identify several sources of innovation.
5. Describe the technology s-curve. What challenges does this present for the engineering manager?
6. What are the steps in formulating an innovation strategy?
7. It is said that the key to product development is to identify those ideas that will not be successful and stop their development. Why is that a good strategy?
8. What is the value of beginning product development with defining product requirements?
9. It can be costly to end conceptual design too soon. Why is that?
10. What questions can simulations answer and how do they benefit the product development process?
11. The construction of prototypes can benefit some product development projects in ways that simulations cannot. What are some examples?
12. How can the engineering manager use techniques of life-cycle engineering to reduce product cost?
13. In what situations can Agile development provide benefits over more common product development approaches?

For Further Information

The Quality Improvement Glossary, by Donald Siebels, 2004. A great place to find the definition of terms and acronyms related to quality improvement.

The Quality Engineer Primer, by Bill Wortman. A good source for practical quality-improvement application tools and templates.

Tom Peters Essentials—Design, by Tom Peters. A concise reference for the resolution of common design issues.

ISO/IEC 15288:2002, Systems Engineering—System Life Cycle Processes, International Organization for Standardization. The ISO standard for system life-cycle processes. (The ISO standard for software system life-cycle processes is currently under development.)

Outsourcing: A Guide to Selecting the Correct Business Unit, Negotiating the Contract, Maintaining Control of the Process, by Stephen Brabb. Contains an effective overview of the outsourcing process with chapters devoted to specific industries.

Harvard Business Review on Strategic Alliances, by Harvard Business School Publications. A useful collection of expert advice on various strategic-alliance topics.

Improving Work Groups: A Practical Manual for Team Building, by Dave Francis and Don Yount. Provides strategies for improving teamwork and productivity.

Building Productive Teams: An Action Guide and Resource Book, by Glenn H. Varney. An excellent resource for identifying and addressing problems associated with teamwork and productivity.

Fundamentals of Project Management (2nd ed.), by James P. Lewis, 1995, New York, NY: Amacon. Contains a useful discussion of risk and risk management.

https://www.agilealliance.org/ - The website for the Agile Alliance

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9

Systems Engineering

Domain 9 Champions

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Alejandro Salado, Ph.D.

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Domain 9: Systems Engineering

Key Words and Concepts

Cybernetics	The study of feedback, control theory, and information theory in the self-regulation of complex systems.
"Ilities"	Qualities of the system not associated directly with specific behaviors or functionalities.
INCOSE	International Council on Systems Engineering, the professional society for systems engineers.
Key Performance Parameters (KPPs)	Parameters describing the overall performance of the system used to evaluate how well the system satisfies the customer's needs.
System Architecture	The arrangement of elements that form the system from different perspectives. The functional and physical perspectives are common, as well as the allocation of functions to components.
Systems Engineer	An engineer trained and experienced in the field of Systems Engineering.
System of Systems	A system composed of independent systems that yield capabilities in addition to those yielded by the individual systems, but that cannot be yielded by any of them individually.
Technical Performance Measures (TPMs)	Quantifiable and measurable characteristics of the system that indicate how well a design is predicted to satisfy a particular system function.

9.1 What Is Systems Engineering?

There are many definitions of what systems engineering actually is. While the nuances vary, there are several key factors. Systems engineering is a multi-disciplinary field of engineering that focuses on the technical design and management of complex systems over their full life cycle. Systems engineering uses, at its core, systems thinking principles to guide analysis, design solutions, and arrange elements and efforts within the domain. Problem formulation techniques, such as elicitation and derivation of requirements, is a cornerstone of systems engineering, since it facilitates that the system developed meets the stated customer's needs. System complexity continues to increase as technology grows. As such, the value of systems engineering in guiding increasingly complex technology designs is critical to achievement of desired outcomes.

9.1.1 Systems Engineering—History, Relevance, and Evolution

Systems engineering is typically traced back to the 1940s and Bell labs (Schlager, 1956), where researchers recognized the need to view the development of large-scale systems as a single entity rather than designing the components individually. As more complex systems were developed, designers found that they behaved differently than suggested by the components making up the system. To deal with these new challenges, new tools needed to be developed to manage the inherent complexity in systems that were required to perform these increasingly difficult tasks. As the world grows more complex and unpredictable, there is increasing interconnectivity between natural, social and technical systems (Cabrera & Cabrera, 2015). Systems engineering, despite remaining a young but emerging field of study, has shown significant growth in importance due to the need to deliver value to the stakeholders in a cost effective and time efficient manner.

Systems engineering encompasses understanding the problem, designing system solutions, assessing alternatives, and implementing the chosen solution through the end of the life cycle while considering both the business and technical aspects of design. It has decreased completion time and project cost for programs in which it was applied. (See Figures 9-1 and 9-2.) Because of these time and funding benefits, the United States Department of Defense requires that systems engineering effort be implemented in any contracts submitted to its agencies. There are a variety of reasons for these savings, including configuration management, design practices that prevent type I and type II errors early in the design process, and traceability that allow for faster and more accurate assessments of proposed changes. In this manner, systems engineering can be thought of as an interdisciplinary approach to accounting for the underlying complexities in modern systems and informing quality decisions.

Figure 9-1. Cost Benefits of Systems Engineering (INCOSE, 2003)

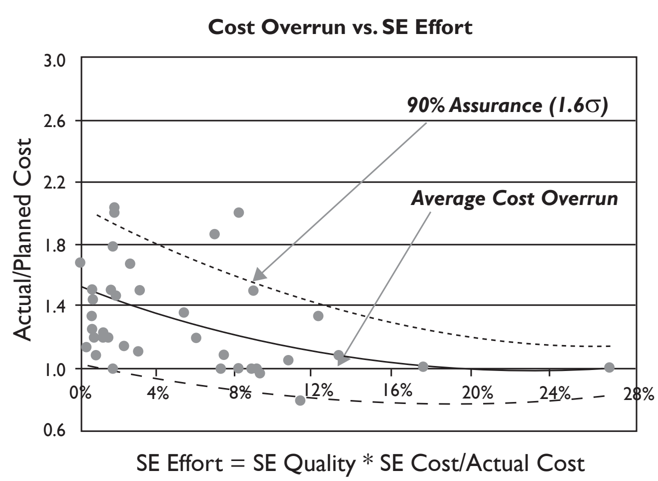
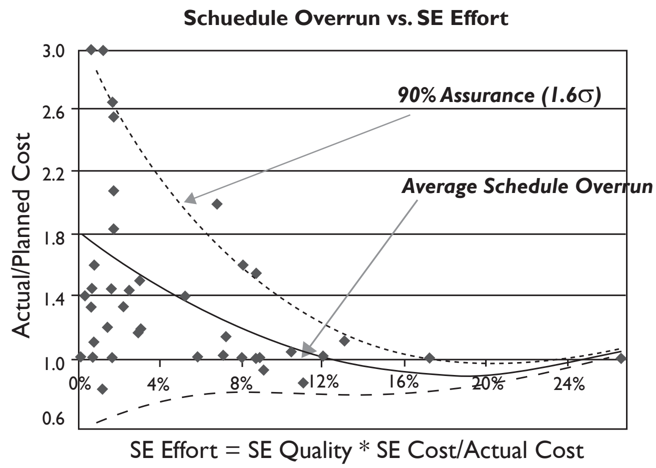


Figure 9-2. Schedule Benefit for Systems Engineering Effort (INCOSE, 2003)



9.1.2 Systems Science

The term “system” in systems engineering should be discussed briefly when considering systems engineering. In this context, a system is a group of related components and sub-systems to regularly interact in a meaningful way to accomplish a useful function. The system is described using boundaries, and anything that is outside of these boundaries is the environment. The environment can be comprised of many factors affecting the system including, but not limited to technological, economic, political, legal, health & safety, social, security, ecological, cultural, historical, moral/ethical, organizational, and emotional (Parnell, Driscoll & Henderson, 2011).

One challenge to systems engineering is accounting for interactions at the interfaces of the system with the environment. The interactions of the system components with each other adds to this challenge as systems dynamically evolve, and changes in a part of the system can affect the whole. This marks a distinct departure from classical design techniques that utilize reductionism, or the description of a product by the sum of its component parts.

The interdisciplinary approach to interacting components of an open system was first captured by Bertalanffy’s General System Theory (1950), in which he described spatial system boundaries in the context of the environment, and how system emergent behaviors materialize. Areas discussed in the theory include cybernetics, complex systems, and complex adaptive systems.

1. Cybernetics

Cybernetics is a field related to the study of how information and feedback is used in systems to achieve complex behaviors found in modern systems. In particular, cybernetics seeks to understand how this information and feedback allows for the control of systems. This gives rise to several areas of research that strive to understand and model these control mechanisms, such as neural networks, artificial life, and self-organization. These techniques for advancing cybernetics have led to many advances in the study of complex systems.

2. Complex Systems

Complex systems refers to systems that typically display nonlinear responses to changes both within the system and to changes in the system’s environment. These changes lead to emergent behaviors that cannot be easily predicted from the parts that make up the system. Understanding the interactions and conditions that give rise to these complex behaviors is one of the founding principles of systems engineering. In addition to the approaches used to advance investigations in cybernetics, several other methods, such as game theory, evolutionary computation, and cellular automata, have been used to model the interactions driving these systems to better understand the factors leading to the observed complexity.

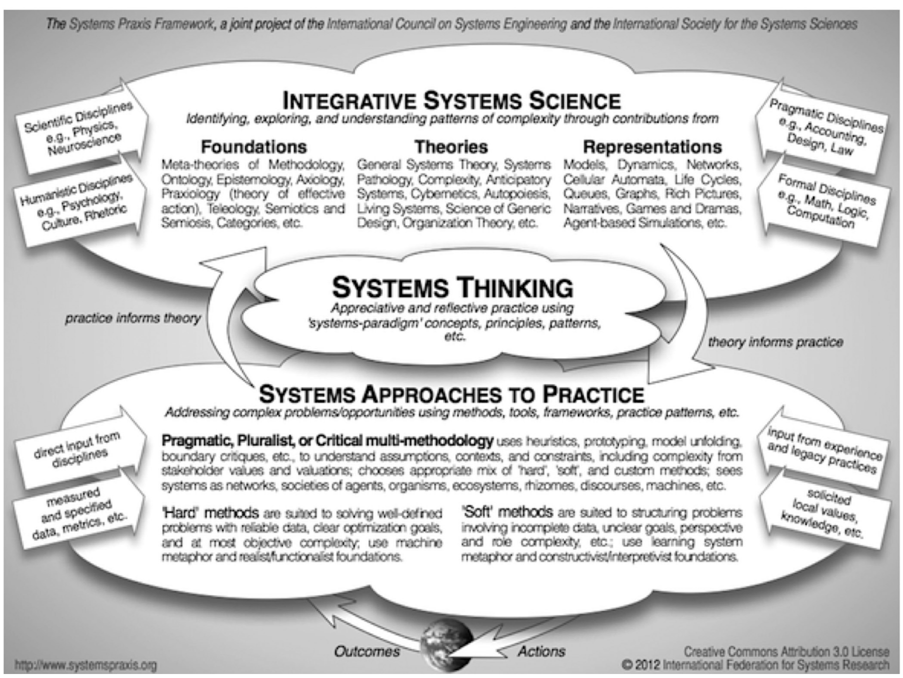
3. Complex Adaptive Systems

Complex Adaptive Systems (CAS) are a subset of complex systems that have the ability to learn from their environment and adapt to changing conditions. The term “Complex Adaptive Systems” was termed at the Santa Fe institute to describe a class of complex systems (Holland, 2006) that display behaviors found in higher forms of life, where work had been done to model and describe how these systems function. Changes in the system environment are perceived through some form of sensor or monitoring mechanism that provides information that is passed into the system as feedback to adjust behavior. The systems analyzed in this manner are normally modeled as “agents” carrying out a set of instructions that are modeled to achieve a particular behavior.

9.1.3 Systems Thinking

Fundamental to systems engineering is first defining the current state of an existing system, or need that a new system would serve. Systems thinking is the mental framework that helps the systems engineer to “think” through how the complex, or complex adaptive system interacts with the environment and other adjacent systems under uncertain, complex, and ambiguous conditions (Parnell et al., 2001; Cabrera & Cabrera, 2015). It is not a one-time activity, but an iterative task that must endure from initial system concept through system termination. And so while systems thinking begins at “defining the problem and system need,” it is equally important throughout the life cycle of the system. Systems thinking becomes the catalyst for theory (systems science) and practice (systems engineering approaches) to work together in a manner for action and desired outcomes for complex systems (Figure 9.3).

Figure 9-3. Systems Thinking



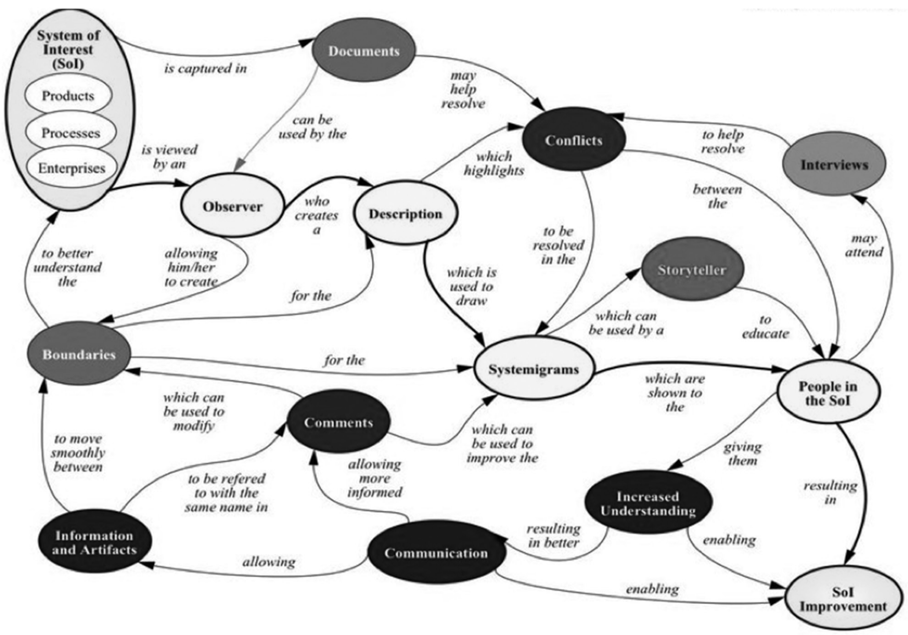
Inherent to systems thinking is the concept of mental models that can be captured by graphical models and enhanced through application of simple rules. A mental model is an “approximation of the real world,” which allows one to think through the interactions of the system with the real world (Cabrera & Cabrera, 2015). This model is iteratively checked against the real world, which then informs an updated mental model in what becomes one large feedback loop.

Systems engineers benefits from the application of simple rules, or patterns to enhance understanding of complex systems and their interactions with the environment. These rules were codified in the Cabrera’s DSRP framework of 2015 (Cabrera & Cabrera, 2015):

- Distinctions: Any idea or thing can be distinguished from the other ideas or things with it.
- Systems: Any idea or thing can be split into parts or lumped into a whole.
- Relationships: Any idea or think can relate to other things or ideas.
- Perspectives: Any idea or thing can be the point or view of a perspective.

Developing systems-diagrams, or "system-i-grams" using Boardman's Soft Systems Methodology (BSSM) developed in the 1980s (Figure 9.4), or similar methodologies, assists in the process of conceptualizing and re-evaluating the systems engineer mental model. These tools consist generally of nodes and links that capture the relationships between the environment and the system of interest. The BSSM can be thought of in the construct of the DSRP framework to enrich the systems engineer mental model as it real world engagement occurs.

Figure 9-4. Example of a Generic System of Interest Mental Model using System-i-gram



The construction of system-i-grams and application of DSRP framework are enriched by the systems engineer considering a handful of complementary systems thinking concepts including (paraphrased from Parnell & Driscoll, 2011):

- System Boundaries—Is the system of interest bounded by an open, partial, or closed boundary to adjacent systems or environmental factors? Drawing the boundary and defining its nature from the perspective of other elements or systems enables the systems engineer to better understand inputs, outputs, and feedback loops for the system of interest.
- Visibility of the System—Are the elements or other systems surrounding the system of interest known or unknown? This can be thought of as black, grey, or white boxes describing transparency of other elements or systems and could motivate the systems engineer's research efforts to eliminate uncertainty.
- Stakeholders can be defined in many categories, including but not limited to:
    - Decision Authority—ultimate decision gate to approve or implement a system
    - Client—source of principle authority for defining system requirements
    - Owner—responsible for system operation
    - User—accountable for purposeful use of the system
    - Consumer—realizes benefits from the system and could be a user
    - Interconnected—connected to the system and have benefits/costs/risks from the system

9.1.4 Common Themes of Systems Engineering

There are four prevalent themes that can be found in most systems engineering efforts, and many "tools" that fit within each. These common themes describes elements of systems engineering in the context the systems life cycle.

1. Top-Down Approach

The number of possible solutions for a simple problem statement can be immense. The ability to functionally decompose the fundamental system objective that is being designed for is key to assessing alternatives. The approach allows for a system architecture to be developed. The systems engineer must also take into account whether an alternative-focused, or value-focused thinking approach will guide solution decisions as a part of the decomposition (Keeney, 1996). Values represent "principles used for evaluation" and are inherently tied to meeting the stakeholder's system needs (Parnell et al., 2011; Keeney 1996). Alternatives could represent existing technology solutions, which might inspire, but do not inherently enable innovation in solutions.

2. Life-Cycle Perspective

All man-made systems have a useful life cycle associated with them. Systems engineering takes into account this full life cycle when evaluating and designing the system of interest to ensure that the solutions provided perform as required over the systems life cycle from initial establishment of a system need through retirement (Parnell et al., 2011).

3. System Requirements Emphasis

Systems engineering is a stakeholder needs motivated discipline, which uses requirements, among other tools for the design and implementation of the system. Starting from an initial need statement created by the customer and an engineering team, a collection of requirements describing how the system is to perform and operate is derived. As the system is developed, these requirements are traced through the system development to control and monitor that the system satisfies all requirements at all stages of development and implementation. In this way, customer needs are constantly taken into account to make sure that the final delivered systems meet all expectations.

4. Interdisciplinary/Integrated Team Approach

Systems engineering introduces methodologies to coordinate the efforts of multidisciplinary design teams to identify the system interfaces, reducing conflict and unifying efforts in system design. If each contribution from these engineering specialty areas was done optimally, the full system would likely be a sub-optimal solution due to interface issues and conflicts between the design efforts. System complexity is the result of combinations of domain technologies that drives the need for smooth functioning, interdisciplinary team solutions.

9.1.5 Systems Engineering Practice

Systems engineering has been used in many application areas and industries. It has been traditionally associated with the defense, space, and aeronautics industries. While these industries are early adopters of systems engineering, the tools and methods have expanded into several other areas, including transportation, biomedical, and agricultural projects. As systems become more precise and capable, they have become more interdisciplinary and complex. This has led several industries to pursue systems engineering as an approach to manage the complexity that arises from the multiple sub-systems interactions found in these new systems.

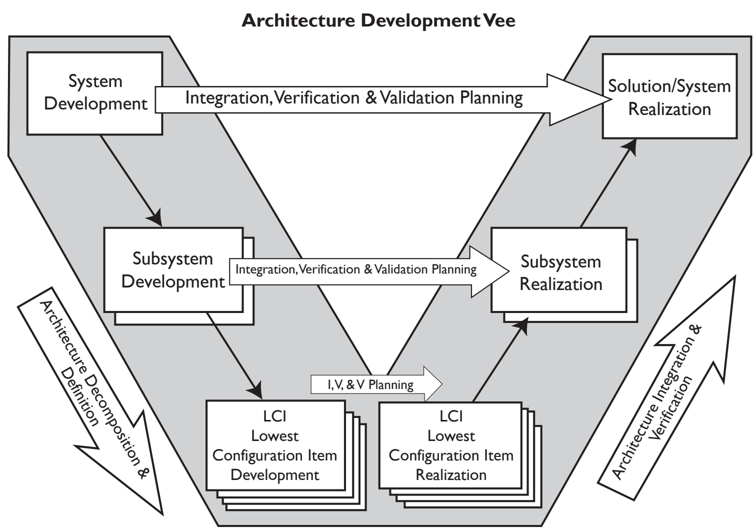
9.1.6 Systems Life-Cycle Process

Systems engineering focuses heavily on a life-cycle analysis of the system being developed through its realization. Some of the key considerations when developing a system are how that system will be maintained and supported, how long the system will be in the field, and how the system will be disposed of when it has reached its end of useful life. Using this life-cycle view of and value provided during system development allows for a comparison of designs based on the fully encumbered cost of system construction, use, and retirement. This cost takes into account not only monetary assets but also manpower, time, and other resources.

