

**AC 2010-196: STRENGTHENING THE U.S. ENGINEERING WORKFORCE FOR INNOVATION: FOUNDATIONS OF PROFESSIONAL GRADUATE EDUCATION FOR THE NATION'S ENGINEERS IN INDUSTRY ? PART I EARLY CAREER DEVELOPMENT: DIRECT LEADERSHIP ?**

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# **Strengthening the U.S. Engineering Workforce for Innovation: Foundations of Professional Graduate Education for the Nation’s Engineers in Industry – Part I Early Career Development: Direct Leadership –**

## **Part I**

### **1. The Direct Leadership Function of Engineering in Industry: Skill-Sets and Actions**

*Engineering is a very creative profession and practice, concerned with the combining of human, economic, and material resources to meet the needs of society ... for the advancement and betterment of human welfare.*

*2000 - National Collaborative Task Force*

#### **DIRECT LEADERSHIP SKILLS**

- **Interpersonal Skills**
- **Conceptual Skills**
- **Technical Skills**
- **Tactical Skills**

#### **DIRECT LEADERSHIP ACTIONS**

- **Influencing Actions**
- **Operating Actions**
- **Improving Actions**

#### **1-1. OVERVIEW**

In this paper, we discuss what practicing engineers must know and do as engineer-leaders. The practice of engineering requires lifelong professional development through continuous learning. A part of this professional development is acquisition of the direct leadership skills necessary for effective engineering leadership. This requires dedication not only to lifelong learning but also to practice. The engineer-leader must learn about effective leadership techniques – the “know” – either by formal classroom instruction or by self-directed learning. In addition, the engineer-leader must implement these leadership skills – “do” – by experiential learning with proper and effective mentorship. The first section of this paper presents the skills required for effective engineering leadership. The second section of the paper presents the actions necessary for effective implementation of these skills.

#### **1-2. DIRECT LEADERSHIP SKILLS – ENGINEERING TO MAKE A DIFFERENCE**

##### **A – INTERPERSONAL SKILLS**

Interpersonal skills or “people skills” could be considered the most important tools of the effective engineer-leader. These skills – communication, team-building, and counseling – are all closely related.

*Communication Leadership* is about coordinating the activities of others in order to achieve an objective so good communication skills are of critical importance for effective leadership. Communication usually occurs in one of two ways: seeing and hearing. The engineer-leader must use each of these effectively.

One-way communication is frequently used to convey ideas and project results. Reports, proposals, and project results are transmitted to others in written form. These documents must be clear, concise, and error free because there is no opportunity for immediate response from the reader. Oral presentations to an audience of peers and superiors also must be clear, concise and error free. In addition, key ideas must be presented visually in such a way that a knowledgeable audience can follow them without prior study. The effective engineer-leader must continually strive to improve both written and oral communication skills.

Two-way communication is much more commonly encountered in day-to-day activities. Here, of course, there is an opportunity for verbal exchange of ideas. Hence, it is important for the engineer-leader not only to convey ideas clearly but also to listen to and respond properly to the ideas of others. Effective speaking should be on point. The inclination to dominate the conversation or wander off topic should be avoided. Effective listening requires ones full attention. This includes attention to verbal and nonverbal responses from the other person. The effective engineer-leader must develop and continue to improve two-way communication skills.

*Team-Building* Effective team leaders properly assess the attributes and skills of others selected to work on a project. Once a team is in place, the engineer-leader must effectively convey ideas to and motivate other members of the team. It is the responsibility of the team leader to insure that all team members understand the goals for the project and their contribution to achieving them. Motivating others to work with you is crucial to the success of a project. It is a critical skill that the effective engineer-leader must develop.

*Counseling* In order to properly motivate members of team, the team leader must be mindful that counseling of individual team members may be required. Engineers are highly trained and self-motivated. However, a team member may not clearly understand his or her role on the project. The effective engineer-leader must insure that each member of the team is aware of the project goals and that success is dependent on the important contributions of each team member.

