AC 2010-217: STRENGTHENING THE U.S. ENGINEERING WORKFORCE FOR INNOVATION: FOUNDATIONS OF PROFESSIONAL GRADUATE EDUCATION FOR THE NATION'S ENGINEERS IN INDUSTRY - PART II MID-CAREER DEVEL

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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 II Mid-Career Development: Organizational Leadership ─

Abstract

This is the second of four invited panel papers prepared specifically for the National Collaborative Task Force Engineer-Leaders Project. The Project concerns the deliberate advancement of professional graduate engineering education relevant to the needs of creative engineering practice in industry to enhance U.S. technological innovation and competitiveness. The strength of the innovation and leadership capacity of America's professional engineering base in our civilian, aerospace, and defense industries is a critical asset in our global economic recovery. As with other learned professions, there are progressive skill sets and actions that must be learned or developed at the advanced levels of the practice of engineering. This series of papers addresses the skills continuum in three main parts: a) Part I addresses the Direct Leadership Skills and Actions required for Engineering Levels [1-3]; b) Part II addresses the Organizational Leadership Skills and Actions required for Engineering Levels [4-6], and; c) Part III addresses the Strategic Leadership Skills and Actions required for Engineering Levels [7-9]. The overall analysis sets the foundation for building a coherent professional graduate curriculum and dynamic educational process reflective of how experienced engineering professionals learn, grow, and create new technology in industry. This paper addresses Part II: the Organizational Leadership Function, Skills and Actions that engineers must learn and develop from Group Leader, Functional Area Manager, Systems Engineer through Technical Program Manager Levels [4-6].

Part II

2. The Organizational Leadership Function of Engineering in Industry: Skill Sets and Actions

> *… Successful innovation is a question of leadership. The need for this capacity is one reason why the product 'champion' is always identifiable in the case of successful innovations.*
>
> William Kingston

ORGANIZATIONAL LEADERSHIP SKILLS
- **Interpersonal Skills**
- **Conceptual Skills**
- **Technical Skills**
- **Tactical Skills**

ORGANIZATIONAL LEADERSHIP ACTIONS
- **Influencing Actions**
- **Operating Actions**
- **Improving Actions**

2-1. OVERVIEW

As engineers mature into mid career planning and leadership positions and assume greater responsibilities, they must learn new skills, develop new abilities, and act in moderately complex situations. Mid level leaders/planners are progressing towards becoming the engineering profession's highest level thinkers, executive practitioners, and leaders of change for continuous corporate improvement and innovation.

2-1-1. Engineering Education: A Lifelong Growth Process ─ The National Collaborative Task Force for Engineering Graduate Education Reform has deliberately taken a broad, holistic approach that addresses the overall professional education of the engineer as a lifelong developmental and self-study growth process that is combined with experiential learning gained through actual progressive engineering practice which extends throughout the engineer's entire creative professional career. As with other learned professions, there are progressive levels of leadership responsibility and skill-sets in the practice of engineering that can be learned, taught, or developed.

As engineers mature throughout their careers and assume greater responsibilities, they must learn new skills, develop new abilities, and act in ever more complex situations. These skills can be divided into interpersonal skills, technical skills, and conceptual skills. Highly competent engineers never stop learning. This requires these competent engineers to hone their skills through lifelong learning and self-direction that must be nurtured first in the undergraduate years of engineering education.

Although engineers build upon their accumulated knowledge and experience throughout their careers, the range of skills and actions required for the mid level leader/planner function of engineering are different from those of the early career engineer that perform their required work. The mid level leader/planner works to become an expert in this/her own domain of engineering leadership, and must work toward developing a holistic systems engineering understanding of their corporate technology through their work experience

a) by mentoring from more senior engineers/leaders,
b) by receiving available in-house training, and
c) by attaining postgraduate degrees.

However, creative/innovative engineers will, and must, enhance their skills beyond their highest attained degree.