9.2 Systems Engineering Method

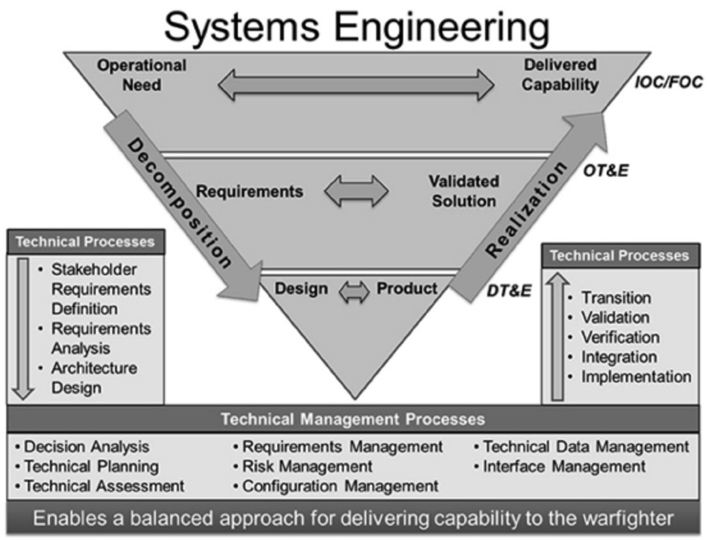
As mentioned previously, systems engineering generally uses a top-down approach, which decomposes the client motivated, fundamental objective. Systems engineering tools can be applied throughout the Vee system design framework. There are several models used to describe system design and implementation, which have been tailored to the particular type of system under consideration. While there are many models aimed at capturing a system's life cycle including the waterfall and other stage-gate models, the systems Vee unpacks the importance of system maturation over time. The Vee model (Figure 9.5) has primarily been adopted by US Department of Defense (DoD) and incorporates the relationship of major SE activities and SE processes. (See Figure 9.6.)

Figure 9-5. The Vee-Process Model for System Design Showing Verification and Validation (Foresberg, Mooz, & Cotterman, 2005)



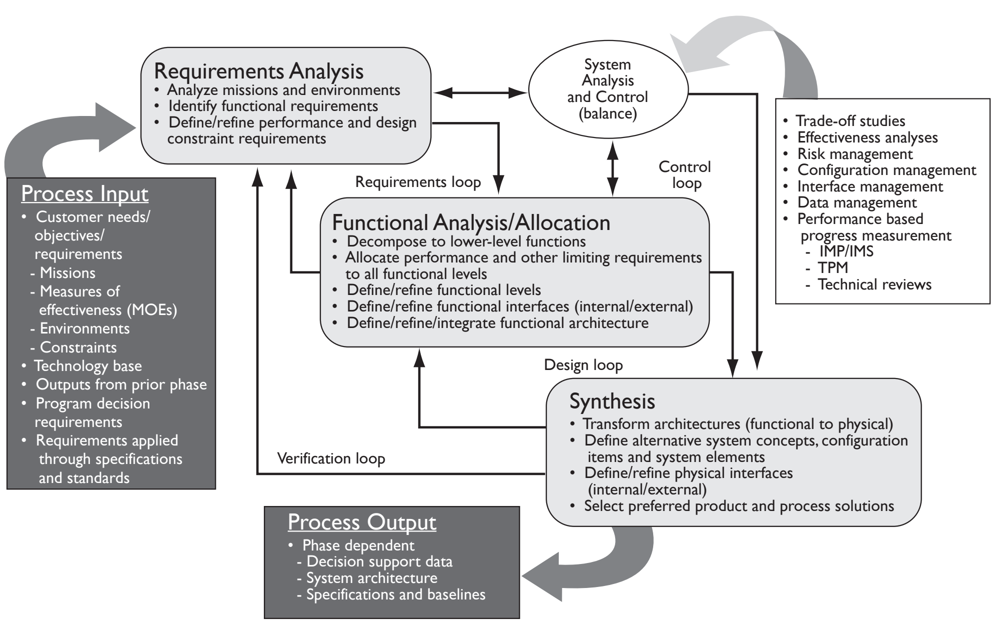
System validation is performed to ensure that all of the needs have been satisfied. System validation against the initial customer needs allows for the movement toward production. The processes for validating satisfaction of the customer needs are developed along with the system, ensuring that none of those needs/requirements has been missed and describing how it will be validated.

Figure 9-6. The SE Process Model for System Design, Showing Associated Processes (Defense Acquisition Guidebook, 2015)



As the system design moves forward (down the left side of the Vee model), another process model is followed. This systems engineering process (see Figure 9.7) describes how the system requirements are taken into account to develop the system architecture. This is an iterative process that incrementally refines and flows down the system requirements based on initial customer needs and allows for traceability of requirements.

Figure 9-7. Systems Engineering Process



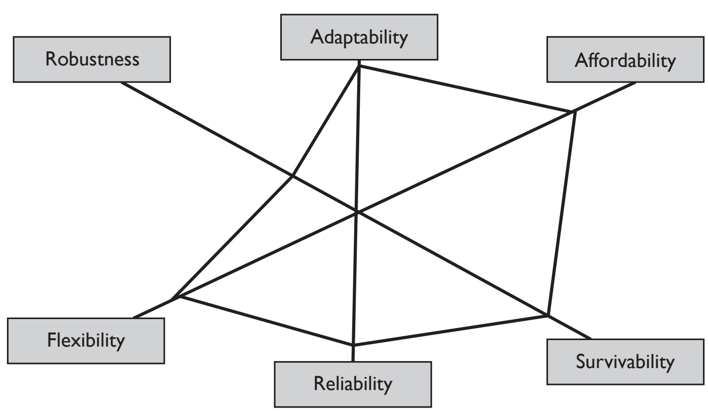
9.2.1 Process Inputs

The first process input is a statement describing what the system's functional purpose will be. For the purposes of the material presented here, the description will be of a project in which the systems engineer has been approached with a specific problem statement, acknowledging that this might not always be the case. Starting with this problem statement, more details are solicited from the customer to develop an agreed-upon goal of the system. This takes the form of a need statement, which is a succinct statement of what the system is to accomplish and any particular restrictions and constraints that the system will have to work within. This need statement is the source for the system requirements and is the final point of validation for a developed system before it is put into service.

To develop a high-performance system, it is necessary to identify how performance will be measured. The objectives/mission of the customer when identifying the need are used to develop key performance parameters, measures of effectiveness, and technical performance measures, which are then used to evaluate different design options.

- Key Performance Parameters (KPPs) are the high-level descriptors that describe the critical system characteristics and attributes of the system. For high-performance system architectures, these are the characteristics that should come to mind when that system is mentioned. KPPs can be measured in naturally occurring, or constructed scales, and should capture minimum thresholds of performance. These constitute "go"/ "no-go" criteria. Figure 9-8 provides a visual representation of possible KPPs.
- Measures of Effectiveness (MOEs) are defined by the defense acquisition university as descriptors that establish how well a system accomplishes the overall goals of the customer (Acquisition Community Connection, accessed on May 26, 2012). These measures are related to the key performance parameters in that they are used to evaluate the system, but they are defined later in the design process when there is sufficient information about the system to provide descriptions of how it is accomplishing the customer goals.
- Technical Performance Measures (TPMs) are specific and quantifiable characteristics that describe how well a system is performing. They are indicators of how well the system is predicted to perform, usually regarding a specific requirement or a constraint. TPMs are typically used after the design has been specified to a level where comparisons can be made between different options to accomplish the system goals, such as selection of fuel types or material for a wearable part.

Figure 9-8. Kiviat Chart for Visualizing System Key Performance Parameters



An example can be provided in a new military aircraft design. If the aircraft was to show military presence, be affordably priced, and be environmentally friendly, then some of the KPPs could be project power, affordability, and green. A measure of effectiveness for the project power could be the lethality and amount of time it can spend in combat. TPMs related to this could be ferry range, acceleration, and carrying capacity.

9.2.2 Requirements Analysis

Once the stakeholder's needs are established, a list of requirements is derived. These requirements represent all of the design criteria that must be satisfied. As such, they should reflect the KPPs that were created at the inception of the program. Often, along with the need statement, the initial set of requirements represents the agreed-to terms between the customer and the design team. This set of requirements should be reviewed, discussed, and agreed to by the customer and the engineering team.

System requirements should be identified as early as possible, reviewed regularly, and traceable to system needs and technical approaches (Blanchard & Fabrycky, 1990). Requirements define thresholds, targets, or criteria for the system that allow the systems engineer to determine whether the system is effective. Requirements should generally:

- Utilize the word "shall" as in "the system shall…"
- Be complete with all information
- Be consistent and not in conflict with other requirements
- Be unambiguous and clear
- Be verifiable
- Clarify customer/user needs and constraints

Elements of a good set of requirement statements include (Blanchard & Fabrycky, 1990):

- **Mission definition**: Identify primary/secondary system missions → what is it supposed to accomplish and how?
- **Performance and physical parameters**: Define the operating characteristics or functions (i.e., size, weight, speed, range, accuracy, capacity, etc.)
- **Operational deployment or distribution**: Identify quantity of resources (equipment, software, personnel, facilities, etc.)
- **Operational life cycle (horizon)**: How long will the system be in operation?
- **Utilization requirements**: Estimated usage of the system and its elements (i.e., hours/day, % of total capacity, etc.)
- **Effectiveness factors**: Requirements specified as "figures of merit" (FOMs) (i.e., cost/system effectiveness, availability, readiness rate, failure rates, etc.)
- **Environmental factors**: Environment in which the system is expected to operate (i.e., temperature, humidity, geography, air/land/sea, transportation modes, storage, handling needs, etc.)

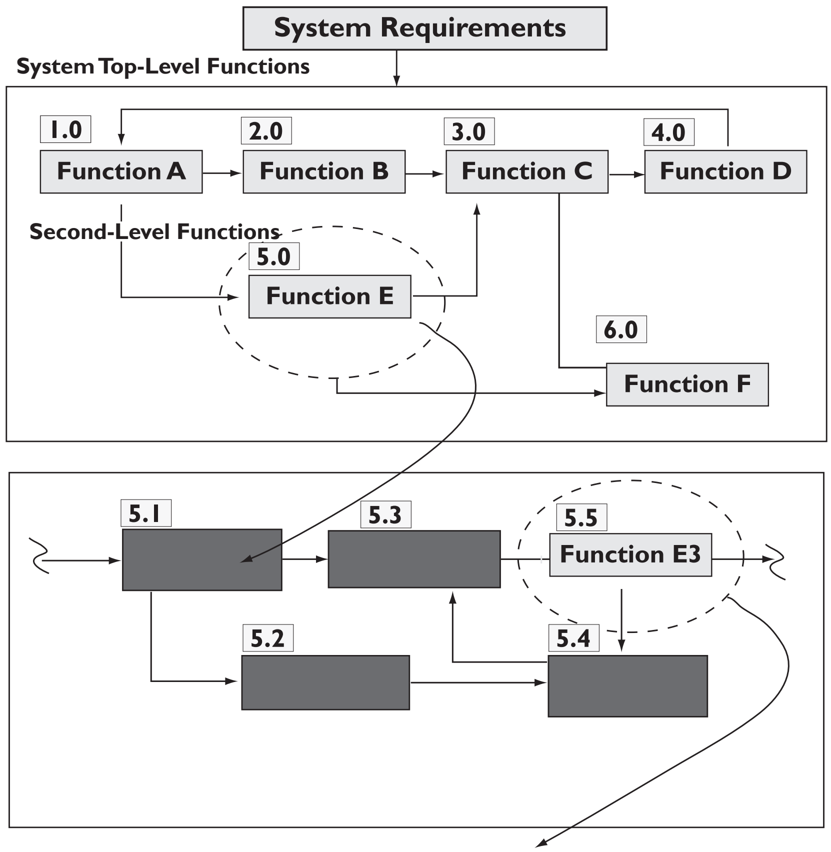
Traceability is another key aspect of requirements analysis. As the system requirements are refined and newly derived requirements are added to the systems requirement document, it is vital to keep track of where the requirements were introduced, what requirement they are a refinement of, and the justification for that requirement. Not only is this essential for keeping track of system development, but also it greatly simplifies configuration management.

9.2.3 Functional Analysis and Allocation

With the requirements of the system identified, the next step is to describe how these requirements are to be satisfied. This functional analysis and allocation is done by considering the initial set of requirements and developing functions that can accomplish the goals of those requirements. It is important to note that at this phase, there are still no physical components of the system proposed. The functional analysis only deals with the functions that are necessary to satisfy the given requirements, not the physical components that accomplish those functions. Functional Hierarchies, Integrated Definition Methods (IDEF) modeling, and functional flow block diagramming (FFBD) are all methods of functional decomposition of a system.

To illustrate one method, the FFBDs show how the functions are arranged, either in parallel or sequentially, to accomplish the system goals. (See Figure 9.9.) When the system-level requirements are being developed, the top-level system functions are developed to satisfy the top-level system requirements. As the system design matures, the functions carried out by the system are further decomposed. This gives a hierarchical representation of how the system functions are developed and provides traceability between the different levels of functions in the system. This structured function approach acts as the system functional architecture. When multiple functions are available for satisfying the system goals, trade studies are necessary to determine which method best fits the needs satisfied by the system architecture. The FFBD limitation is in a lack of detail capturing all inputs/outputs and controls on the system. This is a strength of IDEF modeling.

Figure 9-9. Functional Decomposition

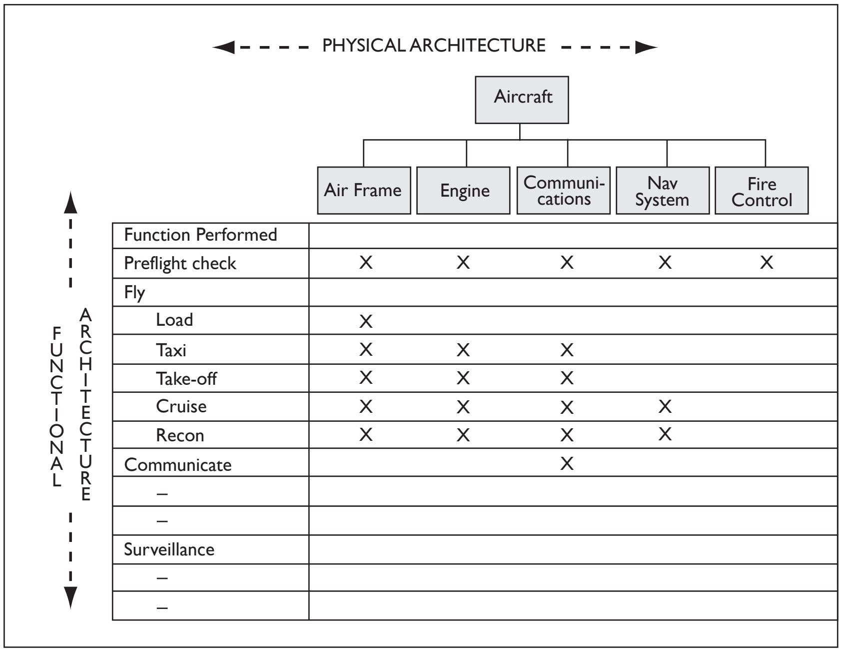


9.2.4 Synthesis

The system synthesis stage is where the system functional architecture represents the sub-systems and components of the system that will perform the mission. Conceptual designs are proposed to accomplish the overall goals of the system, and these different alternatives are compared to determine the best system solution to move forward through the design process.

Verification of the system during this stage. This is done by comparing the physical architecture developed to the functional architecture to ensure that all of the system functions are being accomplished. (See Figure 9.10.) Combining this with the similar matrix used for the functional analysis, this makes it possible to verify that each requirement is being satisfied by a sub-system or component of the physical architecture.

Figure 9-10. Mapping of Functional Architecture to Physical Architecture (Systems Engineering Fundamentals, 2001)



Function Performed	Air Frame	Engine	Communi-cations	Nav System	Fire Control
Preflight check	X	X	X	X	X
Fly					
Load	X				
Taxi	X	X	X		
Take-off	X	X	X		
Cruise	X	X	X	X	
Recon	X	X	X	X	
Communicate			X		
–					
–					
Surveillance					
–					
–					

It is also important to consider the interactions and interfaces of the system at this stage of the development. As alluded to in the systems science section of this chapter, the most common difficulty in designing modern systems is the emergence of unexpected results because of the multitude of interfaces that must be considered, combined with the second, third, and higher-order effects caused by changes in system design.

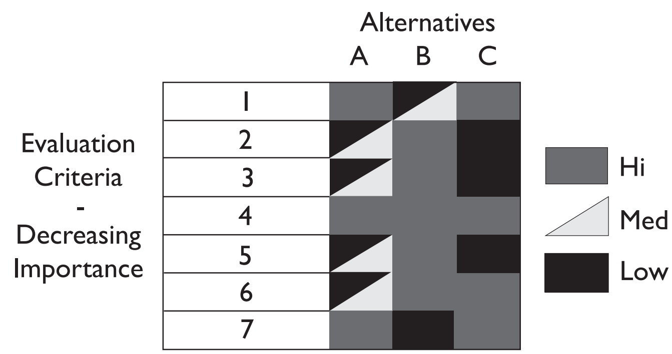
9.2.5 Process Tools

Determination and management of configuration include several tools for employment. While they are not all applicable to every stage of system development, they provide valuable information on the proposed concepts developed in the requirements analysis, functional analysis, and synthesis to allow for an informed engineering decision.

1. Trade-off Studies

With the number of interactions and interfaces in modern systems, it is almost inevitable that there will be conflicting performance measures that will make it necessary to select a compromise solution. For example, a vehicle may be selected that has good acceleration and top speed, but this would likely come at the cost of fuel economy and range. This can be done using several approaches, from a simple matrix comparison (see Figure 9.11) to a rigorous decision analysis approach. By selecting appropriate criteria, either through evaluation and/or soliciting stakeholders, it is possible to prioritize the available alternatives based on the goals of the system users and stakeholders.

Figure 9-11. Example of a Trade Study With Three Alternatives



2. Configuration Management and Change Control

As the system design is shaped through the systems engineering process, a record of the configuration of the system might be maintained. One of the realities of system design is that when dealing with a system, changes could likely be introduced and risk must be reassessed to time/cost/performance of the system. Proper configuration management makes it possible to trace a design out to the decision point that made the configuration no longer preferable (or even feasible) and move forward without having to start the design process from scratch. Proper implementation of change control will keep the design effort coordinated and ensure that all of the necessary interfaces are accounted for when a change in configuration is required.

3. Interface Management

The ability to manage interfaces and integration points is important in systems engineering, as that is one possible failure point in designing complex systems. Because of the difficult-to-predict behaviors at interfaces, extra care is given to make the information crossing these boundaries easily accessible. One example is the use of interface control documents that show a representation of either the whole system or a particular sub-system or component and list all of the interface points for the portion shown. In addition, information relating to the parameters associated with the interfaces is highlighted, making it clear how the interface is to be handled and what may be flowing across the boundary. This information allows the interfaces to be managed along with the rest of the design configuration, decreasing the likelihood that a system change will not be reflected at the integration points with other systems and/or components.