## **B – CONCEPTUAL SKILLS AND VISION**

Conceptual skills include handling ideas, thoughts and concepts. These include critical reasoning, creative thinking, and reflective thinking.

*Critical Reasoning* Critical reasoning involves needs-finding, assessment of alternatives that satisfy the need, and reflection on outcomes. In short, critical reasoning or creative problem solving is what effective engineer-leaders do. Experience plays an important role in critical reasoning because current best practices often are the starting point for exploration of alternatives to a problem. Experience allows the engineer-leader to judge the viability of current technologies and propose new solution to the problems at hand. Reflection on past projects, the solutions to previous problems, allows the engineer-leader to consider new and possibly better ways to meet project goals in safe and economical manner.

*Creative Thinking* The effective engineer-leader always will be willing to “think outside the box.” New projects require new, alternative solutions to the technological challenges posed. Experience, of course, plays an important role in creative problem solving. But the engineer-leader must develop the ability to properly assess not only what has been done but also what can be done within the constraints of the project.

*Reflective Thinking* As the engineer-leader grows in experience, his or her ability to reflect on the success (or failure) of previous projects is expanded. Thus, reflection on what has been done is an important tool that the engineer-leader can employ in assessing the viability of alternative solutions to a technological problem.

## **C – TECHNICAL SKILLS**

Technical skills fall into two categories. The engineer-leader must be familiar with the appropriate body of scientific knowledge and the appropriate body of technical knowledge. In addition, he or she must be able to apply this knowledge to the solution of new and unique problems.

*Scientific Knowledge* The entry-level engineer is familiar with the scientific phenomena that influence his or her area of engineering expertise. This knowledge has been gained at university, usually involving study from both a scientific and an engineering perspective. However, this is usually insufficient for the effective practice of engineering. The effective engineer-leader must develop the skill of applying scientific knowledge not only to the solution of “routine” problems but also to new and unique problems. The latter requires continual self-directed learning.

*Technical Knowledge* Technologies change very rapidly. While the engineer’s education does not become outdated, he or she must continually learn about new technologies as they evolve. These new technologies often represent emerging best practices that can be employed in the effective solution to a new engineering challenge. The effective engineer-leader must be able to properly judge the application of existing and emerging technologies to solution of new and unique problems. Again, this requires continual self-directed learning.

## **D – TACTICAL SKILLS**

Tactical skills are those skills the effective engineer-leader employs to efficiently and successfully manage a project. The project need must be identified. Appropriate goals for the project must be established. Metrics must be established to ensure that project goals have been met. Reflection on the success of the project must be undertaken. Proper and complete reporting of project outcomes must be made. All of these skills must be applied not by the engineer-leader working alone but by the engineer-leader acting as the leader a project which satisfies corporate goals and objectives. Thus, the engineer-leader must be cognizant of role his or her activity plays within this broader corporate context. These tactical skills require knowledge best gained “in-context,” that is, in practice under the mentorship of a more experienced engineer. Supplementary knowledge gained via topic-specific formal education and short courses often is required. However, the importance of relevant knowledge gained as required, as opposed to formal advanced degrees in, say, business administration cannot be overemphasized.

### **1-3. DIRECT LEADERSHIP ACTIONS ENGINEERING TO MAKE A DIFFERENCE**

## **A – INFLUENCING ACTIONS**

Influencing actions are those things an effective engineer-leader does to successfully complete a project. This is direct implementation of the people skills discussed previously. These are communication, decision making, and motivation.

*Communication* An effective engineer-leader must be an effective communicator. This involves written and verbal communication with subordinated, peers and superiors. Good, solid written reports and proposal are necessary components of a successful project. It is the responsibility of the engineer-leader to ensure that these documents are done well and in a timely manner. Effective two-way communication with all the people involved with the project also is required. Team members should not feel as if they are being micromanaged. Rather, the engineer-leader should maintain open communication to ensure that each team member is aware of his or her role and its importance to the project.