9.2.6 Process Outputs

When the synthesis phase is complete, the result is a system concept for that iteration of the systems engineering process. If the review is successful, a baseline configuration is established, updating any changes to the system architecture and making the necessary changes to the system documentation and supporting data. The next iteration of the systems engineering process is then initiated, with the process output now used as the process input. This continues until the system is fully developed and described. Upon reaching this stage (at the bottom of the Vee diagram), the system is fully specified and the final baseline system design is ready for construction/production.

9.3 Implementing Systems Engineering

There are several ways in which systems engineering can be implemented. The specific implementation in a project will depend on the context and objectives of that particular project. In fact, improper adaptation of systems engineering implementation to a project may even negatively affect a system's development. Therefore, consciously defining an implementation plan for systems engineering before its execution is considered essential for a successful system development.

9.3.1 Overview

The implementation of systems engineering needs to be defined in multiple dimensions. Among others, these include the principles and approaches that will be followed and used, the way in which technical disciplines will be technically integrated, the way in which the team will integrate and interact, and the way in which systems engineering will support technology maturation and insertion during system development. The following sections describe the aspects that need to be considered when implementing systems engineering.

9.3.2 Systems Engineering Management Plan

Traditionally, the implementation strategy of SE is defined and planned in the Systems Engineering Management Plan (SEMP). The purpose of the SEMP is to guide the technical aspects of the system development. Therefore, and in line with the previous discussion, the SEMP should be tailored to each project or system development. Some corporations decide to define a standard SEMP that is tailored to each project as a function of the project unique context and conditions.

The SEMP is often captured in the form of a standalone document. However, there is no prescription for such form. As with many other SE artifacts, the essential point is that the implementation of SE is consciously planned in line with the specific system development context and that the systems engineering team operates within the framework it provides.

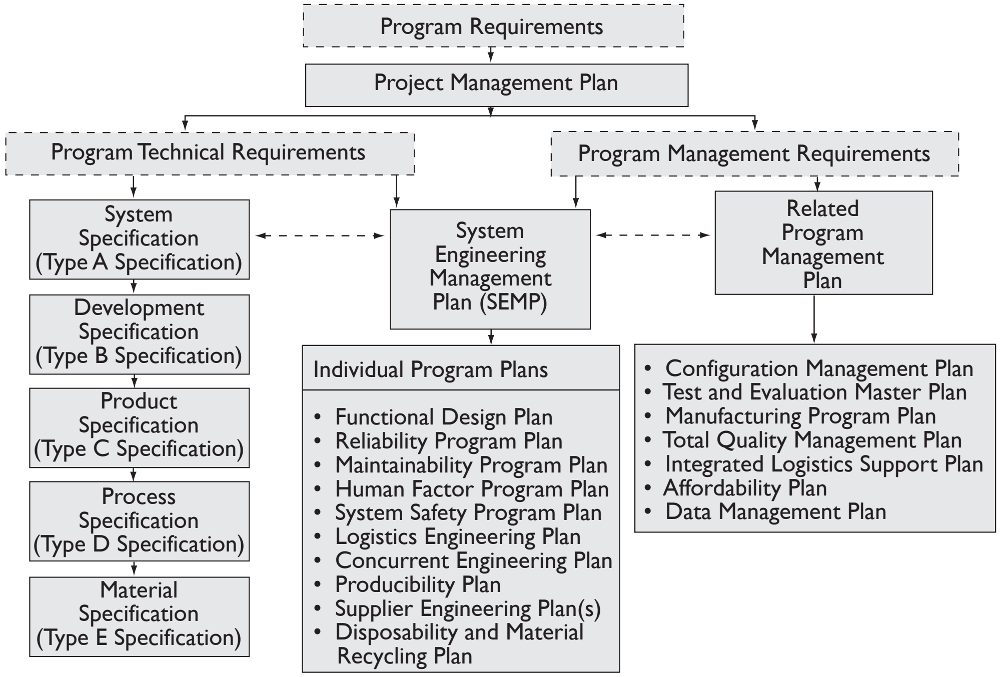
Different industries or corporations may impose a standard SEMP or, more accurately, require a specific table of contents for the SEMP. However, while certainly such required information must be part of the SEMP, its final content does not need to be limited to them. Instead, the systems engineering team should include any other content necessary to fulfill the purpose of the SEMP in the context of each particular project. As an example, a generic table of contents for a SEMP is as follows:

1. Boundary conditions and major drivers
2. SE principles and approaches
3. Key activities
4. Technical effort integration
5. Technical processes
6. Technology insertion
7. Project plan integration
8. Tailoring

In large projects, it is not uncommon that some aspects of a SEMP are contained in stand-alone documents. In these cases, two aspects are essential: (1) avoid repeating information between the different plans; (2) guarantee consistency in approaches, objectives, and overall strategic intent in all plans.

Finally, the SEMP should be considered a living plan (see Figure 9-12) that is adjusted as the system development progresses. This is instrumental: the SEMP should aid the system development, not constrain it. As knowledge is gained during a system development or conditions change, such as for example priorities and drivers, some aspects of the SEMP may cease to be relevant and some other aspects that were not there in the first place may need to be considered at some point.

Figure 9-12. Systems Engineering Management Plan (Adapted from Blanchard & Fabrycky, 2011)



One of the topics often mentioned in systems engineering is "ilities," which describe many of the non-operational requirements that the system under consideration must satisfy. The SEMP provides an opportunity to plan for these needed additions to the system while the system is being developed. Some of these topics are covered in the following plans. It should be noted that this list is not exhaustive.

1. Maintainability Plan (Maintainability)

The ability for the system to be brought back into a usable state or to ensure that the system will be in an operational state when needed falls under the maintainability plan. This plan includes details about preventive and corrective maintenance, which is responsible for the maintenance, and where maintenance items are to be carried out.

2. Human Factors Plan and Safety Plan (Usability)

The usability of the system is defined by the human factors plan and the safety plan. The human factors plan relates directly to human interactions with the system, whether it is human operators or the system operating on humans. A large part of this also concerns which functions are to be allocated to the system and which functions are to be carried out by humans within the system. The safety plan not only relates to the usability of the system, but also to the degree to which the system might pose a danger to humans or the environment and how any risks associated with this will be managed.

3. Logistics Engineering Plan (Supportability)

The supportability of the system refers to the ability to provide the necessary material to keep the system in an operational state. This is different from maintainability, which relates to the work associated with keeping the system working, although the two are closely related. In addition to repair parts, the logistics engineering plan also deals with expendable supplies. In addition, if the system must be transported to the operational site, the logistics engineering plan will also provide those details.

4. Disposability and Material Recycling Plan (Disposability)
As part of the systems engineering life cycle, plans for the eventual disposal of the system must be made. This describes any special care that must be taken with hazardous material, any opportunities for reusing system components, and any recovery possible when the system is decommissioned.

5.Test and Evaluation Master Plan
While not directly under the SEMP, the test and evaluation master plan (TEMP) has a significant impact on the validation of the system and so bears mentioning in this domain. This plan contains the tests and evaluations developed with the system requirements that describe how the final system design will be tested to prove compliance with the requirements agreed to by the customer. This includes information about what will be used to conduct the tests who will perform the test (skill level and available materials), and where the test will be conducted.

9.3.3 Establishing and Monitoring Boundary Conditions and Major Drivers

The implementation of systems engineering will be driven by the way in which the system under development provides value to the organization that develops it, and bounded by the contextual conditions of the project.

Often, the value a system provides is a function of programmatic objectives (e.g., profit, cost, or time to market) and capability objectives (e.g., system performance). However, certain system developments may have different objectives, such as entering a new market, generating new knowledge for the organization (learning, as in innovation projects), or leveraging some owned technology. This list is of course not exhaustive. Therefore, the implementation of systems engineering requires formalizing explicitly the objectives that the system development needs to achieve. In general, these objectives will derive from some business plan related to the system under development. Techniques such as preference elicitation, value modeling, and objective mapping aid in this regard.

In addition, the context in which a system is developed poses constraints and limitations that may shape the implementation of SE. These constraints and limitations need to be elicited and made explicit. Examples include: regulations that limit the use of certain technologies, standards that enforce the use of certain processes, technological limitations imposed by the state of the art or the corporation developing the system, confidentiality agreements that limit information and data storage and exchange, or laws that limit the type of personnel that can be engaged in the development effort. These restrictions may be stipulated throughout several project artifacts, in principle not defined by the systems engineering team, such as statements of work, applicable regulatory documents, or specific contractual clauses. Deriving them or pointing at them from a single source that the systems engineering team can use is recommended. For example, if using requirements as a problem formulation approach, constraints and limitations can be derived as process or product requirements, when applicable.

There may be other drivers, perhaps of a more informal nature, which nevertheless are important to shape the implementation of systems engineering. Examples may include: specifics on the (desired and existing) nature of the relationship with a customer, preference to avoid certain type of work or using certain type of facility, preference on interaction dynamics with suppliers, potential leverages with suppliers, cautionary notes on certain processes, etc. Although it may not be possible to document this type of drivers formally, they should still be made known to the systems engineering team, perhaps treating them as confidential information, so that the actual implementation of systems engineering aligns with all, formal and informal, project objectives, boundary conditions, and drivers.

Project objectives, boundary conditions, and main drivers may evolve during system development. There are multiple causes for this, including contractual changes, results of technology maturation programs, changes in management or corporate interests, or changes in risk attitudes. This list is of course not exhaustive. Nevertheless, mechanisms to identify those causes and monitor their potential materialization, to monitor and evaluate resulting changes in project objectives, conditions, and drivers, and to initiate actions to update the systems engineering strategy on the bases of those changes should be considered when implementing systems engineering.

9.3.4 Defining and Adjusting SE Principles and Approaches

The implementation of systems engineering may be driven by a set of principles and approaches that are defined based on the development characteristics identified in Section 9.3.3. These principles and approaches guide the overall systems engineering effort and represent the overarching technical strategies that will be used to achieve the defined development objectives. Three aspects should be considered:

1. *Lifecycle strategy*: Addresses general principles and strategies related to how the system will be realized. Among others, examples include agile, waterfall, direct validation, rapid prototyping, and gated development.
2. *Development strategy*: Addresses principles and strategies that operationalize project objectives. Among others, examples include Design to Cost (DtC) and Cost As Independent Variable (CAIV).
3. *Development guidelines*: Addresses guidelines about what aspects should be considering when designing and developing the system in pursue of the project objectives. Among others, examples include Design for Manufacturing (DfM) and Design for Testing (DfT).

It should be noted that hybrids of these may be defined as well, for different aspects of the system development. Describing each approach in detail is beyond the scope of this *EMBOK Guide*. The reader may refer to external references for specific information about each SE approach.

9.3.5 Identifying and Monitoring Key Activities

Since resources for developing a system are likely finite, it is necessary to identify those key development activities where SE can exert its maximum influence. Furthermore, limitations and other constraints, as identified in Section 9.3.3, may require specific attention to or care with certain development activities. Note that a list of such activities cannot be prescribed; it will depend on each individual project. Examples of such activities may include:

- Critical transport of a technology due to risk of deterioration.
- Critical transport of a technology due to risk of breaches to confidentiality/export control regulations.
- Critical integration of a component due to high safety hazard for operator.
- Critical acquisition of a component due to incompetence of a vendor.
- Critical requirements management due to conflicting needs from different stakeholders.

These key activities are then used to justify certain engineering decisions, as well as to drive the allocation of technical effort (ref. Section 9.3.6). In addition, specific processes (ref. Section 9.3.7) may be defined in relation to them.

Generally, implementing SE will require the identification of alternative development or action paths. These decision gates or opportunity windows may also be considered as part of the key activities for SE, since they may as well drive certain decisions and process implementations. Examples include:

- Pre-defined events to decide whether new technology under development may be incorporated into or removed from the system architecture/design.
- Pre-defined events to decide whether a prototype will be terminated or repurposed for further learning.

9.3.6 Defining the Integration of Technical Effort

The implementation of systems engineering requires the integration of multiple disciplines. This integration needs to be defined and to occur on multiple dimensions:

1. Team, roles, and communication

Roles in systems engineering may be defined in two dimensions: (1) in terms of the systems engineering activities that are performed or (2) in terms of the disciplines that form the systems engineering teams. Teams may be formed using either of the approaches or a combination of them.

Using the first approach, which has been traditionally employed in practice, a systems engineering team is comprised of a technical manager or chief systems engineering team, supported by a team of architects in various domains, such as electrical architect, mechanical architect, operations architect, etc. In this type of team setting, all members of the team contribute to systems engineering activities, such as requirements engineering, system architecture, or verification, for example, by leading the aspect related to their domain of expertise.

Using the second approach, a systems engineering team is comprised of a technical manager, a requirements analyst, a systems architect, a verification engineer, and so forth, (or a team of each of those roles) supported by a team of domain experts that provide information but do not lead systems engineering activities such as requirements, architecture, or verification, for example.

The different structures for systems engineering teams yield different strengths and weaknesses. The first approach is efficient from a human resource perspective, but generally suffers from lesser expertise in systems engineering methods and a threat to holism. The second approach may yield a higher quality of the systems engineering outcomes, but it requires a significantly higher consumption of human resources. This *EMBOK Guide* does not prescribe a team approach. Instead, it should be selected based on the nature of the project and other organizational constraints.

Regardless of the team structure, the following systems engineering activities should be considered and allocated to different roles when defining the systems engineering team (adapted from INCOSE):

- *Requirements engineering*: Manage a business or mission analysis; Define a problem or opportunity space; Characterize a solution space; Evaluate alternative solution classes; Define stakeholder needs; Develop operational concepts and other life cycle concepts; Transform needs into stakeholder requirements; Analyze stakeholder requirements; Manage stakeholder needs and requirements definition; Define system requirements; Analyze system requirements; and Manage system requirements.
- *Architecture/Design development*: Develop architecture viewpoints; Develop models and views of candidate architectures; Relate architecture to design; Assess candidate architectures; Manage selected architectures; Assess alternatives for obtaining system elements; Establish design characteristics and design enablers; and Manage system design.
- *Systems integration*: Perform and manage system element implementation; Identify, agree and manage system-level interfaces; Plan and perform integration; and Manage integration results.
- *Verification and validation*: Plan and perform verification; Manage verification results; Plan and perform validation; Manage validation results; Plan and perform system transition; Manage results of system transition; and Obtain qualification, certification, and acceptance.
- *System operation and maintenance*: Plan operation; Manage results of operation; Perform and support system/product operation; Plan and perform maintenance; Perform logistics support; Manage results of maintenance and logistics; and Plan, perform, and finalize system phase out.
- *Technical planning*: Define the SE project; Plan the SE project and its technical management; Activate an SE project; Identify and record tailoring influences and mandated structures; Obtain input from parties affected by the tailoring strategy; and Make tailoring decisions and select life cycle processes.
- *Technical monitoring and control*: Plan SE project assessment and control; Assess SE projects; Control projects from an SE perspective; Plan and perform system measurement; Plan system quality assurance; and Perform system product or service evaluations.
- *Acquisition*: Plan system acquisition; Select suppliers; Establish, maintain and monitor acquisition agreement; Accept products or services from suppliers.
- *Information and configuration management*: Plan configuration management and information management; Perform configuration identification, change management, configuration status accounting, configuration evaluation, and release control.
- *Risk and opportunity management*: Plan technical risk and opportunity management; Manage the technical risk profile; Analyze, treat, and monitor technical risks and opportunities.
- *Lifecycle process definition and management*: Establish, assess, and improve lifecycle processes including the definition and implementation of life cycle models.
- *Specialty engineering and organizational project enabling activities*: Plan system-level activities associated to a specific domain of expertise such as training, electromagnetic compatibility, etc.

Communication rules and vehicles, including levels of authority over systems engineering artifacts, should be defined for the different members of the SE team, in order to guarantee technical consistency during the system lifecycle. Some projects may require rigid structures, while others will be more effective with loose ones. This *EMBOK Guide* does not prescribe any specific structure; instead, the structure should be defined based on the specific characteristics of the project, as presented in Section 9.3.3.

2. Decision making

Decision-making is at the heart of systems engineering. Decisions are made throughout the system lifecycle, such as to select system architectures, decide what verification activities to perform, or choose whether to adopt certain technologies or not. Often, systems engineering decisions require integrating inputs from diverse disciplines. The conditions for such integration need to be defined, considering the following aspects:

- *Taxonomy of decisions*: Since different types of decision may require different decision approaches, a taxonomy is used to distinguish between types of decisions using a predefined set of criteria. For example, some decisions may be routine or subjected to a pre-established action protocol, while some may deserve dedicated sophisticated analyses. This *EMBOK Guide* does not prescribe any specific taxonomy of decisions, and hence of criteria, that need to be taken as part of a systems engineering effort. Examples of such criteria may include thresholds on consequences to the project (e.g., financial, performance, etc.), the decision maker, or the time that is available to make a decision.
- *Decision approach*: For each type of decision, a decision approach must be defined. For example, whereas for some decisions established protocols of action may have been defined, some other decisions may require a formalized decision analysis.
- *Decision ownership*: Decision ownership for the different decisions that the systems engineering team may face needs to be defined in order guarantee decision effectiveness. The definition may be on a specific list of decisions and the associated decision maker or based on a set of conditions (e.g., Rule 1: if financial resources are affected, the decision needs to be made by the Project Manager outside of the SE team; Rule 2: if the system performance is affected, decision to be made by chief SE).
- *Decision objectives*: The project objectives (identified in Section 9.3.3) may be derived into objectives to be used by the systems engineering team and, if applicable, its members individually, when making decisions. Rules for integrating objectives within the team need to be established.
- *Information*: For each type of decision, conditions are defined to guide identifying what team members are needed to support what decisions. Furthermore, approaches for integrating disciplinary information are also defined. For example, technical data may be converted to a ranking system of preferences, may be monetized, or may be incorporated in a value function.
- *Decision execution*: A plan for how the technical effort necessary to execute the decision will be distributed and a plan of action need to be established, in particular with respect to understanding potential deviations with respect to the initial plan of distribution of technical effort.

3. Data exchange

A systems engineering effort usually requires the integration of multidisciplinary technical data, as well as from data through various assembly levels. These data need to be integrated at various levels in order to guarantee overall consistency. First, tools and data formats that allow for lossless information exchanges are necessary. Second, conditions and rules for updating information and, most importantly, for communicating those updates, must be defined and followed. This helps avoiding different system components or engineering roles working on the assumptions informed by different data. In addition, rules for accessibility to data (e.g., due to security restrictions) may need to be defined and enforced. Processes for checking data consistency may be implemented. Third, data generated by one engineering domain or at one level of assembly may be relevant or could be leveraged by a different domain or level of assembly. Therefore, integrating technical data includes purposefully defining a data plan that accounts for and pre-defines those potential cross-disciplinary and cross-level usages of data. In several cases, such data dependencies may be informed by the requirements and the verification criteria. For example, when verifying the field of view of an optical instrument, one may want to measure the same points at the telescope level and at instrument level to verify consistency of integration, but another one may prefer to measure different points at different levels to have more information about coverage.

In large-scale projects, maintaining data consistency is difficult because systems engineering has been traditionally practiced as a document-driven discipline, in that all of the steps of the system development are meticulously documented and stored for review and traceability. Model-based systems engineering (MBSE) is a paradigm shift from this document-based paradigm to a model-based paradigm (Friedenthal, Moore, & Steiner, 2011). The goal of this effort is to provide a method for faster and more consistent information sharing and an overall increase in the speed and accuracy of the system development. MBSE involves the recording of information within models, the sharing of information between models, and the execution of these models to allow for system design and validation. By maintaining technical data within or linked through a central model, currency and consistency can be easily achieved.

Five aspects need to be distinguished when implementing MBSE: the models, the modeling language, the diagrams, the tool, and the integration of external models. The models capture the different aspects of the system. Models are created by leveraging modeling languages and may be visualized in the form of diagrams. However, and this is important, a diagram is just a representation and may not contain all the information that the model contains. Modeling, and representation of diagrams, can be executed using a tool. However, the modeling language and the tool are not MBSE, but enable MBSE. Finally, a full MBSE approach aims at integrating data from other modeling tools used in engineering, realizing that it will not be feasible to capture the model of a system to fulfill all the purposes of the engineering work within a single tool and with a single modeling language. Several modeling languages exist, such as the Systems Modeling Language (SysML) – an extension of the Unified Modeling Language (UML) widely used in software engineering – the Object Process Modeling (OPM) – used as an ISO standard – and STRATA, which is a proprietary one. Arguably, the most extended language at the time of writing this *EMBOK Guide* is SysML.

4. Tools and processes

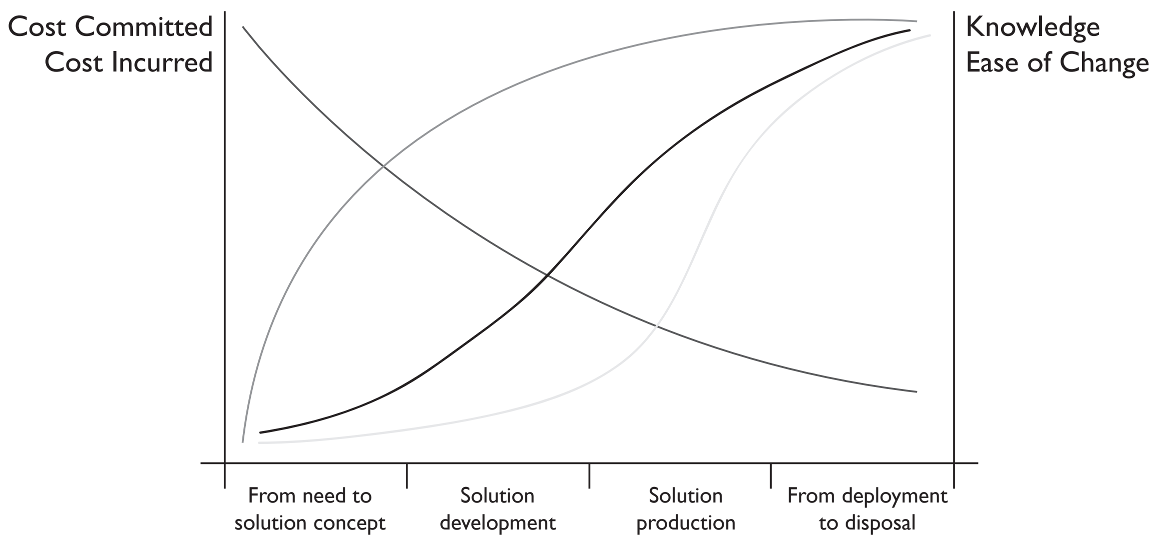
In line with the previous subsection, implementing SE often requires using several tools. The integration of those tools needs to be defined and managed, not only from the data integration aspects (previously described), but also from guaranteeing that there are no conflicts between the underlying assumptions employed in the tools.

Furthermore, as will be discussed in Section 9.3.7, technical processes also need to be integrated. In general, the selection of technical processes needs to guarantee that there are no execution conflicts between the processes. Other than that, no rules for such integration are prescribed, but they should derive from the conditions explained in Section 9.3.3. For example, in one project it may be interesting to minimize overlap between processes to reduce waste, whereas in another project some overlap may be sought to provide certain level of redundancy in certain tasks.

5. Allocation of effort during the life cycle

Since resources are limited in an engineering project, the systems engineering tasks to be performed need to be planned and allocated among the systems engineering team. Allocation of effort is critical to the value of systems engineering, in particular with respect to when certain activities occur in the system lifecycle. It is generally accepted that systems engineering can exert its maximum influence early in the lifecycle, since it is then when major decisions affecting the system development occur. This is caricaturized in Figure 9.12, which shows that early decisions in the system lifecycle will drive future incurred development costs.

Figure 9-13. Evolution of Key Development Metrics with Life Cycle Phases [adapted from (Fabrycky & Blanchard, 1991)]



In addition, the definition and allocation of effort needs to align with the technical strategies elaborated to develop the system and the system architecture. Since both the technical strategies and the system architecture are developed in order to mitigate risks and leverage opportunities, they may inform certain dependencies in the technical effort that should be followed in order to materialize those mitigation actions and potential opportunities. For example, if the system architecture informs that the boundaries of a specific uncritical component will be highly volatile because of its interaction with other critical components that will have to be newly developed, it would make sense to (1) prioritize work to mature the critical components and (2) not start the development of the uncritical component until certain maturity of the critical components is reached.

Standard practices to define, structure, and organize work, such as Work Packages, may be used for defining, structuring, and organizing systems engineering effort. Project control methods to assess and measure the evolution and progress of the systems engineering effort, such as Earned Value Management (EVM), may be put in place to guarantee systems alignment of systems engineering execution with planned strategies.

9.3.7 Technical Processes

Implementing systems engineering encompasses the execution of several engineering activities. Technical processes may be defined to help organize and guide their execution. In essence, a technical process identifies (1) the inputs necessary to begin an activity, (2) the outputs that the activity is expected to provide, (3) the triggers that dictate when the activity must begin and end, and (4) the enablers that are necessary to execute the activity.

Different industries have developed different taxonomies of what technical processes must be defined, controlled, and executed by systems engineering. This reinforces the need for a formal identification, definition, and allocation of technical processes within a systems engineering team, since different team members may be accustomed to execute systems engineering differently.

This *EMBOK Guide* does not prescribe any taxonomy in particular. Rather, we reproduce in Table 9.1 the systems engineering technical processes identified by ISO due to the generality of its taxonomy.

Table 9-1. ISO's Taxonomy of Systems Engineering Processes

Process	Purpose
Business or mission analysis	Define the business or mission problem or opportunity, characterize the solution space, and determine potential solution class(es) that could address a problem or take advantage of an opportunity.
Stakeholder needs and requirements definition	Define the stakeholder requirements for a system that can provide the capabilities needed by users and other stakeholders in a defined environment.
System requirements definition	Transform the stakeholder, user-oriented view of desired capabilities into a technical view of a solution that meets the operational needs of the user.
Architecture definition	Generate system architecture alternatives, to select one or more alternative(s) that frame stakeholder concerns and meet system requirements, and to express this in a set of consistent views.
Design definition	Provide sufficient detailed data and information about the system and its elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture.
System analysis	Provide a rigorous basis of data and information for technical understanding to aid decision-making across the lifecycle.
Implementation	Realize a specified system element.
Integration	Synthesize a set of system elements into a realized system (product or service) that satisfies system requirements, architecture, and design.
Verification	Provide objective evidence that a system or system element fulfills its specified requirements and characteristics.
Transition	Establish a capability for a system to provide services specified by stakeholder requirements in the operational environment.
Validation	Provide objective evidence that the system, when in use, fulfills its business or mission objectives and stakeholder requirements, achieving its intended use in its intended operational environment.
Operation	Use the system to deliver its services.
Maintenance	Sustain the capability of the system to provide a service.
Disposal	End the existence of a system element or system for a specified intended use, appropriately handle replaced or retired elements, and to properly attend to identified critical disposal needs.

9.3.8 Technology Insertion

Engineering innovative systems often requires combining new and mature technologies. A critical activity in systems engineering is to plan and control the insertion of new technologies during system development and during system operation. This is because the insertion may occur directly during the system development to achieve certain initial capability, as well as during a system operation to upgrade its existing capability. In general, and without prescribing a specific process, systems engineering should accompany technological developments aimed at being inserted into systems under development or in operation by defining and controlling for:

1. Maturity conditions that need to be attained by the new technology before it is inserted into the system. These may include various readiness levels, successful certifications, or meeting performance targets, among others.
2. Insertion gates defined in the overall development or operation plan. These gates indicate the time events during system development or operation when the technology may be inserted. In this way, system development drives the insertion of technology and not otherwise.

3. Alternative development and operation paths that may be exercise if the technology insertion does not succeed, either because of integration problems or simply because the technology is not ready at the insertion gate.

9.3.9 Integration with Project Plan

Systems engineering needs to be integrated within the overall project plan for a consistent project execution. In line with the discussion in Section 9.3.6, integration needs to occur on several dimensions, including a design of how the systems engineering team exchanges information, communicates, and supports decision with other disciplines in a project (e.g., project management, legal, risk management, quality, etc.).

In addition, some project level activities, such as planning, configuration control, or risk management, are generally partitioned and delegated to different disciplines, being systems engineering one of them, and later wrapped up and consolidated at project level. For example, ISO describes the following technical management processes as part of the systems engineering effort: project planning process, project assessment and control process, decision management process, risk management process, configuration management process, information management process, measurement process, and quality assurance process. An effective implementation of systems engineering includes defining:

1. The boundaries of the technical management processes, specifically what aspects, limits of responsibility, and authorization of action of those activities are delegated to systems engineering and which ones would need to be ignored or escalated to project level.
2. Requirements and constraints on the execution of the technical management processes to guarantee consistency at project level. These requirements and constraints are used to develop and implement technical management processes that are consistent or at least compatible with the various management plans at project level that leverage the inputs provided by systems engineering.
3. A process to report and integrate systems engineering contributions with the contribution of other areas at project level.

9.3.10 Tailoring

There is no one-size-fits-all when it comes to systems engineering. Consequently, the implementation of systems engineering needs to be tailored specifically to the project or domain of application. Tailoring aims at facilitating maximum return on the invested systems engineering effort. This is achieved by:

1. Avoiding using certain systems engineering approaches or processes that are traditionally used, but that are not applicable or not valuable for the system development.
2. Adjusting or changing certain systems engineering approaches or processes, so that they address the opportunities and concerns of the system development in a more effective and efficient manner.
3. Using only those systems engineering approaches or processes that are effective and efficient, given the specific characteristics of the system development.

Given the diversity of projects or system developments undertaken by some organizations, some organizations develop tailoring processes that guide the tailoring effort for the implementation of systems engineering.

Review

Upon completing the study of Domain 9: Systems Engineering, you will be able to answer the following questions.

1. What benefits are realized by utilizing a team comprised of engineers from a variety of engineering disciplines?
2. Describe the benefits of using simulation models.
3. What are the benefits to analyzing product and process life cycles?
4. Why is the voice of the customer an important design consideration?
5. Explain why it is important to include assessment of end uses other than those for which the product is designed?

6. What are the advantages of using interdisciplinary project teams? What challenges does this approach present?
7. What is the purpose of the SEMP? What is the general content it should include?
8. List and explain the purpose of SE processes.
9. Explain what drivers and factors need to be considered when defining a SE approach for a project.

For Further Information

INCOSE Systems Engineering Handbook, SE Handbook Working Group, International Council on Systems Engineering (INCOSE), 2011, San Diego, CA.

www.incose.org – The website of the International Council on Systems Engineering has a searchable repository of systems engineering information.

Systems Engineering and Analysis, by Benjamin Blanchard and Wolter Fabrycky, 2010, Englewood Cliffs, NJ: Prentice Hall. A good text for systems engineering basics and methods.

A Practical Guide to SysML – The Systems Modeling Language, by Sanford Friedenthal, Alan Moore, and Rick Steiner, 2008, Burlington, MA: Morgan Kaufmann. Gives a very thorough treatment of how systems engineering information is stored for use in MBSE.

ISO/IEC 15288:2002, Systems Engineering – System Life Cycle Processes, by the International Organization for Standardization, 2007. The ISO standard for system life cycle processes. (The ISO standard for software system life cycle processes is currently under development.)

NASA Systems Engineering Handbook, National Aeronautics and Space Administration, Office of the Chief Engineer, 2007, Hanover, MD. Gives a good description of how systems engineering is performed for the space agency. Copies can be requested via SP6105rev1SEHandbook@nasa.gov, or downloaded at https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook.pdf

Introduction to Systems Engineering, by Andrew Sage and James Armstrong, 2000, New York, NY: John Wiley & Sons. Gives a good perspective with some alternate methods to the other text given here.

Systems Engineering Fundamentals, by the Defense Acquisition University, 2001, Defense Acquisition University Press. A useful view of systems engineering and how the Department of Defense views the process. This is also available online at https://www.dau.mil/tools/dag/Pages/DAG-Page-Viewer.aspx?source=https://www.dau.mil/guidebooks/Shared%20Documents%20HTML/Chapter%203%20Systems%20Engineering.aspx

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Guide to the Systems Engineering Body of Knowledge (SEBOK) http://www.sebokwiki075.org/wiki/Guide_to_the_Systems_Engineering_Body_of_Knowledge_(SEBoK), 2012. The systems engineering community's work on making available a body of knowledge, which strongly adds to this chapter. This is a multi-institution body of knowledge effort led by Stevens Institute of Technology for the Systems Engineering Research Center (http://www.sercuarc.org/)

http://boardmansauser.com/Worlds_of_Systems/Thoughts.html

https://www.google.com/search?q=systemitool&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiXkuiFnY_iAhWHrVkKHbbXBVkQ_AUIECgD&biw=1520&bih=776#imgdii=roSosz3HufqDCM:&imgrc=KglqmvQeqBkdlM

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Cabrera, D., & Cabrera, L. (2015). *Systems thinking made simple: New hope for solving wicked problems.* Ithaca, NY: Odyssean Press.

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10

Legal Issues in Engineering Management

Domain 10 Champions

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Domain 10: Legal Issues in Engineering Management

Key Words and Concepts

Continuous Professional Development	A continuing series of development activities engaged in by engineers to stay abreast of the latest advances in their field, including changes in the knowledge base and advances in the tools of their trade.
Copyright	The exclusive legal rights to reproduce, publish, and sell original works including computer software, literary works, and artistic works.
Environmental Management System	A series of practices and procedures that, when taken together, result in an overall system for managing environmental performance and compliance.
Governmental Regulations	Rules formulated and issued by a governmental agency; typically have the force of law.
ISO 14000	Series of voluntary international standards in the environmental field.
Patent	The exclusive legal right to make, sell, or license novel and useful inventions.
Standards	Descriptions established by authority, custom, or general consent as a model of performance, quality, etc.; also an established rule of measurement.
Terms and Conditions	The various clauses that collectively make up a contract.
Trademark	The exclusive legal right to use an identifying mark (logo, symbol, product name) as long as it is kept in use.

10.1 Business Contracts

10.1.1 Business Law

Business law takes on many forms and regulates a variety of business entities and commercial transactions. Laws are designed to protect all parties through directing how *terms and conditions,* specific performance expectations, breach of contract agreements, and so forth will be articulated (Business Law, 2006).

Contract Law

Contract laws are generally well-defined and specific. When entering into contracts, it is always best to engage the services of a lawyer or a member of the corporation's in-house legal team.

Many contracts are written, controlled, and enforced by specific departments in an organization, depending on the purpose. Contracts with suppliers, customers, sales representatives, and partners are often handled by their counterparts within the organization.

The various clauses that collectively make up a contract are called *terms and conditions* (Ts and Cs). Many companies have standard Ts and Cs on hand to use when requesting proposals from suppliers and when beginning contract negotiations with customers.

Common Ts and Cs follow:

- Work specifications
- Deadlines
- Delivery terms
- Price and payment terms
- Standards and codes to be followed
- Warranties
- Indemnification clauses
- Force majeure clauses

Indemnification and force majeure clauses are designed to protect contracted parties by creating provisions for circumstances when the contract cannot be fulfilled in accordance with the original agreements.

10.1.2 Interpreting and Applying Laws for Contract and Projects

The contract management process (Figure 10-1) can be described as having three stages:

- *Negotiation* involves all parties responsible for clarifying and reaching consensus on the contract requirements and components.
- *Formation* brings together the understandings reached in negotiation and commits them to written/documented form.
- *Administration* requires that all parties strive to ensure that the terms and conditions agreed upon are met.

Figure 10-1. Contract Management Stages

Contract Management
- Negotiation
- Formation
- Administration

The U.S. legal system strives to maintain an effective balance between the rights of the individual and the needs of society. This dynamic interaction dramatically influences our approach to business interactions as well. The resulting relationship between business contracts and the laws that govern them is also dynamic, as much is open to interpretation. Therefore, the most effective engineering managers develop the fine art of negotiation. The engineer's role in contract development and management is to advocate for the company's advantage—while still maintaining a balanced, "win-win," and ethical perspective. At the same time, it cannot be stressed enough how vital it is for engineers to enlist the support of contract law advisors.

Managing International Contracts

Engineers working with international contracts should be mindful of the differences between domestic and international contract practices (see Figure 10-2).

Figure 10-2. Domestic Versus International Contracts

Domestic Contracts	International Contracts
Written contract required for service of >1 year and > $500.	Written sales contracts are not required.
Acceptance of contract is indicated by signatures.	Written contracts do not need to be signed.

Approaches to disagreement litigation vary from country to country. For example, the U.S., Britain, and Canada operate within a common law system, where court opinions are largely based on precedent. In many other countries, a civil law system is in effect. Judgments in these jurisdictions are based strictly on very specific, well-defined laws, codes, and regulations—not on precedent. Before doing business in a foreign country, engineers and legal staff should be aware of which approach, common or civil law, is practiced there.

10.2 Environmental Issues

Engineers and engineering managers must consider environmental issues when working on projects or programs that may have environmental implications. Those implications may be far-reaching and complex, so it is imperative to understand requirements and regulations relating to the environment.

10.2.1 Environmental Protection Requirements

The Environmental Protection Agency (EPA) has primary responsibility for enforcing many of the environmental statutes and regulations of the United States. As such, the EPA is granted explicit enforcement authority in environmental statutes. Sometimes, however, that authority needs to be further refined or explained. In such cases, the EPA may develop and implement policies and write guidance. In addition, the EPA sometimes issues policy or guidance to encourage compliance with environmental requirements (Environmental Protection Agency, "Policy & Guidance," n.d.).

Policy documents represent EPA's official interpretation or view of specific issues. Guidance documents are published to further clarify regulations and to assist in implementation of environmental regulations.

Significant Guidance Documents

The EPA maintains a set of documents (Environmental Protection Agency, "Significant Guidance Documents," n.d.), as prescribed by the Office of Management and Budget's (2007) *Final Bulletin for Agency Good Guidance Practices*.

Other Policy & Guidance Websites

Air

- Office of Air and Radiation (OAR) Policy and Guidance Information (Environmental Protection Agency, n.d.): Provides access to rules, policy, and guidance documents produced by the USEPA OAR.

- Radiation Information for Technical Users and the Regulated Community (Environmental Protection Agency, n.d.).

Compliance and Enforcement

- Enforcement and Compliance Policy and Guidance Documents (Environmental Protection Agency, n.d.): The Enforcement and Compliance Document and Information Center (ECDIC) documents providing regulatory, case settlement, and other policy-related information supporting the Agency's enforcement and compliance activities.

Emergencies

- Emergency Management Policy and Guidance (Environmental Protection Agency, n.d.): Policy, guidance, and compliance assistance documents related for preventing oil spills, chemical accidents, and other emergencies, and implement planning and response requirements.

Pesticides and Toxic Substances

- Pesticides, Science and Policy, Policy and Guidance (Environmental Protection Agency, n.d.): Science policy issues key to the implementation of the Food Quality Protection Act (FQPA).

Waste

- Resource Conservation and Recovery Act (RCRA) Guidance, Policy and Resources (Environmental Protection Agency, n.d.): Guidance documents, policy statements, training modules, and more for the RCRA.

Water

- Office of Water Policy and Guidance (Environmental Protection Agency, n.d.): Policy and guidance information for drinking water, National Pollutant Discharge Elimination System (NPDES), water quality standards, Clean Water Act Section 404, and fish advisory technical guidance.

10.2.2 U.S. Environmental Laws and Regulations

The EPA's foundation for protecting the environment and public health is grounded in a variety of laws. However, the laws often do not have enough detail to be put into practice right away. The EPA then must write regulations that explain the critical details necessary to implement environmental laws. In addition, a number of Presidential Executive Orders (EOs) may affect the EPA's activities.

Summaries of Environmental Laws and EOs

The following laws and EOs help to protect human health and the environment. EPA is charged with administering all or a part of each (www.epa.gov).