*Decision Making* The engineer-leader must consistently make sound decisions that will ensure the success of a project. Decisions should be made with confidence. This requires careful assessment of the problems, issues, and challenges of the project. To make sound decisions, the engineer-leader must be able to think creatively within the constraints of science and technology. This requires a deep understanding of each. The engineer-leader also must make decisions about management of a project: What are the project goals? What steps must be taken to reach these goals? Which individuals / talents can best be used to reach project goals? How should each task be prioritized? Thus, the effective engineer-leader must be not only a visionary creative problem solver but also an effective manager of project activities.

*Motivation* Engineers as a group are highly self-motivated. However, it is the responsibility of the effective engineer-leader to ensure that the talents of each project team member are fully utilized. Each member of the project team should have a sense of empowerment and responsibility. The engineer-leader should carefully and consistently provide positive reinforcement to each member of the project team. Of course this requires effective two-way communication. But it also requires the engineer-leader to be aware of individuals, their personalities, and their circumstances. Only one disgruntled team-member is required to undermine a project, so this is a critical responsibility for the effective engineer-leader.

## **B – OPERATING ACTIONS**

Operating actions in the con text of effective engineering leadership refer to planning activities or goal setting, completing those tasks that accomplish the established goals, and using appropriate metrics to ensure that the goals have been achieved. The responsibility of the engineer-leader is to ensure that each project team member fully understands the project goals, how they are to be achieved, and their responsibility in achieving them. The engineer-leader should monitor the project tasks using appropriate benchmarks and be prepared to offer more intensive guidance to team members as necessary. The engineer-leader also is responsible for reporting the status of the project to both superiors and team members using appropriate metrics.

## **C – IMPROVING ACTIONS**

Improving actions are those reflections upon a project which lead to improvements or benefits for the company. These reflections consider technological and financial benefits for the company, professional development for the engineer-leader, and mentorship of project team members.

*Technological and Financial Benefits* Each project is initiated by a company with the expectation of a return on investment. Different metrics may be used to assess the financial benefit of a project depending on its scope as a technology improvement project, a technology implementation project or as a technology development project. Of course, not all projects are successful. But the effective engineer-leader will have a teach record of involvement in successful projects. Thus, the engineer-leader must reflect on the technological and financial benefits of each project, asking “What can be done better?”

*Professional Development* The effective engineer-leader is engaged in continual professional development activities. Each project represents an opportunity to grow professionally by improving his or her leadership skills. Thus, the engineer-leader must reflect on those aspects of each project that fostered professional growth, asking “What did I learn and how does it help me become a more effective engineer-leader?”

*Mentorship* The effective engineer is an effective mentor to those with whom he or she works. A company benefits when its engineers emerge from entry-level to become engineer-leaders. Engineers create technologies that are of benefit to the company. Proper mentorship of junior engineers by more senior engineers makes it possible for a company to sustain and grow. Thus, the engineer-leader must reflect on those aspects of each project that afforded him or her an opportunity to mentor project team members and ask “How was I able to aid the professional development of a project team member through mentorship?”

## **1-5. SUMMARY**

In this paper, we have discussed the skills and actions required of effective engineer-leaders. The practice of engineering requires lifelong professional development through continuous learning. A part of this professional development is acquisition of the direct leadership skills necessary for effective engineering leadership. This requires dedication not only to lifelong learning but also to professional practice. The engineer-leader must learn about effective leadership techniques – the “know” – either by formal classroom instruction or by self-directed learning. In addition, the engineer-leader must implement these leadership skills – “do” – by experiential learning with proper and effective mentorship.

## **Acknowledgement**

Because of the excellence of its writing and intent, the National Collaborative Task Force has drawn unashamedly from much of the direct context of the document “*Army Leadership FM 22-100*”.<sup>6</sup> This document represents a seminal landmark in professional leadership literature for the graduate development of highly experienced practitioners operating at the frontline of their profession.

## References

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6. *Army Leadership FM 22-100*, Headquarters, Department of the Army, August 1999.