Regulatory Information By Sector	Regulatory Information by Topic
Agriculture	Air
Automotive	Cross-Cutting Issues
Construction	Emergencies
Electric Utilities	Land and Cleanup
Oil and Gas	Pesticides
Transportation	Toxic Substances
	Waste
	Water

10.2.3 Environmental Management Systems

ISO 14001

The International Organization for Standardization (ISO) promotes the development and implementation of voluntary international standards, including those for environmental management issues (n.d.). ISO 14000 are the standards in the environmental field under development by ISO. Included in this series are the ISO 14001 environmental management system (EMS) Standard and other standards in fields such as environmental auditing, environmental performance evaluation, environmental labeling, and life-cycle assessment.

The ISO 14001 standard requires that an organization implement a series of practices and processes that result in an EMS. The major requirements of an EMS include the following:

- Creating a policy statement that includes commitments to prevention of pollution, continual improvement of the EMS leading to improvements in overall environmental performance, and compliance with all applicable statutory and regulatory requirements.
- Identifying all aspects of the community organization's activities, products, and services that could have a significant impact on the environment, including those that are not regulated.
- Setting performance objectives and targets for the management system that link back to the three commitments established in the community or organization's policy (i.e., prevention of pollution, continual improvement, and compliance).
- Implementing the EMS to meet these objectives that includes activities such as training of employees, establishing work instructions and practices, and establishing the actual metrics by which the objectives and targets will be measured.
- Establishing a program to periodically audit the operation of the EMS.
- Checking and taking corrective and preventive actions when deviations from the EMS occur, including periodically evaluating the organization's compliance with applicable regulatory requirements.
- Undertaking periodic reviews of the EMS by top management to ensure its continuing performance and making adjustments to it, as necessary.

10.3 Human Resources

10.3.1 Professionalism

Linguistically, professionalism means the standing, practice, or methods of a professional distinguished from an amateur. Culturally, it means the expertness characteristic of a professional performing a profession, regardless of the task or job he or she performs. In the context of engineering and management, a profession has particular attributes that distinguish it from other jobs and expertise. These attributes include the following:

- Membership requirements:
  - Extensive formal education and training of intellectual character
  - Sophisticated skills, autonomy, and use of judgment; not routine
- Public and society view:
  - The knowledge and skills of the members are vitally needed for society's well-being.
  - Professional organizations are allowed to self-control and regulate the practice.
  - Professionals are normally regulated by ethical standards, embodied in a Code of Ethics.

Examples of professions include engineering, medicine, and law. These professions have an implicit contract of trust with society to practice according to the highest professional standards. It is also understood that they will self-regulate their professions in exchange for guarding and protecting the health and welfare of the public. Some of the ethics and standards of practice for these professions are enforced by laws; others are self-imposed. Regardless of the enforcement mechanism, all professionals must fully understand that their actions, the image they convey to the public, and the physical impact they have on the public's health and welfare will either influence the public's trust in the profession or the opposite. For these reasons and many others, it is the responsibility of every engineer and engineering manager to apply and promote the ethics of the profession as part of his or her professional practice.

10.3.2 Continuous Professional Development

In the 21st century, continuous professional development (CPD) is fundamental to survival in all professions, and engineering is no exception. To remain commercially and professionally viable, engineers must stay abreast of the latest advances in their field, including changes in the knowledge base and advances in the tools of their trade. To do otherwise would be to jeopardize one's reputation and career.

Staying current is also a central tenet of the engineer's professional code of ethics. Practicing engineering based exclusively on the tools and knowledge acquired during one's first engineering degree would breach this code and pose a clear ethical problem. In specific, practicing with outdated tools, skills, and knowledge would be a practice outside one's limits of expertise. To reinforce the ethical importance of life-long learning, CPD is currently required for professional engineers' registration in most states and is an accreditation requirement for engineering schools and programs.

Engineering managers should establish CPD as a standard practice and benefit for members of their engineering team, group, or department. In exchange, the organization enjoys the benefit of a highly competitive workforce.

Numerous opportunities exist for engineers to upgrade their knowledge and skills. For example, professional organizations and educational institutions have established ongoing programs. Examples of these programs include the professional development program offered by ASEM and career-enhancement short courses and certification by IEEE and SME, to name a few.

It should be noted that CPD activities are frequently carried out by professionals on an ad-hoc basis, usually as part of a job or accreditation requirement. However, for engineers to survive in this century, continuous learning should be performed as a way of life. Within an engineering practice, this means incorporating CPD into each of its engineer's career-development programs. (Check websites of your respective professional organization or licensing board. Also see Barakat, 2009.)

10.3.3 Certification, Accreditation, and Licensure

Because the engineering profession has a significant impact on the health and welfare of the public, it is logical that the practice would be regulated as a means of protecting both the public and its practitioners. As a profession, self-regulation is the norm with engineering, with legal enforcement functioning as an extension of the self-regulation that guarantees its organized application.

Engineering regulation starts at the education stage, where schools and programs of engineering are monitored and accredited through a specialized organization. In the U.S., this organization is the Accreditation Board of Engineering and Technology (ABET). ABET is a federation of 36 professional and technical societies representing the fields of applied science, computing, engineering, and technology. ABET is also the recognized accreditor for these fields. ABET is recognized internationally and has reciprocity with multiple internationally equivalent organizations, such as the Canadian Engineering Accreditation Board (CBET) and the Engineering Council of UK (ECUK), among others.

Once an engineer graduates from a college or university, he or she acquires a license to practice by following a set procedure and passing a qualifying exam. These licenses are governed in the U.S. by professional organizations and governmental agencies through the National Council of Examiners for Engineering and Surveying (NCEES). NCEES supervises and organizes the actual examination. However, the final decision of granting the license is controlled by each state, with variations depending on the state's laws and requirements. Other countries have similar procedures and organizations. An engineering manager should know that the licensed engineers are the only engineers allowed to work on governmental projects dealing directly with the public. Although many engineers practice without this license, public projects are not open to them.

Engineering managers now have an opportunity for certification as well. ASEM offers an Engineering Manager Professional Certification (EMPC) program leading to certification as an Associate Engineering Manager (AEM) or a more advanced Professional Engineering Manager (PEM).

10.4 Intellectual Property

Intellectual-property laws differ from country to country, complicating the issue for engineers and others. The U.S. Patent and Trademark Office regulates the issuance of domestic intellectual-property rights in the U.S. On an international level, the World Trade Organization (WTO) and the World Intellectual Property Organization (WIPO) encourages member nations to establish and enforce minimum levels of *copyright, trademark, patent,* and *trade secret* protection within their jurisdictions. The information provided in this section is general in nature and should not be construed as legal advice. It should also be noted that laws and precedents related to intellectual property are always in flux, and as such, when issues arise, qualified experts should be consulted.

10.4.1 Patents, Trademarks, Copyrights, and Trade Secrets

Intellectual properties are valuable business assets, and they are the products of creative thinking. The four types of intellectual property (IP) are *trademarks, copyrights, patents,* and *trade secrets*. Each of these forms of intellectual property offers protections for different types of works, and each offers a different set of advantages and drawbacks. A party who illegitimately uses IP belonging to another party is described as performing acts that *infringe* upon the IP of the rightful owner.

Trademarks, copyrights, patents, and trade secrets, while all forms of intellectual property, are addressed differently in domestic and international legal systems. In the United States, the process of granting IP is overseen at a federal level by the United States Patent and Trademark Office (USPTO) and the United States Copyright Office (a department of the Library of Congress). Because engineering managers work regularly with an array of ideas and technology that are company assets, understanding the distinctions and becoming familiar with intellectual-property practices will prevent accidental complications. Familiarity, however, is no replacement for competent legal representation. Domestic and foreign IP laws are in constant change, making it easy for the lay person to perform actions that might forfeit his or her IP rights.

While some general guidelines are given in this document, **none of this information is to be taken as legal advice**. *Always seek the counsel of a qualified intellectual-property attorney or agent* as early as possible so that he or she can help maximize your rights and the value of your IP, as well as generally keep you out of trouble. Your company likely has such resources identified already.

10.4.1.1 Trademarks

Under U.S. law, a trademark can include words, names, symbols, or devices (i.e., logos), or any combination of these used (or intended to be used) in commerce to identify and distinguish the *products* of one vendor from products made or sold by others, and to indicate the source of the products. In short, a trademark is a brand name. Examples are the Kleenex product name, the Nike "swoosh" symbol, and the ASEM logo.

Service marks serve a very similar purpose. A service mark is any word, name, symbol, device, or any combination thereof used in commerce to identify and distinguish the *services* of one provider from the services provided by others, and to indicate the source of the services.

Use of the "TM," "SM," and "®" symbols is highly dependent on the jurisdictions in which they are used, as they are governed by local, state, or foreign laws to identify the marks that a party claims rights to. The U.S. has a two-tiered system of trademark protection: federal and state.

The "TM" and "SM" symbols are generally used with IPs registered with an individual U.S. state. Common examples of state registrations are small/individual business names, since the registration process is generally less expensive and complicated than federal registration, and there might be less need to distinguish one business from similarly named businesses in another state. For example, a business named "Bob's Café" in the state of Minnesota is unlikely to be confused with a business named "Bob's Café" operating in the state of Florida (or vice versa), and as such, federal registration might not be worth the trouble and state registration may suffice.

The federal registration symbol "®" (i.e., the R enclosed within a circle) may be used once the mark is actually *registered* in the USPTO. Even though an application is pending, the registration symbol may <u>not</u> be used before the mark has actually become registered. The federal registration symbol should only be used on goods or services that are the subject of the <u>federal</u> trademark registration, and not for state registration. Several foreign countries also use the letter R enclosed within a circle to indicate that a mark is registered in those countries. Use of the symbol by the holder of a foreign registration may be proper.

Federal registration gives the registrant rights throughout the entire U.S. and its territories and possessions; a state registration gives the registrant trademark rights only within the territory of the state. This is an important distinction that affects the scope of legal actions that can be taken against potential infringers, e.g., damages sought in a lawsuit against a party accused of infringing a state registration would be limited to just the losses in that state. Federal-trademark registration has several benefits:

- Constructive notice nationwide of the trademark owner's claim
- Evidence of ownership of the trademark
- Jurisdiction of federal courts may be invoked
- Registration can be used as a basis for obtaining registration in foreign countries
- Registration may be filed with U.S. Customs Service to prevent importation of infringing foreign goods

Obtaining a Trademark

Trademarks can be registered at the state or federal level. Federal registration can be done online for a few hundred dollars, plus the cost of hiring an attorney to help (recommended). The process of state registration varies from state to state. Considering the relative ease, speed, low cost, and legal advantages of federal registration, under the advice of your attorney, you might find state registration to have little added benefit. The USPTO website provides a trademark database that is searchable by the public and might be a good place to start looking to get an idea whether or not a particular mark is already in use.

10.4.1.2 Copyrights

Copyright is a form of protection grounded in the U.S. Constitution and granted by law for original works of authorship fixed in a tangible medium of expression. Copyright covers both published and unpublished works. Copyright is a legal right that grants the creator of an original work exclusive rights to its use and distribution, usually for a limited time, with the intention of enabling the creator (e.g., the photographer of a photograph or the author of a book) to receive compensation for his or her intellectual effort.

Copyright protection subsists in original works of authorship fixed in any tangible medium of expression (i.e., print, online, recorded). Works of authorship can include the following:

- Literary works
- Musical works, including lyrics
- Dramatic works, including any accompanying music
- Dances, pantomimes, and other choreographic works
- Pictorial, graphic, and sculptural works
- Motion pictures and other audiovisual works
- Sound recordings
- Architectural works

The duration of a copyright is highly dependent upon the jurisdiction, the date, the type of media, and other factors for owners claiming copyright. As an example of this complexity in the U.S. alone, copyrights for newly created works remain in effect for the life of the author plus 70 years for non-anonymous published or unpublished works, or 95 years from publication or 120 years from creation (whichever is shorter) for anonymous works, pseudonymous works, or works made for hire. In the U.S, these durations are different for works created in the past, which adds to their complexity.

Copyright protection for an original work of authorship does <u>not</u> extend to any idea, procedure, process, system, method of operation, concept, principle, or discovery, regardless of the form in which it is described, explained, illustrated, or embodied in such work. Such forms of IP may, however, be eligible for protection as *patents* or *trade secrets*.

Obtaining a Copyright

Copyright exists from the moment a work is created. *Copyright notice* is given by the author's use of the copyright symbol "©" (i.e., the letter C inside a circle), the abbreviation "Copr.," or the word "Copyright," followed by the year of the first publication of the work and the name of the copyright holder. International treaties have made the explicit use of copyright notices optional in order to claim copyright. However, the lack of notice of copyright using these marks might have consequences in terms of what defenses may be used and/or what damages may be sought in an infringement lawsuit.

Copyright *registration* is voluntary but may be desirable for a number of reasons. Some authors choose to register their works because they wish to have the facts of their copyright on the public record and have a *certificate of registration*. Registered works may be eligible for statutory damages and attorney's fees in successful litigation. Also, registration is considered *prima facie* evidence in a court of law if done within five years of publication.

The U.S. Copyright Office provides an online service for registering works, although "hard copies" are still accepted. At the time of this writing, it takes about a year to obtain a certificate of registration after filing, and the fees are very low.

10.4.1.3 Patents

A *patent* is the grant of a property right to the *inventor*, issued by the USPTO in the U.S. Generally, the term of a new patent is 20 years from the date on which the application for the patent was filed in the United States. U.S. patent grants are effective only within the U.S. and its territories. In general, a patent grants the owner a temporary monopoly in exchange for publicly disclosing how the invention works (e.g., to recoup development costs and incentivize innovation). After a patent expires, the invention becomes part of the *public domain* in which anyone can copy and use the idea freely.

A patent grants its owner the right to exclude others from making, using, offering for sale, or selling the invention in the U.S. or to import the invention into the U.S. The right is not to make, use, offer for sale, sell, or import but to *exclude* others from making, using, offering for sale, selling, or importing the invention.

Patent law in the U.S. is defined by Title 35 of the United States Code. In the language of the law, any person who "invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent," subject to the conditions and requirements of the law. The word "process" is defined by law as a process, act, or method and primarily includes industrial or technical processes. The term "machine" used in the statute is self-explanatory. The term "manufacture" refers to articles that are made and includes all manufactured articles. The term "composition of matter" relates to chemical compositions and may include mixtures of ingredients as well as new chemical compounds. These classes of subject matter taken together include practically everything that is made by man and the processes for making the products.

In order to obtain a patent, an invention must be "new," or in the language of the statute, an invention has to be both *novel* and *non-obvious*. With regard to novelty, an invention cannot be patented if the following conditions exist:

- "(1) the claimed invention was patented, described in a printed publication, or in public use, on sale, or otherwise available to the public before the effective filing date of the claimed invention"
- "(2) the claimed invention was described in a patent issued [by the U.S.] or in an application for patent published or deemed published [by the U.S.], in which the patent or application, as the case may be, names another inventor and was effectively filed before the effective filing date of the claimed invention."

In short, an invention is considered *novel* as long as the public did not know about it before a patent was filed (e.g., it was not in the *public domain*) and nobody else had tried to apply for a patent on the same invention. However, several exceptions exist. The most commonly used exception provides a one-year grace period to the inventor. In general, the actual inventor of an invention has one year to file a patent application on an idea from the date that he or she first publicly reveals the invention, publishes something describing the invention, or offers the invention for sale. An invention is not considered to have been made "public" if it was disclosed to others under a *non-disclosure agreement* (NDA), which is a legal contract of confidentiality between two or more parties. Under current U.S. laws, it is extremely important that employee, business partners, vendors, etc., be bound by NDAs to help protect your IP and other rights.

With regard to *non-obviousness*, the language of the statute is broader. In general, an invention is considered to be non-obvious if a "person of ordinary skill in the art" (i.e., a person having approximately a bachelor's degree in the technical field of the invention) could reasonably have been able to come up with the same idea at or before the time when a patent application was filed, based on information that was publicly known at that time. For example, a bicycle with 10 wheels might never have been built or patented, but a person with a BSME degree would probably know how to design such a mechanism without great difficulty, and as such a 10-wheeled bicycle would likely be *obvious* (and therefore not patentable) even if such a design was *novel*.

There are three types of patents:

- *Utility patents* may be granted for new and useful processes, machines, articles of manufacture, compositions of matter, or any new and useful improvement of these
- *Design patents* may be granted for new, original, and ornamental designs for an article of manufacture; design patents protect purely aesthetic features rather than functional ones
- *Plant patents* may be granted for distinct and new varieties of plants that are asexually reproducible

Note that most living organisms, mathematical formulae, naturally occurring materials, and physical phenomena are considered to have been in the public domain forever and are, therefore, not "new" or patentable. Patents are granted for *inventions*, not *discoveries*.

The general descriptions of patents in this section pertain to U.S. patent practice. While patent laws in other countries are similar, important differences exist. For example, a number of countries do not recognize a grace period, as the U.S. does, but instead require *absolute novelty*. In such countries, any public disclosure, publication, sale, etc., by anyone (including the inventor) can make an invention ineligible for patent protection in that jurisdiction. Again, patent laws around the world are surprisingly complex, so engineering managers should be sure to seek the counsel of a registered patent attorney or patent agent to make sure that their IP rights are protected.

Obtaining a patent is by far the most complex, expensive, and risk-laden of all forms of IP. As such, U.S. law only allows *patent attorneys*, *patent agents*, and inventors to file patent applications. In fact, U.S. law does not even allow all attorneys to prosecute patent applications. Patent agents are required to have at least a four-year degree in at least one of a predetermined collection of technical majors (e.g., engineering, physics, chemistry, computer science) as well as having passed a separate patent bar examination. A patent attorney is required to have all the qualifications of a patent agent plus a law degree and admission to at least one state bar. Patent agents have all the same rights and privileges as patent attorneys to represent patent applications in prosecution matters before the USPTO. Patent-litigation matters are carried out in the regular district-court system. As such, patent agents are not able to represent clients in litigation matters, since they do not have law degrees. This also means that patent-bar registration or a technical, undergraduate degree is not necessary for an attorney to represent clients in patent-litigation matters.

Most competent patent litigators are registered patent attorneys even though it is not strictly necessary, since the requirements and credentials needed for USPTO registration provide a distinct advantage in court for IP matters.

Since patent prosecution is such a specialized field, the prices for such professional services can be very high even when compared to other forms of legal help. As such, an inventor might be tempted to seek more economical options, such as the technically but ill-advised option of representing oneself. "Do-it-yourself" online and late-night-television patent "help" services offer low prices and extremely high risks, including loss of your IP rights either to the service or in their entirety. In general, patents are easy to get, but good patents are definitely not. Cheap patents are rarely ever good, good patents are rarely cheap, and it can be very difficult for a layperson to tell the difference until it is too late.

Obtaining a Patent

Inventors should keep accurate records (e.g., lab notebooks) in order to capture the moment that the idea behind an invention first comes to be. An idea is an invention and is therefore eligible for patent protection as soon as the inventor is able to describe how to make the idea work in sufficient detail to let others recreate it, even if the inventor has not yet made the idea work in the real world. As such, a patent agent or patent attorney should be consulted as soon as a potential inventor realizes that he or she has formed a complete idea, since there is no requirement for the invention to ever be built first.

In general, you will be asked to provide an invention disclosure, which is a technical summary and overview of the idea. The attorney or agent will then likely wish to interview you to make sure that he or she fully understands the idea. The attorney or agent will take that information and draft a specification (a lengthy, plain-language description of the idea), a set of claims (a legal description of metes and bounds of the invention), and usually one or more figures (drawings of the invention). You will likely be asked to review and approve the draft to make sure it actually describes the idea before eventually being filed with the USPTO.

Then you wait…possibly for several years before hearing anything at all. At the time of this writing, the USPTO has many months' worth of backlogged patent applications awaiting prosecution. In general, you can expect the USPTO to issue an *office action* rejecting your claims as allegedly not being patentable for various reasons, and your attorney or agent will file a response to amend the claims and/or make legal arguments on your behalf in an attempt to overcome these rejections while preserving the most value in your claims. The exchange of office actions and responses can be thought of as a negotiation in which the applicant is trying to claim as much IP "space" as possible and the USPTO is trying to narrow it in view of IP space already claimed by others. Months or years can pass between such rounds of prosecution.

Ultimately, the prosecution phase will eventually end with the patent application either being *allowed* to *issue* (or be *granted*) as a patent, or it will not. If a patent is *granted*, you now have a legally enforceable monopoly in the U.S. to use your IP as you see fit: you may implement the idea yourself (e.g., manufacture and sell it), license the rights to others to implement the idea in exchange for payment or royalties, sell the patent rights to others, etc. You may also enforce your patent rights against others who you believe are infringing your IP by filing lawsuits against them in the court system. If your lawsuit is successful, then the infringers can be forced to halt their activities, compensate you for damages, pay you royalties, etc.

10.4.1.4 Trade Secrets

Trade secrets consist of information and can include formulae, patterns, compilations, programs, devices, methods, techniques or processes. In a common definition of a trade secret, it must be used in business and provide an opportunity to obtain an economic advantage over competitors who do not know or use it.

Trade-secret protection is an alternative to patent protection. In general, patents require the inventor to publicly disclose how the invention works in exchange for the right to exclude others from practicing the invention for a limited period of time, and during that time, the inventor is protected even if somebody else independently figures out how to duplicate the invention. Once a patent's term expires, the idea behind the patent is no longer protected. By contrast, trade secrets do not have a defined lifespan and allow their owners to keep them confidential. Trade secrets, however, are not protected from independent discovery (but they can, and should, be protected by NDAs).

Familiar examples of trade secrets are Kentucky Fried Chicken's famously secret blend of eleven herbs and spices and the formula for Coca-Cola. While thousands of people around the world probably know the "secrets," they are prevented from disclosing them. Even though people have been tasting these products for many decades, no one has been able to duplicate these tastes exactly, and for this reason, the trade secrets continue to provide a competitive advantage for their owners.

If a given invention is eligible for either patent or trade-secret protection, then the decision on how to protect that invention depends on business considerations and weighing of the relative benefits of each type of intellectual property. For example, trade secrets are "free", immediate, permit/require secrecy, and can last indefinitely, but do not protect against independent discovery by others, whereas patents do protect against independent discovery but can take many years to pursue and obtain, can be very expensive, require public disclosure of the invention, and have a fixed lifespan. Again, a qualified IP professional should be consulted early in the process.

Obtaining a Trade Secret
Unlike copyrights, trademarks, and patents that generally require some form of publicly visible action on the part of a creator in order to obtain or assert his or her IP rights, trade secrets do not. By contrast, the value of a trade secret lies in maintaining its secrecy. In practical terms, absolute secrecy is generally not possible to maintain; after all, even a magician has to reveal his or her secrets to his or her assistant in order to perform certain tricks. In order to prevent your own "assistants" (e.g., employees, vendors, visitors) from revealing your trade secrets, you should work with a qualified attorney to help draft a quality *non-disclosure agreement* (NDA) and implement a strict policy of requiring anyone who may be exposed to the trade secret to sign the NDA. By requiring anyone and everyone who is ever allowed to learn all or part of the trade secret to sign the NDA, you can legally bind them to not reveal the trade secret or use it for themselves. A person who violates an NDA may be sued individually for damages, and in some cases, damages may also be sought from others who profit from the violator's disclosure of the secret.

10.4.2 Value of Intellectual Property
Physical items and financial assets (e.g., inventory, investments, land, buildings) have value, and as such can be bought, sold, leased, and shared. It is usually easy for engineering managers to understand the value that financial and physical assets add to a business and the importance of managing them.

Even though intellectual property is sometimes a less tangible concept, IP is similar to physical property in many ways. IP also has value that can be bought, sold, licensed, shared, etc. By increasing the amount of IP in a company's *portfolio*, the company's overall value can be increased. In fact, some companies exist whose only value is in the IP that they own, by buying, selling, and licensing the IP, and by litigating (suing) others for damages relating to infringement, etc.

As such, a company's value can be increased through the creation of IP in addition to saleable products and services. Methods for protecting various forms of IP (and its value) were discussed in general terms earlier. Engineering managers can increase their companies' value by encouraging innovation and the subsequent creation of IP. IP creation can be stimulated and maximized by the following (Charmasson, 2008):

- Working closely with qualified IP legal counsel
- Establishing and enforcing a consistent non-disclosure policy
- Identifying and purging potentially infringing IP from the company
- Identifying and protecting existing IP created by the company
- Establishing and enforcing the consistent use of a recordkeeping system to document all new developments
- Establishing a process for determining if new developments infringe upon existing IP owned by others
- Setting aside time for "personal" projects (e.g., 20% time, Skunkworks projects)
- Establishing a process for rewarding innovative employees (bonuses, royalties, bounties, recognition, etc.) (Charmasson, 2008)

10.5 Warranties, Liability and Insurance
10.5.1 Warranties
Engineering is based upon the practitioners' professional judgment (National Society of Professional Engineers, "Design and Construction Contract Provisions," 2010). Its practitioners cannot guarantee or warrant perfection, as is either explicitly stated or implied in a guaranty or warranty. Accordingly, guarantees and warranties might shift an unacceptable amount of responsibility to the professional engineer.

The National Society of Professional Engineers (NSPE) holds that contractual provisions such as "indemnification/hold harmless," "guarantee/warranty," "liquidated damages," and other contractual provisions that shift risks from those in the best position to assume those risks to the engineer are inappropriate ("Design and Construction Contract Provisions, 2010).

The NSPE specifically opposes the following:

- Provisions to indemnify (hold harmless) the owner or client or other parties, as these provisions represent obligations and costs that should be borne by the owner or client. The NSPE recommends that in all cases in which the professional engineer is requested by the owner to include special or unusual liability clauses in the contract, the engineer consult an attorney and insurance representatives.

- The use of liquidated damage clauses in contracts for professional engineering services. While it is recognized that the engineer has a duty to meet the time schedules agreed upon with the owner, the concept of liquidated damages is contrary to the necessary trust and confidence that must be reposed in the engineer to provide services at the highest level of competence in the interests of the most economical and efficient facility.
- The requirement of a performance bond from professional engineers in contracts for the performance of professional services. The NSPE Code of Ethics already requires that engineers act for their clients as a professional and perform their services in accordance with the appropriate standard of care.
- Clauses in design contracts requiring the professional engineer to guarantee or warrant his or her engineering services.

10.5.2 Professional Liability

Legal liability often is the most significant threat to the financial health of professional engineers and their firms.

Generally, when an engineer negligently performs services on behalf of his or her firm or employer, the individual allegedly suffering damage from the engineer's negligent performance may sue the company and/or the individual engineer (National Society of Professional Engineers, "Liability of Employed Engineers," n.d.). Typically, an engineering firm's professional-liability insurance carrier will respond to claims related to the professional work of any past or present principal, partner, director, officer, or employee. It should be noted that who signs or seals the drawings, plans, or specifications is not necessarily relevant to whether the engineer and/or the firm will be found negligent.

Engineers employed by federal, state, or local agencies, and universities providing engineering services within the scope of their employment are usually immune under the common-law legal doctrine of "sovereign immunity" (i.e., "the king can do no wrong"). Few engineers employed in large industry are at risk, as many large industrial employers self-insure and have professional and product-liability insurance coverage. Some employers might or might not agree to indemnify their employees for negligent actions that arise within the scope of their employment.

10.5.3 Insurance

Normally, a firm's professional-liability insurance policy will provide adequate liability protection. However, if the nature of the work projects or assignments creates greater professional-liability exposure, the firm might consider increasing its maximum limits of coverage. Individual engineers employed by a firm should confirm coverage with their employers.

If individual engineers believe that their services increase their firm's liability, they should bring this to the attention of their employer. If warranted, engineers might want to explore these issues with their insurance broker and carrier, since umbrella personal-liability policies are relatively inexpensive.

10.6 Regulatory Requirements, Codes, and Standards

Standards are essential to the complex business operations of the 21st century. Standards are designed to accomplish the following:

- Improve process efficiency.
- Ensure interchangeability.
- Protect employers, consumers, and the environment.

Industry (voluntary) standards: Voluntary standards are usually industry standards that regulate how a product must perform and/or be manufactured. Industry standards are considered to be the compilation of industry-wide wisdom as to how to evaluate industry products. Although voluntary in name, an industrial standard issued by a very powerful or prestigious body might become virtually mandatory due to industry or consumer pressure.

Regulatory (mandatory) standards: In contrast, regulatory standards are usually issued by governmental bodies and have the force of law. Traditionally, governmental standards have been related to safety and health issues, but in more recent years, they have grown to include environmental protection. The two most common types of governmental standards are codes and regulations.

It should be noted that certain voluntary standards in one country might be mandatory in others.

10.6.1 Knowledge of Regulatory and Industry Standards Involving Safety and the Environment

Engineering managers must remain aware of current safety and environmental codes and standards. Ignorance of the law is no excuse, nor is the unacceptable justification that the company has been acting in violation of such codes and standards for years. Failing to comply with these regulations has a variety of detrimental consequences, not the least of which is criminal prosecution and plant shutdowns.

The Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) are familiar U.S. government offices charged with protecting the public wellbeing. In addition to these agencies, industry professionals should also be aware of and conform to safety, environmental, and other regulatory standards developed by several other groups, including the following:

- National Fire Protection Association (NFPA)
- Consumer Product Safety Commission (CPSC)
- Food and Drug Administration (FDA)
- National Institute of Standards and Technology (NIST)
- Electronic Industries Alliance (EIA)
- Controlled Environment Testing Association (CETA)
- Equal Employment Opportunity Commission (EEOC)
- International Association of Plumbing and Mechanical Officials (IAPMO)
- American Society of Mechanical Engineers (ASME)
- American National Standards Institute (ANSI)

See Figure 10-3 for additional federal, state, and local government regulations resources.

Figure 10-3. Federal, State, and Local Government Regulations Resources

Federal, State and Local Government Regulations Resources
ASSIST Online (Acquisition Streamlining & Standardization Information System) • A comprehensive database on military and federal specifications and standards; the official source for the U.S. Department of Defense standard • http://assist.daps.dla.mil/online/faqs/overview.cfm (ASSIST Online provides downloadable information about Department of Defense specifications and standards. The site requires the searcher to establish an account and password. Available at http://assist. daps.dla.mil/online/faqs/overview.cfm)
Code of Federal Regulations (CFR) • A database of permanent and general rules issued by federal agencies • http://www.gpoaccess.gov (The Code of Federal Regulations (CFR) database allows the searcher to access permanent and general rules issued by federal agencies. Available at http://www.gpoaccess.gov/cfr/)
FirstGov.gov • Federal website offering links to information about state and local governments and agencies, including a link to lists of state agencies organized by topic • http://www.firstgov/Agencies/State_and_Territories.shtml (The federal website FirstGov.gov has tremendous resources for searching, including a number of links to information about state governments. Available at www.firstgov.gov)
Council of State Governments (CSG) • Providing easy links to all state websites • http://www.csg.org/CSG/States/state+pages/default.htm (The Council of State Governments (CSG) provides a chance for states to share information and work together to solve state and regional problems. The website also provides easy links to the official websites of all the states. Available at www.csg.org)
International Code Council (ICC) • A composite of what used to be Building, Officials and Code Administration (BOCA), International Conferences of Building Officials (ICBO), and Southern Building Code Congress International (SBCCI) • http://www.iccsafe.org

States, municipalities, and other local governments are likely to issue their regulations as a set of codes, such as building or zoning codes. Approach local sources directly in order to determine which codes are applicable in your area.

Safety Requirements

Many countries have adopted standards designed to ensure the safe operation of facilities in which companies operate. In the U.S., the Occupational Safety and Health Administration (OSHA) was created in

1970 to be the leading governmental agency that develops and administers regulations governing worker safety (n.d.).

OSHA's mission includes "setting and enforcing standards; providing training, outreach, and education; establishing partnerships; and encouraging continual improvement in workplace safety and health" (Occupational Safety and Health Administration, n.d.). See Figure 10-4 for examples of safety areas that OSHA regulates.

Figure 10-4. Examples of Safety Areas OSHA Regulates

Examples of Safety Areas OSHA Regulates
• Eye and Face Protection • Ergonomics • Evacuation Plans and Procedures • Noise and Hearing Conservation • Repository Protection • Fire Safety • Hazard Awareness • Electric Power Generation • Steel Erection • Machine Guarding

The OSHA website (www.OSHA.gov) offers access to a variety of informational tools to help companies understand and comply with regulations, including the following:

- eTools
- OSHA Safety and Health Topics Pages
- OSHA Recordkeeping Handbook

Environmental Regulations

Environmental regulation strives to ensure that companies do not harm the environment in which they operate by discharging harmful wastes, producing excessive noise, wasting scarce natural resources, and so forth. See section 10.2.2 for details on environmental regulations.

10.6.2 U.S. and International Codes, Standards, and Regulations

Just as there are many agencies and governmental bodies involved with setting mandatory regulatory codes and standards in the U.S., there are also numerous bodies involved in the creation of voluntary industry standards. One of the most influential is the American National Standards Institute (ANSI) (www.ansi.org).

ANSI is the largest standard-setting organization in the U.S., with more than 11,500 voluntary national standards in its portfolio. ANSI is a private, non-profit organization of approximately 1,200 members consisting of other member organizations, including trade associations, technical societies, industrial companies, labor organizations, consumer organizations, and governmental agencies.

ANSI itself does not create the standards. Instead, it accredits other organizations and groups to develop them. Typically, the standard is created by a consortium of trade associations, professional societies, or other groups representing the impacted industries.

Through ANSI's searchable database, NSSN (https://www.ansi.org/internet_resources/overview/overview?menuid=12), provides searches by document number or keyword for standards of many kinds, including standards by other regional, national, and international standard developers, and information found in the Code of Federal Regulations (CFR).

U.S. Codes, Standards, and Regulations

When working with international companies, managers must be very aware of the correlations and differences between U.S. and international standards. This is particularly important because of the higher cost associated with loss-of-product for international non-compliance.

U.S. Standards for Working with International Companies

For engineers dealing with overseas companies and international issues, many of the standards, international and U.S., mentioned in the last few pages might be relevant. Whether a standard is relevant depends on the location of the work and whether the international company is going to be sharing a project on U.S. soil or the U.S. company is going overseas to work. Certainly, the technical standards of ISO and ANSI might be involved. Provisions of the NAFTA and GATS agreements may apply in relationship to both products and services. If the work is done in the U.S., all U.S. laws and regulations would apply.

Regulations related to foreign-worker entry, worker permits, and immigration must be addressed whether the employer is from the U.S. or from another country. United States federal travel advisories or prohibitions must be observed, and if there are no travel prohibitions, passport, visa, and immigration rules still must be obeyed. Regulations regarding earnings overseas and U.S. (or foreign) income taxes must be followed. Questions about withholdings from salary or wages must be addressed, from the point of view of both countries, as well as questions of healthcare coverage while the foreign worker is in the U.S. The worker must understand what his or her status as a foreigner means and what requirements (U.S. and foreign) that status entails. NAFTA and/or GATS and any such negotiated agreements would apply if the country is a signatory to those agreements. Contact information about the nearest U.S. embassy or consulate should always be available.

Applying Standards to International Projects

Prior to initiating the design phase of an international project, the engineering manager should acquire the standards from each applicable country. Once those are in hand, the manager will be able to determine whether, given the different standards of each country involved, the proposed activity is feasible or even desirable. To gather and assess these standards, engineering managers should take the following steps:

- Determine what standards will apply.
- Acquire copies of the standards and codes.
- Ensure that all standards are updated.
- Communicate updated regulations to all employees who require the knowledge.
- Interpret the standard, seeking expert assistance if needed.
- Ensure all parties involved have the same exact standards.

When working in multinational teams, communication is critical. Even if team members are fluent in a common language, the likelihood of misunderstandings and communication errors is high. Experts advise the following:

- Agree on a single language to be used for communications.
- Whenever possible, communicate in writing.
- Confirm understanding of what international team members are saying. (For example, confirm times for teleconferences when individuals are in different time zones.)
- Agree on metric standards to be used (such as the metric system, English system, etc.).
- Remember cultural differences, and respect diversity.
- Become familiar with the expectations and customs of the country(ies) you are working with.

Critical Information for International Projects

In order to ensure that international projects are successful and that standards can be applied, find out as much about the local situation as possible. This inquiry must be conducted before the design procedures begin—especially if the project locale is in a rural area or in a less-developed country.

Completing a project will be especially challenging without the necessary resources—human, mechanical, electrical, electronic, and so forth. For example, immediately after the breakup of the Soviet Union, electric power was only available in some eastern European countries for a few hours per day. In some instances, the power grids and the telephone lines did not operate at the same time; phone calls were made and received in the dark.

Consider the following questions when analyzing local conditions as they relate to available resources and a project's technical requirements:

- *Human Resources:* What are the characteristics of the local labor force? What are its skills? How many workers are available? What cultural norms will influence their work?
- *Electrical/Mechanical:* What are the local power sources? How easily are they accessed? What are the voltages? Are there frequent power outages? What are the local mechanical support resources? Are parts and components readily available?
- *Communication/Transportation:* Is there high-speed Internet access? Will cell phones in general, and the company's cell phones in particular, work in the area? Where is the closest public or usable phone? What are transportation options in the area? How reliable are they? Where is the nearest fuel station or source?
- *Facilities/Accommodations:* What are the characteristics of the facility you will be operating in? Does the environment meet your requirements? What are building codes in the area? What will living conditions be like for staff? Will running water be available 24 hours a day?
- *Cultural Specifics:* What kind of clothing is considered acceptable? What is the day of rest? How are "good manners" different there? For example, in many cultures, the jovial slap on the back or squeeze of the shoulder is not polite and touching the head is absolutely insulting. What rituals are considered necessary and polite at a dinner party? At a business meeting?

When working on an international project, some of the most important standards to be concerned with are the standards of behavior. Obtaining the answers to these and other questions impacts project planning, as well as the ability to meet deadlines and achieve a number of quality, safety, environmental, production, and other standards.

Sources of Helpful Information

It is always useful to have a staff member with experience in the area, especially someone who speaks the language. If a translator is needed, try to get realistic recommendations, perhaps from other U.S. companies in the area or a college or university, particularly if the school has an engineering program.

Consider enlisting assistance from some advisor or go-between from the actual locale of any project. There may be companies in the project area with which to form temporary partnerships. Handle such partnerships with care, as the ethics, business culture, and social expectations of the partner-company or consultant might be very different from your own. If need be, the diplomatic network may be accessed via consulates.

There are also resources within the profession that can provide advice throughout the project:

- *The World Federation of Engineering Organizations (WFEO) (www.wfeo.org)* offers advice and assistance in matters related to international engineering efforts. The website provides names, addresses, and phone numbers of the members, which are accessed by choosing the country of interest.
- *The United States Council for International Engineering Practice (USCIEP) (https://ncees.org/)* promotes cross-border engineering practice and ease of business restraints.
- *Tourist bureaus, local chambers of commerce (or equivalents), and local municipal offices* might also prove helpful.

International Codes, Standards and Regulations

Almost all businesses are increasingly affected by globalization. Globalization makes national boundaries less important and international cooperation much more crucial.

Treaties, Agreements, and Protocols

International treaties, agreements, and protocols are standards to be followed when two or more countries, or persons or organizations from different countries, have dealings with each other. Treaties are by definition formal agreements negotiated by governments and therefore have the effect of law. Agreements and protocols may represent voluntary agreements between non-governmental organizations and might not be as binding, although those who seek to engage in international business usually find it politically and economically wise to follow them.