## Appendix: A

### Stages of Professional Maturation, Autonomy, and Responsibilities in Engineering Practice for Responsible Technology Leadership

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#### **Stages of Growth**

#### **Typical Responsibilities-Autonomy-Judgment**

ENGINEER IX	An engineer-leader at this level is in responsible charge of programs so extensive and complex as to require staff and resources of sizeable magnitude to meet the overall engineering objectives of the organization.
ENGINEER VIII	An engineer-leader at this level demonstrates a high degree of creativity, foresight, and mature judgment in planning, organizing, and guiding extensive engineering programs and activities of outstanding novelty and importance. Is responsible for deciding the kind and extent of engineering and related programs needed for accomplishing the objectives of the organization.
ENGINEER VII	In a leadership capacity, is responsible for an important segment of the engineering program of an organization with extensive and diversified engineering requirements. The overall engineering program contains critical problems, the solutions of which require major technological advances and opens the way for extensive related development.
ENGINEER VI	In a leadership capacity, plans, develops, coordinates, and directs a number of large and important projects or a project of major scope and importance. Or, as a senior engineer, conceives, plans, and conducts development in problem areas of considerable scope and complexity. The problems are difficult to define and unprecedented. This involves exploration of subject area, definition of scope, and selection of important problems for development.
ENGINEER V	In a leadership capacity, plans, develops, coordinates, and directs a large and important project or a number of small projects with many complex features. Or, as an individual principal engineer, carries out complex or novel assignments requiring the development of new or improved techniques and procedures. Work is expected to result in the development of new or refined equipment, materials, processes, or products. Technical judgment, knowledge, and expertise for this level usually result from progressive experience.
ENGINEER IV	Plans, schedules, conducts, or coordinates detailed phases of engineering work in part of a major project or in a total project of moderate scope. A fully competent engineer in all conventional aspects of the subject matter of the functional areas of assignments. Devises new approaches to problems encountered. Independently performs most assignments requiring technical judgment.
ENGINEER III	Performs work that involves conventional types of plans, investigations, or equipment with relatively few complex features for which there are precedents. Requires knowledge of principles and techniques commonly employed in the specific narrow areas of assignments.
ENGINEER I/II (Entry Level Engineer)	Requires knowledge and application of known laws and data. Using prescribed methods, applies standard practices/techniques under direction of an experienced Engineer.



## Appendix B

# The Modern Paradigm of the Practice of Engineering for Creative Technology Development and Innovation Responsive to Real-World Needs of Industry and Society

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Needs ⇒ Engineering ⇒ Technology



Directed Basic Scientific Research to  
gain a better understanding of natural  
phenomena when needed or anticipated  
during the technology development project

## Appendix C

### Comparison of Integrative Framework for the Professional Master's of Engineering and the Professional Doctor of Engineering

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**Professional Master of Engineering –  
For Creative Engineering Practice and  
Leadership**  
Level III Engineer – Skill-Sets / Outcomes

**Focus: Professional Development of  
Emerging Engineer-Leaders in Industry  
For Creative Technology Development and  
Innovation at Project Engineering  
Leadership Level**

❑ **Curricular Components Integrative with  
Creative Engineering Practice**

**Core Professional Courses: 18 Credits Hrs.**

Emphasis on the professional dimensions, knowledge, and critical skill-sets required in engineering practice (at Level III Engineer) for engineering leadership, professional responsibility, and creative problem solving at project engineering level for technology development and innovation in industry / government service. (Six Professional Courses)

**Professional Electives: 6 Credits Hrs.**

Emphasis on flexibility in tailoring program electives to be relevant to the participant's field of technology/or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules. (Two Elective Courses)

**Directed Technology 6 Credit Hrs.  
Development Project:**

Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development and innovation needs of the participant's sponsoring industry. This work should represent innovative development at the project engineering leadership level wherein the graduate participant is in responsible charge (Level III Engineer).