International Technical Standards

Some of the leading organizations working on international standards and codes follow:

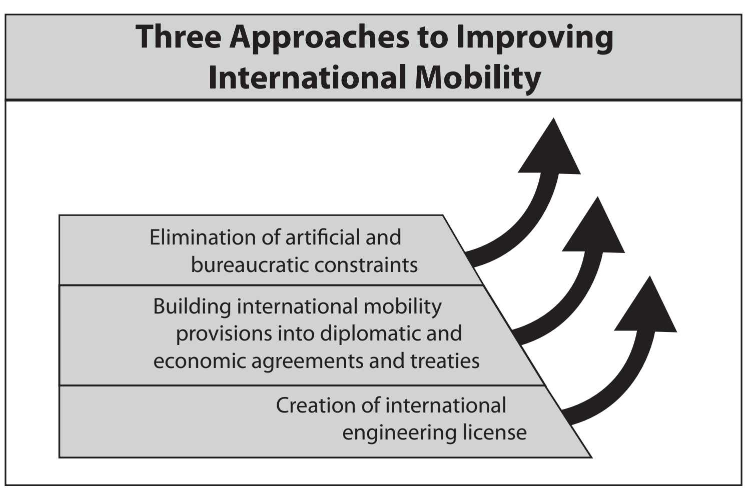
- *International Organization for Standardization (ISO) (www.iso.org):* The ISO is perhaps the world's leading developer of international standards. As of June 2019, the ISO had a portfolio of more than 22,600 standards, covering diverse topics from manufacturing motorcycles to protecting the water quality of a watershed. The ISO is a non-governmental federation of the principal standard-setting entities from about 164 countries. The members suggest what standards are needed and then provide assistance in creating them. After a standard is developed, it is assumed that at least some nations will also adopt it as a national standard (International Organization for Standardization, n.d.).
- *International Electrotechnical Commission (IEC) (www.iec.ch):* IEC develops international standards in the field of electrical, electronic, and related technologies. IEC standards are widely adopted as the basis of national or regional electrotechnical standards, and are often quoted in manufacturers' specifications and by users when calling for tenders. The IEC's present membership of 51 countries includes most major trading nations (International Electrotechnical Commission, n.d.).
- *International Telecommunication Union (ITU-T) (www.itu.int):* ITU-T works with ISO, governments and the private sector to coordinate global telecom networks and publishes international standards for the telecom industry.
- *World Trade Organization (WTO) (www.wto.org):* WTO addresses the rules of international and global trade.
- *International Code Council (ICC) (www.iccsafe.org):* ICC is a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national construction codes. The founders of ICC are Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International, Inc. (SBCCI).

In addition to organizations focused on developing international standards, many countries have their own standards-setting organizations to address national codes. Engineers doing business in those countries should become familiar with these organizations and the standards set by them.

International Mobility Standards

In order to practice or operate globally, many individuals and organizations require standards and procedures that make it easier for them to work in and travel between different countries. (See Figure 10-5.) Professional societies, organizations, and governments are taking the lead in the creation of such mobility standards.

Figure 10-5. Improving International Mobility



- *Removal of Mobility Constraints:* The National Council of Examiners for Engineering and Surveying's (NCEES) International Registry for Professional Engineers (IRPE) works to develop and promote procedures that would enable U.S.-registered engineers to practice internationally. The Council seeks to identify and eliminate constraints to cross-border practice and negotiate and recommend tentative agreements that will allow such practice (National Council of Examiners for Engineering and Surveying, n.d.).
- *Mobility via Treaty:* The North American Free Trade Agreement (NAFTA), passed in 1994, is a comprehensive free-trade agreement between the U.S., Canada, Mexico, and the World Trade Organization. NAFTA provides for reciprocal licensing of engineers from the three signatory countries (Wust, 2003). The General Agreement on Trade in Services (GATS) was enacted in January 1995 by the World Trade Organization (WTO). GATS now calls for more than 135 WTO members to facilitate international mobility (Wust, 2003).
- *International Licensure:* The development of a widely-accepted international engineer's license would enhance international mobility for engineers. Currently, Engineering Credentials Evaluation International (ECEI) evaluates the engineering credentials of engineers from outside the U.S. (n.d.). This service can be helpful to U.S. companies wanting to hire qualified engineers from outside the country, whether the hires are for stateside or international work.

10.6.3 Communication and Training

Engineering managers, unfortunately, have no single all-encompassing source to access thorough and timely information about the wide range of standards and regulations they are required to meet. Dependent upon the industry, different regulatory agencies are involved. For example, the aerospace industry follows many military specifications for design and testing of aircraft while pharmaceutical companies are monitored by the Food and Drug Administration and must follow Good Manufacturing Practices (GMP). Most organizations preserve information about standards applicable to their specific jobsite. How the information is disseminated and managed varies.

Internal standards are often maintained on the company intranet and can include descriptions of processes as simple as filling out expense reports to precise electrical test procedures for interpreting diagnostics of radio-feedback waves. Engineering companies often have an internal group dedicated to interpreting standards. See Figure 10-6 for a list of possible regulatory-requirement-information resources within an organization.

Figure 10-6. Accessing Regulatory Requirements

Regulatory Requirement Information Resources
• A centralized standards office • A standards updating website/service (Techstreet, IHS, etc.) • Company legal advisor(s) • Jobsite documentation (databases, websites, manuals, etc.) • A designated staff member • Supervisory staff

Internal Standards

While companies have numerous industry standards to adhere to, most organizations develop additional internal-performance standards to guide staff actions. Of course, standards related to management systems might be less precise than standards used for testing different grades of steel. However, even standards for management systems define what is expected and provide methods for measuring success.

The most effective standards begin with what is mandated and are further developed to include standards that would benefit the specific jobsite, maximize efficiency in use of natural resources, and so forth. Investing the resources to develop effective internal standards can give companies a decided edge in a competitive marketplace. When drafting standards, or revising them as part of process-improvement activities, follow this checklist:

- Consider the frequency with which the standard will be used (e.g., rarely, regularly, intermittently, etc.).
- Consider the knowledge and experience of users (e.g., novice, expert, etc.).
- Structure the standard in an easy-to-read format.
- If modifying an existing standard, allow for customization in order to meet the requirements of the specific workgroup or task, when appropriate.
- Design metrics to use when assessing whether standards have been met.
- Clarify accountabilities and responsibilities.
- Circulate drafts among staff for input and feedback. Be sure to determine a due date for responses.
- Check and double-check.

Training Staff

Whether introducing a new set of standards to employees or a new employee to the existing standards, remember that human beings have limited abilities for information retention. Take into consideration the amount of information an individual can reasonably absorb and retain at any given time. Explore using existing communication and training resources. For example, OSHA (www.osha.gov) has numerous materials that can be used to train staff, including videos and PowerPoint presentations.

Steps for Standards Training

- Begin with an orientation session where the "larger" topics and issues are discussed. If necessary, introduce standards in stages and leave smaller details for later training sessions.
- Share standard goals and discuss how standards are intended to meet those goals.
- Discuss the scope of the standard—to whom the standards apply and by whom they will be implemented.
- Use visual aids to boost learner retention.
- Provide staff with job aids, or show them where informational resources are located.
- Give hands-on experience whenever possible. If learners are to be using forms, web-based tools, safety equipment, software applications, and the like, give them opportunities to practice using the actual items.

Reinforcing Standards Training

- Offer refresher training sessions.
- Make reviewing standards a regular part of weekly or monthly meetings.
- Schedule monthly standards meetings.
- Weave standards training into existing training activities.
- Have job aids and documentation readily available, especially for emergency processes.

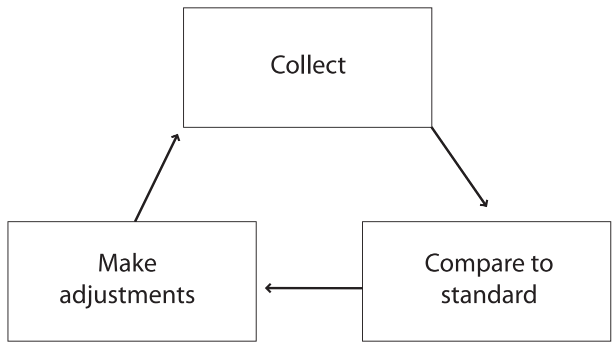
10.6.4 Monitoring and Enforcement

Standards today typically contain at least two elements: (1) the design of the standard itself, plus (2) specific built-in methods for measuring whether, or how well, the product, process, or employee performance conforms to that standard. Engineering managers are entrusted with the task of ensuring that standards are maintained and followed. Planning and monitoring are key to doing this successfully.

As shown in Figure 10-7, engineers and their staff must first collect system, process, and employee-performance data. Once the data has been collected, engineering managers then evaluate the results by comparing them to the standard.

An examination of why a standard is not being met will dictate the appropriate course of action. On one hand, a single adjustment to a piece of equipment or a gentle employee reminder might be all that's required. On the other hand, a thorough re-evaluation of an entire process might be in order.

Figure 10-7. Enforcing Standards



Employee commitment to performance standards is vital. Employees must see that the company is committed to meeting standards and will back up that commitment with enforcement. To effectively enforce standards, the following should be done:

- Develop clearly articulated *key performance indicators (KPIs),* which are quantifiable measurements, agreed to beforehand, that reflect the critical-success factors of an organization.
- Review process design to ensure that performance indicators are reasonable.
- Make sure that staff members understand the stated KPIs and why they are being used.
- Keep everyone on track by making KPIs highly visible.
- Create structures for encouraging compliance, such as checklists, inspection schedules, reviews, and inspections.
- Reward desired behaviors. Tie rewards and incentives to compliance with safety practices and to meeting standards.
- Link compliance with individual performance evaluations and address at performance reviews.

10.6.5 Addressing Violations

Regulatory Violations

Consequences of regulatory violations vary widely depending on the severity of the infraction. Plants can be shut down if GMPs are compromised, or ISO accreditations can be taken away for multiple incidents of noncompliance. Tyson, WorldCom, and Enron executives have faced trials for what would now be a breach of the Sarbanes-Oxley Act.

Any actions taken to address violations in regulatory codes and standards must respond directly to the requirements expressed by the governing body. Be sure to review communication carefully, create a team to address the issue(s), consult internal and external experts, and resolve the issue(s) as expediently and carefully as possible. Avoiding further negative consequences is a priority for the organization.

Staff Violations

Employees are human beings and will make errors or occasionally become less vigilant when completing their tasks. When standards are not met due to deficiencies in employee performance, take the following actions:

- Assess supervisory activities to determine whether employees have been supported appropriately in a manner that will enable them to meet standards.
- Examine systems to uncover any inadvertent disincentives to compliance with standards.
- Address violations formally and in a timely manner. Be careful to be fair and appropriate when correcting behaviors.

Rules and guidelines are most effective when they are extremely visible, communicated clearly, and understood by all. Make it abundantly clear to staff that appropriate punitive actions for violations will be employed. So that the staff understands the outcome of violations, managers must communicate their knowledge of the violation and describe corrective actions taken.

Engineering managers must serve as role models for their staff members who are striving to achieve company and regulatory standards. Be careful to adhere to the following practices:

- Be well informed about the standards and procedures, seeking input from other sources as necessary.
- Ensure that standards are reasonable, measurable, and accurately create a description of the expected work performance.
- Apply standards consistently and fairly to all concerned.
- Document actions taken by all involved parties. This might include explaining the standards; applying, monitoring, and assessing their application; and/or punishing violations.

Many individuals who find it challenging to meet standards might need extra support and coaching from their supervisors. When giving constructive, corrective feedback to staff, be direct, specific, respectful of the employee, and definitive about actions to be taken. Be sure to follow up and compliment team members for their accomplishments.

10.6.6 Improving Adherence

Improving adherence to standards is a group effort. As opposed to addressing individual performance, teams of employees commit to examining procedures and implementing process improvements. However, corporate culture and attitude play a major role in encouraging and building a practice of monitoring standards and adhering to them as closely as possible. Therefore, a significant part of the responsibility for applying standards is shared by the corporate culture, which automatically becomes another piece in the upper-management responsibility.

For example, a computer system can assess how orders are being received into the warehouse and monitor the level of on-time deliveries. If a discrepancy is found between the standard (the expected result) and the actual performance, the manager may communicate with the supplier. Together, they could develop a plan to achieve the standard—in this case, increasing the number of on-time deliveries. The improved adherence to the standard would then involve a collaborative, problem-solving team.

Key people from the suppliers work with the customer to identify reasons for late deliveries and take corrective action to improve results. Because adherence to standards is vital to both project and organizational success, engineering managers must make addressing these issues a high priority. Whether ensuring adherence to a mandatory regulatory standard or a voluntary industry standard, management will have to both prepare and continually retrain its staff on applicable standards.

Preparing Staff for Standards Adherence

Prepare staff for adhering to standards by taking the following actions:

- Enlisting commitment of top management
- Assigning department or team ownership of standard maintenance and communication
- Creating teams or committees to monitor organizational activities
- Designating a team leader and delegating accountability
- Reviewing established processes
- Planning for emergencies
- Ensuring process documentation is readily accessible to staff
- Making critical information highly visible
- Developing clearly articulated Key Performance Indicators (KPIs)
- Setting up control charts to monitor process
- Setting up a Statistical Process Control (SPC) project on adherence

Maintaining Staff Adherence

Human and mechanical systems tend to break down, and a bit of fine-tuning is needed on a regular basis. Maintain staff adherence to standards by taking the following actions:

- Scheduling regular meetings to review and assess adherence to standards
- Having data monitored and collected to view trends and patterns

- Using safety incidents, production shortfalls, variability in outputs, and so forth to assess problems in the system and plan and implement improvements
- Regularly conducting training refreshers:
  - Bringing discussion of various standards into regular staff meetings to keep staff conscious of key topics
  - Being creative
  - Delegating responsibility for mini-trainings to staff
  - Keeping training sessions engaging and fun, as well as productive

Review

Upon completing the study of Domain 10: Legal Issues in Engineering Management, you should be able to answer the following questions:

1. List the common elements in the terms and conditions of contracts.
2. Describe the two major differences between domestic and international contracts.
3. Describe an environmental-management system and explain why it is important.
4. Explain why it is important for engineers to continue their professional development.
5. Explain the NSPE's position on warranties.
6. What are the four types of intellectual property? Describe the basic characteristics of each.
7. What should engineering managers do to protect the intellectual property they are responsible for at their place of business?
8. Whose advice should engineering managers seek as early as possible with regard to intellectual property matters?
9. What are the differences between industry and regulatory standards?
10. How are regulatory standards developed? By whom and for what purpose?
11. Describe the process by which most industry standards are developed. Be sure to discuss who develops the standards and why.
12. Identify actions you, as a manager, can take to promote staff compliance to standards.
13. Describe the two types of standards violations.
14. What help would you enlist when facing challenges in understanding and meeting standards for an international project?
15. What are professional associations and government agencies doing to improve international mobility for engineers?

For More Information

Barakat, N. (2009). Merging continuous professional development into engineering education and practice. ASEE NCS Annual Conference, Grand Rapids, MI.

www.bizmanualz.com – Bizmanualz offers a wide variety of software packages with templates to simplify the process of documenting a wide variety of procedures.

Writing Effective Policies and Procedures, by Nancy Campbell, 1998, New York, NY: American Management Association. A straightforward resource addressing the topic generally. It does specifically address engineering documentation.

www.epa.gov – The U.S. Environmental Protection Agency. Information on all environmental laws, regulations, and policies.

www.nspe.org – The National Society of Professional Engineers. Good source of information on accreditation, professional development, warranties, and insurance.

http://www.aaes.org/program-committees#international-activities – The International section of the American Association of Engineering Societies has information available about international organizations that might be helpful to engineers.

www.theiet.org – The Institution of Engineering and Technology (IET) (a merger of the IEE and IIE), offers a course in contract law designed specifically for engineers.

www.uspto.gov – The United States Patent and Trademark Office provides a website that offers a wealth of general information, publicly searchable databases, and online filing resources.

www.uspto.gov/web/offices/pac/mpep/ – The Manual of Patent Examining Procedure is the guidebook that the USPTO uses to guide the process of patent prosecution as best it can in accordance with federal law, international treaties, and court precedent.

www.copyright.gov – The United States Copyright Office provides a website that offers a wealth of information, publicly searchable databases, and online filing resources.

http://uscode.house.gov/ - The United States House of Representatives provides a website that hosts the entire collection of federal laws. Title 17 pertains to copyrights. Title 35 pertains to patents.

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11

Professional Codes of Conduct and Ethics

Domain 11 Champion

William Daughton, Ph.D., PEM

Domain 11: Professional Code of Conduct and Ethics

Key Words and Concepts

Ethics	Concerned with the kinds of values and morals an individual or society ascribes as desirable or appropriate.
Ethical-Decision Models	Practical models that can be used in aiding an engineer or manager in making a decision with ethical implications.
Ethical Principles	Operating principles that guide the ethical behavior of engineers and managers.
Ethical Theories	Systems of rules or principles underlying decision-making about what is right/wrong and good/bad in a specific situation.
Professional Code of Conduct	Code outlining what is ethical behavior for persons in a profession—usually developed by a professional membership organization.
Stakeholders	The people and groups that supply a company with its productive resources and have a claim on and stake in the company.

11.1 The Nature of Ethics

11.1.1 Ethics and the Law

In light of the important social function that engineering serves, engineering professionals have always held themselves to a high ethical standard.

Ethics address what behavior is considered right and wrong, good and bad—what a person should and should not do. Ethics is not about law per se, although many behaviors that are illegal are also unethical. Many unethical behaviors are forbidden by law, but other unethical behaviors are perfectly legal. Several organizations, including professional societies, create codes of ethics to help members develop the ability to make effective ethical decisions and follow them up with ethical actions.

It should be noted that the distinction between legal and ethical regulation varies in an international context. Some ethical infractions in the U.S. are considered legal infractions elsewhere, and vice versa. A common example that frequently confuses engineers practicing internationally is the problem of differentiating between a gift and a bribe. While the distinction between gifts and bribes is clearly defined by the majority of businesses in the U.S., in some countries the distinction is not as clear. Some nations view highly priced gifts as a common business practice while in the U.S. or other nations, they would be considered a bribe, which is a crime punishable by law.

11.1.2 The Definition of Ethics

According to Northouse (2016, p. 330), ethics is the following:

- Derived from the Greek word ethos, meaning customs, conduct, or character
- Concerned with the kinds of values and morals an individual or society ascribes as desirable or appropriate
- Focused on the virtuousness of individuals and their motives

11.2 Stakeholders and Ethics

11.2.1 The Stakeholder Environment

The collection of people and groups affected by the behavior of an organization is referred to as the organizations' stakeholders. Stakeholders stand to gain direct benefits or suffer harm, depending on the actions of the organization. In the context of ethics, then, decisions to be made by engineers and managers must take into account the impact on the stakeholders (Jones & George, 2007, pp. 94-97).

1. Stockholders

If the organization is a publicly owned company, stockholders have a direct financial stake in the success of the company. These stakeholders do not want a company to engage in unethical actions that could negatively impact the value of their shares. As an example, part of the well-known collapse of Enron can be attributed to both illegal and unethical actions. Senior managers abused their positions of trust with the stockholders, costing many their life savings.

2. Employees

In this context, managers, professionals, and hourly workers constitute the employees of an organization. Each in their own way, within their broad or limited spans of authority, may make decisions that have ethical implications. In turn, they are each affected directly by the ethical decisions made by their employee counterparts. Clearly, managers have more potential for creating benefits or inflicting harm on their peer employees, due to their broad decision-making authority. One classic example that is faced by companies during a downturn in business is whether to have a layoff and if so, how to do it.

3. Suppliers and Distributors

There are few, if any, companies today that are totally vertically integrated. They all depend on suppliers for raw materials, component parts, information, and so forth, and many companies depend on distributors who act as intermediaries in distributing products to final customers. Both suppliers and distributors are part of the larger value chain that includes the company using both entities. The business ethics of the company can profoundly affect the success of these organizations connected to the company through this value chain. For example, during the recent downturn in the automobile industry, many small suppliers to U.S. automakers were adversely affected, some of them unable to continue in business.