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**Total 30 Credits Hrs.**

**Professional Doctor of Engineering –  
For Creative Engineering Practice and  
Leadership**  
Level VI Engineer - Skill-Sets / Outcomes

**Focus: Professional Development of  
Experienced Engineer-Leaders in Industry  
For Creative Technology Development and  
Innovation at Program and Policy  
Leadership Levels**

❑ **Curricular Components Integrative with  
Creative Engineering Practice**

**Core Professional Courses 12 Credit Hrs.**

Emphasis on the professional dimensions, knowledge, and critical skill-sets required in engineering practice (at Level VI Engineer) for engineering leadership, professional responsibility, and creative problem solving at program and policy levels for technology development and innovation in industry/government service. (Four Professional Courses)

**Professional Electives 6 Credit Hrs.**

Emphasis on flexibility in tailoring the program electives to be relevant to the participant's field of technology or other professional needs to be selected by the participant with approval of oversight committee; including self-directed learning and independent study in special topics, as well as formal courses/modules. (Two Elective Courses)

**Directed Technology 12 Credit Hrs.  
Development Project:**

Emphasis on gaining real-world experience in creative problem-solving through project-based (problem-centered learning) focusing on innovation through a quality tangible experience of meaningful significance that is directly relevant to the technology development and innovation needs of the participant's sponsoring industry. This work should represent significant innovative development at program / policy levels wherein the graduate participant is in responsible charge at (Level VI Engineer).

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**Total 30 Credit Hrs.**

## Professional Master of Engineering (cont'd)

### ☐ Professional Maturation Components

- **Residency Component**  
Full-time employment in engineering practice in industry/government service
- **Progressive Experience Component Beyond Entry-Level**  
Minimum of 2 to 5 years of progressive experience beyond entry-level in engineering practice
- **Technical Competency Component**  
Demonstrated growth from novice to competent professional in a specific technological field

### ☐ Admission Requirements to Program

Graduate of ABET program in engineering; Minimum of at least 6 months beyond entry-level experience in engineering practice; Level II Engineer; plus strong letters of recommendation from the graduate participant's sponsor; or from distinguished practicing professionals in engineering; and the FE when appropriate

## Professional Doctor of Engineering (cont'd)

### ☐ Professional Maturation Components

- **Residency Component**  
Full-time employment in engineering practice in industry/government service
- **Progressive Experience Component Beyond Entry-Level**  
Minimum of 6 to 10 years of progressive experience beyond entry-level in engineering practice
- **Technical Competency Component**  
Demonstrated growth from competent professional to expert in a technological field

### ☐ Admission Requirements to Program

Holder of the professional Master of Engineering (M.Eng.) degree or equivalent; six years of progressive experience in engineering practice beyond entry-level; Level IV Engineer; plus strong letters of recommendation from the graduate participant's sponsor; or from distinguished practicing professionals in engineering; and the PE when appropriate.

## Appendix D

# Core Knowledge, Attributes, and Critical Skill-Sets Required in the Practice of Engineering for Leadership of Technology Development And Innovation in Industry and Government Service

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### First Levels — Technology Leadership

#### Early Career Development

[Levels I thru III Engineer]

#### Project Levels

##### Project Engineer Levels Position Titles:

- Engineer III – Project Engineer
- Engineer II – Design Engineer, Development Engineer, Manufacturing Engineer, Process Engineer
- Engineer I – Entry Level

##### Core Characteristics —

Degreed Engineers, at the first levels of technology leadership, grow from entry-level novice to fully competent experienced engineers:

- Performing non-routine assignments, assuming greater responsibility at project levels
- Growing in-depth competency of company knowledge relevant to projects, products, processes or operations technology
- Gaining real-world experience in the practice of engineering and use of the engineering method for:
  - Creative problem-solving for generating effective solutions to open-ended practical problems
  - Continuous incremental improvement, development and innovation of components within a subsystem or project technology

### Mid Levels — Technology Leadership

#### Mid-Career Development

[Levels IV thru VI Engineer]

#### Program/Systems Levels

##### Senior Engineer Levels Position Titles:

- Engineer VI - Functional Area Manager
- Engineer V - Senior Engineer Principal Engineer, Project Leader, Group Leader
- Engineer IV – Senior Project Engineer, Process Engineer

##### Core Characteristics —

Degreed Engineers, at the mid levels of technology leadership, grow from fully competent engineer to fully competent engineer-leader for a functional technological area/program/system in responsible charge for:

- Gaining in depth expertise in needs-finding and planning, organizing, leading original development and innovation of large-scale complex projects / programs / systems within functional areas
- Growing in depth and breadth of company knowledge of complex programs and systems technology
- Gaining in depth competency in leading effective teams for collaborative creativity and innovation
- Gaining in depth competency in leading and ‘championing’ needs-driven technological change and innovation

### Top Levels Corporate — Technology Leadership

#### Senior Career Development

[Levels VII thru IX Engineer]

#### Corporate Policy Levels

##### Executive Engineer Levels Position Titles:

- Engineer IX - Vice President of Engineering and Technology
- Engineer VIII - Director of Engineering
- Engineer VII - Department Division Manager

##### Core Characteristics —

Degreed Engineers, at the senior levels of technology leadership, grow from fully competent engineer-leader for a functional program / system area to executive engineer-leader with broad skills in responsible charge for:

- Building an overall corporate organization of trust and engineering purpose that fosters a culture for continuous learning and collaborative creativity for meaningful innovation to flourish
- Setting the overall values of corporate engineering for safety issues, environmental issues, financial issues, and socio issues
- Defining the mission, and goals of the technology organization
- Setting overall vision, technology policy, planning, and staffing for continuous technology innovation
- Allocating adequate financial and manpower resources to sustain the company’s overall innovative technological thrust

## Early Career (cont.)

[Early Engineering Levels of **known laws and data** under mentoring, guidance and supervision]

### □ Core Competency Skill-Sets as Defined by Tasks of Engineering Practice

- Gaining in depth competency of project / product / process technology
- Gaining in depth competency of creative problem solving
- Engineering ethics relevant to safety / environmental issues
- Concepts of systems engineering
- Project engineering management
- Knowledge of Six Sigma
- Communication skills
- Customer oriented
- Understanding of engineering methodology for innovation
- Understanding of financial metrics for investment in projects
- Self-directed learning skills

### Qualifications for Entry Level Degreed Engineer [ABET] into Engineering Practice

- a) an ability to apply knowledge of mathematics, science, and engineering
- b) an ability to design and conduct experiments, as well as to analyze and interpret data
- c) an ability to design a system, component, or process to meet desired needs
- d) an ability to function on multi-disciplinary teams
- e) an ability to identify, formulate, and solve engineering problems
- f) an understanding of professional and ethical responsibility
- g) an ability to communicate effectively
- h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
- i) a recognition of the need for, and an ability to engage in lifelong learning
- j) a knowledge of contemporary issues
- k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

## Mid-Career (cont.)

[Mid Engineering Levels of **technical judgment**, decision making, tactical planning and responsible charge]

### □ Core Competency Skill-Sets as Defined by Tasks of Engineering Practice

- Gaining in depth corporate expertise of technical programs and systems technology
- Gaining in depth expertise in creative vision [invention, innovation, thinking out of the box] at program / systems level
- Gaining in depth expertise in systems architecture
- Engineering ethics relevant to technology / socio issues
- Expertise in technical judgment
- Gaining a systems perspective
- Systems engineering leadership
- Global perspective of technology and economic competitiveness
- Communication skills
- Needs-finding, vision and program formulation skills
- Strategic thinking
- Understanding core principles of business
- Understanding financial metrics of corporate decision making for investment in innovation
- Understanding root causes and scenarios of systems failures and their prevention
- Gaining expertise in learning skills of reflective practitioners — how professionals think in action
- Self-assessment skills for continuous professional improvement
- Awareness of emerging technologies and sciences
- Gaining expertise in people skills for leading effective innovative teams and collaborative creativity — what motivates / de-motivates creative engineers in actual work
- Understanding modern concepts of how creative engineers learn, grow / develop as professionals
- Understanding concepts of statistics and variations for continuous improvements
- Understanding concepts of operations research in planning and allocating resources for development programs