4. Customers

Clearly the success of any company depends on its ability to attract customers to buy its products or services. Ethical decisions by the company can impact the quality, value, and performance of those products and services. While there are laws that protect consumers from companies delivering substandard products or financial schemes meant to defraud consumers, legal but unethical decisions might have an impact as well. As an example, the credibility of some automakers has been adversely affected by companies downplaying the seriousness of known problems until a catastrophe occurred.

5. Communities

Communities here refer to both the local communities where companies have a physical presence and the larger global community of nations and society. Companies have a profound effect on local economies and quality-of-life issues in communities in which they operate, and their success or collapse can have broad implications in their home countries and across the world. The decision to bail out General Motors and Chrysler in recent years was based at least partially on the impact of their potential collapse on the overall U.S. economy.

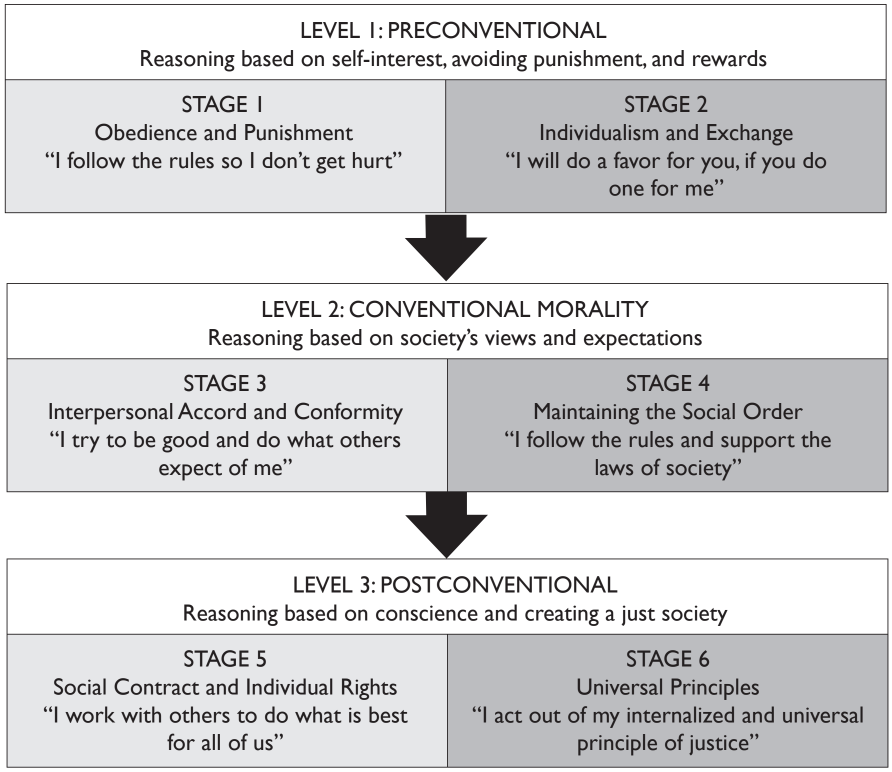
11.2.2 Ethical Decision Considerations Relative to Stakeholders

In making decisions with ethical implications, engineers and managers must be mindful of the impact to the various stakeholder groups. The considerations are different for the various classes of stakeholders and not all will be affected either fully or partially by such decisions. Some of the basic ethical-decision considerations are shown in Figure 11-1.

Figure 11-1. Organizational Stakeholders and Ethical Decision Considerations

Stakeholders	**Decision Consideration**
Stockholders	Stockholders want to ensure that managers are behaving ethically and not risking investors' capital by engaging in actions that could hurt the company's reputation. They want to maximize their return on investment.
Employees	Companies can act ethically toward employees by taking the following actions: • Creating an occupational structure that fairly and equitably rewards employees for their contributions. • Creating a physical environment that ensures a safe and accommodating workplace. Employees have an ethical responsibility to efficiently and effectively use the company assets
Supplies and Distributors	Suppliers expect the following: • To be paid fairly and promptly for their inputs • To be treated with respect as a value chain partner Distributors expect the following: • To receive quality products meeting all specifications at agreed-upon prices • To be treated with respect as a value-chain partner
Customers	Company must work to increase efficiency and ensure effectiveness in order to create loyal customers and attract new ones. Customers expect fair return on their investment in company products and services in the form of value, quality, and performance.
Communities	Companies must work to ensure that their presence is a positive contributor to the local community and contributes to the economy of nations and the world.

Figure 11-2. Kohlberg's Stages of Moral Development (Northouse, 2016, p. 331)



11.3 Stages of Ethical and Moral Development

An individual's ethical choices are strongly influenced by their moral development. A series of stages of moral development was proposed by Kohlberg (1984) that describes how moral reasoning develops in individuals. As seen in Figure 11-2, there are three levels of development with two stages in each level.

At the first stage, a person tends to judge the ethics of any actions taken based exclusively on the consequences. So, punishment avoidance and personal reward dominate an individual's thinking. At level two, ethical decisions are largely based on society norms. Level three is also known as the principled level, since individuals at this level develop their own set of ethical guidelines which, in turn, steers their behavior. Depending where individuals are in their moral and ethical development, Kohlberg's model provides a sound basis for an individual's ethical leadership.

11.4 Ethical Theories

All ethical decision-making is based on two underlying domains that have embodied in them several basic theoretical concepts regarding ethics. Each provides system of rules or principles underlying decision-making about what is right/wrong and good/bad in a specific situation. They also provide a basis for understanding what it means to be a morally decent human being. The practical decision-making models and other considerations related to ethical decision-making are based on these theories.

11.4.1 Conduct Theories

Teleological theories focus on *consequences* of engineers' or managers' actions and results:

- Ethical egoism (create greatest good for the engineer or manager)
- Closely related to transactional leadership theories
- Example: engineer or manager takes a political stand on an issue for no other reason than to get re-elected

Utilitarianism theories focus on creating the greatest good for the greatest number:

- May include either uniform or weighted distribution of benefits or harm
- Example: program manager distributes scarce human resources to various projects related to the program so as to optimize the success of each individual project

Altruistic theories focus on showing concern for the best interests of others:

- Authentic transformational leadership is based on altruistic principles.
- Example: the work of Mother Theresa, who gave her entire life to help the poor

11.4.2 Character Theories

Virtue-based theories focus on an engineer's or manager's *character:*

- Focus on who people are as people.
- Rather than tell people what to do, tell people what to be.
- Help people become more virtuous through training and development.
- Virtues present within person's disposition, and practice makes good values habitual.
- Examples: courage, honesty, fairness, justice, integrity, and humility.

11.5 Principles of Ethics for Engineers and Managers

11.5.1 Ethical Behavior

Ethical behavior can be thought of as acting in a socially responsible manner. Society in this context includes all the organization's stakeholders, and responsibility refers to doing the right thing and acting in the appropriate way that yields benefits for those stakeholders. It is incumbent on engineers and managers to operate in a way consistent with this social responsibility.

11.5.2 Operating Principles of Ethics

There are several operating principles that guide the ethical behavior of engineers and managers. Figure 11-3 provides a breakdown of the fundamental behavior, the corresponding principle, and, very importantly, observable behavioral characteristics that engineers and managers use to support the principles.

Figure 11-3. Ethical Behaviors and Operating Principles (From Northouse, 2016, pp. 341-347)

Behavior	Principle	Behavior Characteristics
Respect others.	Treat stakeholders as ends (their own goals) rather than means (to engineers' or managers' personal goals).	Is respectful of other people's values and decisions. Is empathetic. Is tolerant of opposing viewpoints.
Serve others.	Place stakeholders foremost in engineers' or managers' plans.	Mentors and empowers subordinates. Builds strong and effective teams. Models good citizenship relative to stakeholders.
Show justice.	Place issues of fairness at the center of decision-making affecting stakeholders.	Treats subordinates equally without favoritism or bias. Actively considers impact on stakeholders in decision-making. Respects the rights of all individuals.
Exhibits manifest honesty.	Be sensitive to the feelings and attitudes of affected stakeholders.	Accepts responsibility. Balances openness and candor with monitoring what is appropriate to disclose. Acknowledges and rewards ethical behavior in the organization.
Builds community.	Seeks goals that are compatible with all stakeholders.	Considers the purposes of everyone in a group or team setting. Reaches out beyond personal goals to the wider community. Is sensitive to cultural considerations in a global environment.

11.6 Practical, Ethical Decision-making

11.6.1 Ethical Decision Models

There are four common models that can be used in aiding an engineer or manager in making a decision with ethical implications. (See Figure 11-4.)

There is no absolute template for making ethical decisions. In practice, most ethical decisions involve consideration of some or all of the model elements mentioned earlier. A more concise set of questions that can be asked about a decision with ethical implications follow:

- Does it violate the obvious "shall nots"?
- Will anyone be harmed?
- How would you feel if your decision were reported on the front page of your newspaper?
- If you did it 100 times, would you still be okay with it?
- How would you feel if someone did it to you?
- What's your gut feeling about the decision?
- What would your mother think of your decision?

Figure 11-4. Models for Ethical Decision-Making (Jones & George, 2007, pp. 99-102)

Model	Description	Challenges
Utilitarian	A decision that produces the greatest good for the greatest number of stakeholders.	How do you measure the benefits and harms that will be done to each stakeholder group? How do you evaluate the rights and importance of each stakeholder group?
Moral Rights	A decision that best maintains and protects the fundamental or inalienable rights and privileges of the stakeholders affected by it.	Rights and privileges might be different in other cultures around the world.
Justice	A decision that distributes benefits and harms among stakeholders in a fair, equitable, or impartial way.	How do you measure the benefits and harms that will be done to each stakeholder group? What constitutes "fair and equitable" in weighting the distribution?
Practical	A decision that an engineer or manager has no hesitation about communicating to people outside the company because the typical person would think it is acceptable.	Could be self-deluding in that an engineer or manager might think or want to believe how the typical person would react to the decision.

11.6.2 Common Ethical-Decision Problems

Sometimes individuals do not see that a situation has ethical implications, even if they are familiar with the codes of ethics or decision models. Or if they recognize the ethical problem, they don't know how to apply the guidelines. Ethics training enables employees to recognize ethical problems and learn how to think them through to a best solution. Training in a variety of modes, such as professional-development courses and on-the-job training by taking actual situations at hand and demonstrating how to deal with them, can be useful in sensitizing decision makers to ethical considerations. Figure 11-5 illustrates some typical ethical problems encountered by employees and some approaches to resolving them.

A discussion of ethical decision-making in the face of these types of challenges would be incomplete without including the option for whistleblowing. A whistleblower is someone who exposes alleged misconduct or dishonest or illegal activity occurring in an organization. The subject-alleged activities might be a violation of a law, rule, regulation and/or a direct threat to public interest often involving fraud, environmental and safety violations, and corruption. Whistleblowers may be the subject of retribution by the organization, and, as such, federal and state laws have been enacted to protect them.

Whistleblower protection is covered under federal law in three main areas under the Department of Labor, and a number of states also have whistleblower-protection laws in place (www.whistleblower.gov). Figure 11-6 shows an example of whistleblower protection enacted by U.S. OSHA through the OSH Act.

Whistleblowing has gained prominence in recent years due to a number of well-publicized cases, and several organizations have emerged to provide information and assistance to whistleblowers. For example, The National Whistleblowers Center (www.whistleblowers.org) provides legal assistance, attorney referrals, seminars, and training. It is strongly recommended that an individual considering whistleblowing as an ethical-decision option seek qualified legal advice before proceeding.

Another practical issue to consider in ethical decision-making is rationalization. This can occur at the individual level as well as within an entire organization. At this level, it is often referred to as *"Corporate Think."* Some typical rationalizations are shown in Figure 11-7. It is critical to ethical decision-making not to be caught in these rationalization traps.

Figure 11-5. Common Ethical Problems and Solutions

Problems	**Solutions**
Some employees are unfamiliar with codes of ethics or behavior guidelines. Sometimes people are unaware of the ethical codes or behavioral guidelines by which they should be guided. Or they don't see how these ethics apply to situations they are in. They don't think far enough ahead to see that not doing something they are supposed to do or doing something they are not supposed to do can result in extremely negative consequences—for the individual and the organization.	• Organizational management needs to make sure that employees are made aware of rules and guidelines for behavior. • Direct engineers to whichever professional code is appropriate—show actual codes so that staff become familiar with the style and format used. • Participate in professional societies that create and promote ethical codes. • Distribute copies of company and industry codes of ethics. • Create a structure for employees to commit themselves in writing to the established ethical standards and corporate codes. • Offer or require periodic (e.g., annual) training in professional ethics.
Employees are tempted or pressured to behave unethically.	• Make codes of ethics public and a priority. Public pledges to follow codes may act as a sort of shield to support an employee's ability to resist pressure or temptation. • Create structures for employees facing ethical dilemmas to discuss issues with an informed and impartial third party. • Establish resources and procedures for employees who feel unduly influenced.

Figure 11-6. The OSH Act (https://www.osha.gov/laws-regs/oshact/toc)


Workplace Safety and Health

The OSH Act prohibits employers from discriminating against their employees for exercising their rights under the OSH Act. These rights include filing an OSHA complaint, participating in an inspection or talking to an inspector, seeking access to employer exposure and injury records, and raising a safety or health complaint with the employer. If workers have been retaliated or discriminated against for exercising their rights, they must file a complaint with OSHA within 30 days of the alleged adverse action.

Since passage of the OSH Act in 1970, Congress has expanded OSHA's whistleblower authority to protect workers from discrimination under twenty-one federal laws. Complaints must be reported to OSHA within set timeframes following the discriminatory action, as prescribed by each law. These laws, and the number of days employees have to file a complaint, are:

- Environmental and Nuclear Safety Laws
- Transportation Industry Laws
- Consumer and Investor Protection Laws

KNOW YOUR RIGHTS

OSHA's whistleblower statutes protect you from retaliation.
Learn more*...

Figure 11-7. Obstacles to Ethical Decision-Making (Josephson, 2002, pp. 27-28)

Obstacles to Ethical Decision-making: Rationalizations
1. If it's necessary, it's ethical. 2. "The False Necessity Trap" 3. If it's legal and permissible, it's proper. 4. It's just part of the job. 5. It's all for a good cause. 6. I was just doing it for you. 7. I'm just fighting fire with fire. 8. It doesn't hurt anyone. 9. Everyone's doing it. 10. It's OK if I don't gain personally. 11. I've got it coming. 12. I can still be objective.

11.7 Professional Codes of Conduct

11.7.1 The Need for Codes of Conduct

Recent business scandals have challenged the public's trust and faith in business leaders and organizational integrity. Consequently, it is more critical than ever that leaders act as ethical engineers, holding themselves and their organizations to the highest ethical and professional standards. This means remaining constantly vigilant that they and their staffs are in compliance with all applicable codes and standards.

The Enron scandal was certainly shocking in terms of the amount of money involved and the apparent arrogance of the company officials involved. Other large and previously respected businesses and government officials have been revealed to have engaged in practices that are, at the very least, of questionable ethics and possibly illegal.

Individuals who are determined to behave ethically face challenges at the workplace (i.e., when an employee's ethical behavior or decision is not in line with the company's profitable course of action, the management is not generally supportive of that employee). Having well-conceived company codes of behavior or ethics can provide much-needed clarity and guidance to employees when behavioral or ethical issues arise. In this respect, codes of ethics and standards for good behavior might be more important than ever before.

11.7.2 Codes of Ethics Provided by the Engineering Societies

One of the more important services provided by the professional engineering societies is creating, updating, and promoting professional codes of ethics. These codes are usually created by committees or councils comprised of members who are active in the profession, and, as a result, are often very practical.

While each society's or organization's code is unique, there are elements common to each. For example, the codes of ethics for the American Society of Mechanical Engineers (ASME), the National Society of Professional Engineers (NSPE), and the American Society of Civil Engineers (ASCE) all stress that engineers should first consider the safety, health, and welfare of the public. Also common to all engineering codes of ethics are statements calling engineers to uphold the honor and integrity of their profession and to perform service only in their areas of competence.

Examples of Codes of Ethics

American Society for Engineering Management (ASEM) — http://www.asem.org

American Society of Mechanical Engineers (ASME) — https://community.asme.org/colorado_section/w/wiki/8080.code-of-ethics.aspx

Institute of Electrical and Electronics Engineers (IEEE) — https://www.ieee.org/about/corporate/governance/p7-8.html

The National Society of Professional Engineers (NSPE) — https://www.nspe.org/resources/ethics/code-ethics

The Online Ethics Center for Engineering and Science at Case Western Reserve University (offers some international codes and codes in Spanish) — https://online-engineering-info.case.edu

11.7.3 Codes of Ethics Provided by Corporations

Many corporations have detailed codes of ethics that include statements of principle as well as detailed information on compliance, conflicts of interest, disclosure requirements, reporting, and accountability. These codes speak to the integrity and citizenship of the corporation in conducting its business. You should become familiar with the code of ethics in your own organization as well as those of suppliers and customers in your value chain.

Examples of Codes of Ethics

AT&T Inc. — http://www.att.com/gen/investor-relations?pid=5595

The Hersey Company — https://www.thehersheycompany.com/content/dam/corporate-us/documents/investors/code-of-conduct.pdf

John Deere — http://keithnewman43.blogspot.com/2012/04/john-deere-has-code-of-ethics-that-was.html

Medtronic — https://www.medtronic.com/us-en/about/corporate-governance/code-conduct.html

11.7.4 International Codes of Ethics

Given the wide variety of cultural differences around the world, it might appear that developing an international code of ethics for engineers would be a daunting task. Various professional societies within the engineering profession, however, have already created examples of such codes. An especially encouraging sign is the code of ethics developed for work under the NAFTA treaty. The World Federation of Engineering Organizations (WFEO) has also created a modeul code of ethics (http://ethics.iit.edu/codes/WFEO%20Undated.pdf) that is to be used by organizational members of the Federation.

Another source of useful advice and tools relating to the prevention of corruption can be found at the Global Infrastructure Anti-Corruption Centre (GIACC) (http://www.giaccentre.org/index.php). This center provides free online information about dealing with corruption, as shown in Figure 11-8.

Figure 11-8. Screenshot of GIACC Website (http://www.giaccentre.org/)

The central tenet of all these codes and sources of information dictates that when engineers practice or work in an international context, they must respect local cultures and regulations. In addition, they should avoid the presumption of their own moral superiority or inferiority and be cognizant that the laws and ethics of their home country do not necessarily apply in other nations. Engineers and managers should contact local organizations governing professional practice for information and guidance.

Review

Upon completing the study of Domain 11: Professional Codes of Conduct and Ethics, you should be able to:

1. Define ethics.
2. List the stakeholders of an organization.
3. Describe the stage of moral and ethical development.
4. Differentiate between ethical conduct and ethical character theories.
5. Describe the operating principles that guide ethical behavior in engineers and managers.
6. Discuss the four common, ethical decision-making models.
7. Identify three obstacles to ethical decision-making you have observed in your workplace, and what you would do to overcome each of them.
8. List the benefits of using a carefully crafted code of ethics in the workplace.
9. Identify sources for codes of ethics for professional engineers and managers.

For Further Information

Defining Moments: When Managers Must Choose between Right and Right, by Joseph Badaracco (1997), ISBN: 0-87584-803-6. A thought-provoking book on business ethics.

Ethics for the Real World: Creating a Personal Code to Guide Decisions in Work and Life, by Ronald A. Howard and Clinton D. Korver (2008), ISBN: 978-1-4221-2106-1. A practical guide to making ethical decisions.

"Ethical Breakdowns," by M. Bazeman and A. Trenbrunsel, *Harvard Business Review*, April 2011, Vol. 89, Issue 4, pp. 59-65.

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Jones, G. R., & George, J. M. (2007). *Essentials of contemporary management* (2nd ed.). New York, NY: McGraw-Hill Irwin.

Josephson, M. (2002). *Making ethical decisions.* Marina del Rey, CA: The Josephson Institute of Ethics.

Northouse, P. G. (2016). *Leadership theory and practice* (7th ed.). Thousand Oaks, CA: SAGE.

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