## Senior Career (cont.)

[Senior Engineering Levels of **value judgment**, decision making, strategic planning, and responsible charge]

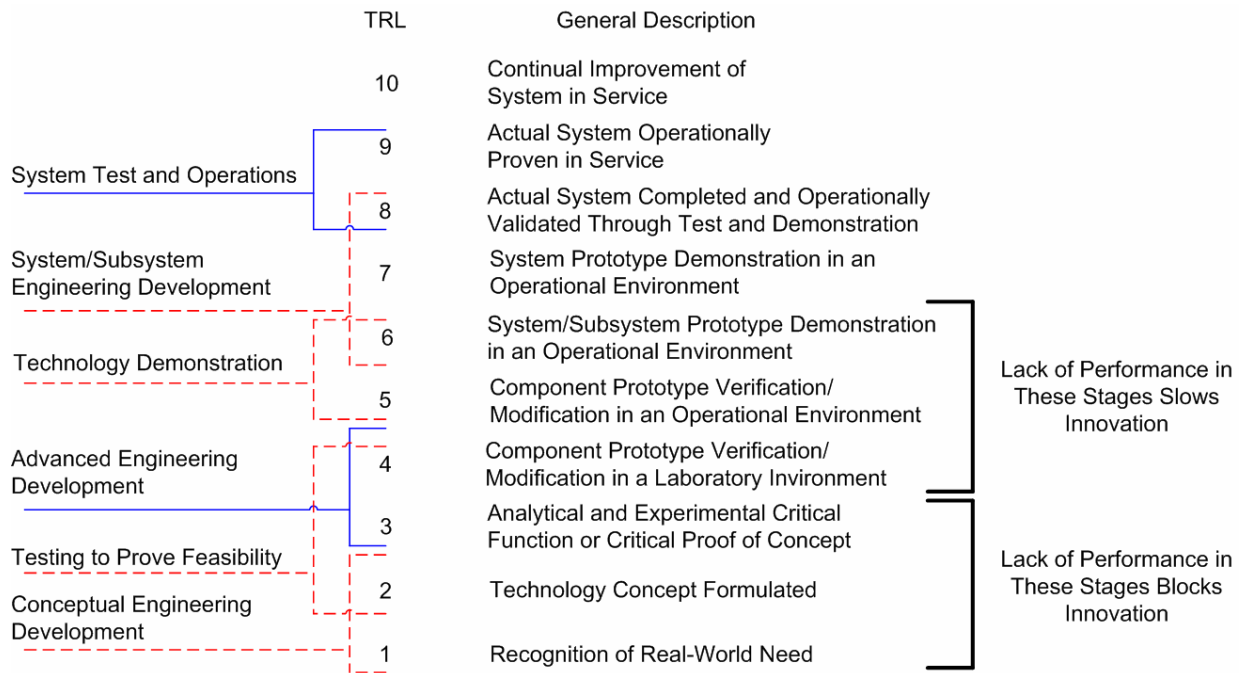
### □ Core Competency Skill-Sets as Defined by Tasks of Engineering Practice

- Broad overall knowledge of corporate systems technology
- Awareness of competitive technologies
- Strategic vision
- Engineering ethics relevant to technology / socio issues
- Value judgment
- Leading people
- Results driven
- Business acumen
- Building coalitions
- Corporate communications
- Technology policy making
- Integrity

## Appendix E

# The Modern Paradigm of the Practice of Engineering Yielding Technology Readiness Levels of New Technology for Real-World Needs of Industry and Society

### Technology Readiness Level (TRL)



TRL = Technology Readiness Level