Engineering leaders must be developed who will, in turn, guide other engineers to develop innovative new designs, and who will lead the development of products providing what the customer wants and needs. Management styles that will both encourage innovation, and meet the basic human needs of engineers are needed. This will include the adoption of cutting-edge concepts and best practices from other nations. This, in turn, will lay the groundwork for turning theory into practice. Engineers must also drive changes in their fields. The field of engineering is changing so rapidly, that an engineer must keep up with the rapid advances in their field of practice to avoid obsolescence.

A solid foundation of professional engineering graduate education is required to encourage, inspire, and enable the continued professional growth of the nation's engineers, working in industry.

2-1-2. Industrial Innovation ─ Strengthening industrial innovation in America's industry is the engine for economic recovery and job creation. Engineering innovation is the deliberate process and practice of conceptualizing, developing, and converting an "idea" into a commercially suitable technology, product, process, system or operation, in response to a desire, a problem or a need.

However, industrial innovation is constrained by the supply, retention, and further professional graduate development of the "innovative capacity" of the professional U.S. Engineering Workforce in America's technology-based industries. Central to this issue is the idea of improved collaboration between America's universities and industry in the professional graduate engineering educational process. To further the graduate education of the nation's engineers who are the primary generators of the nation's technology for competitiveness.[1]

2-2. Strategic Engineering Leadership Skills ─

> *"Engineering is a very creative profession and practice concerned with the combining of human, economic, and material resources to meet the hopes, wants, and needs of society … for the advancement and betterment of human welfare."*
>
> 2000 ─ National Collaborative Taskforce for Engineering Graduate Education Reform

> *"The key idea is that engineering is a system of leadership that results in the satisfaction of human needs."*
>
> Eric Walker, former President of Pennsylvania State University and Former President of the American Society for Engineering Education

2-2-1. Interpersonal skills - Mid career Development [Engineer Levels 4–6] affect, set and sustain the overall engineering values and innovation culture of the technology-based organization ─ They continue to use the interpersonal skills developed as practicing engineers, and as planners/mid level leaders, but because of the responsibilities of their positions, these skills must be continually honed. As mid level leaders, they must strive to continue to grow their skills by seeking all of the training they can take, and take graduate level courses, and work toward postgraduate degrees that will help them advance in their field.

2-2-2. Conceptual skills and vision - Mid level organizational leaders should have a long-term focus to continue to grow their skills and to become a strategic engineer-leader in the future ─ To achieve a strategic engineer-leader position they must look forward and understand their corporate organizations in terms of long range strategic-systems plans. They must begin to think in terms of strategic engineering systems and overall systems approaches for their company's future technological advances.

2-2-3. Technical & leadership skills - Growth of a Mid level Engineer (leader/Planner) skills (both technical and leadership) ─ The Mid level leader/planner must continue to grow/expand both their technical and leadership skills. Additional technical skill training will give the Mid level Engineer the additional technical skills required to better master his/her area of expertise so to better lead a group of engineers, and/or plan the manpower and timing of projects. Leadership skills training will help the Mid level Engineer do a better job at their assigned position, and allow them to grow into a higher position of leadership. A postgraduate degree (Masters and/or Doctoral) with the proper courses chosen is a prime path towards this goal. This degree must be one that is aimed at the engineer in industry, rather than an engineer in academia. The National Collaborative for Engineering Graduate Education Reform is the major organization that is pushing for such graduate degrees.

A professional graduate degree in Engineering is needed, because the preparation of future leaders and technical experts within the engineering profession has truly changed. Teaching improved skill sets is becoming increasingly more important. The ability to select team members, facilitate open discussions, and resolve conflicts is as important as technical knowledge. Preparing our future leaders and technical experts is required to achieve industrial success and it must be emphasized throughout an engineer's graduate education. This form of graduate education will play a vital role in the transformation of engineers into innovators and leaders. The U.S. needs a workforce that is mature at all levels of engineering practice to fuel world-class technology development and innovation.

2-2-4. The need for Businesses in Industry to develop Engineering Inovation ─ Innovation is what makes engineering firms succeed. However, developing technological innovation requires more than an undergraduate degreed engineer's knowledge of science and of engineering fundamentals. Effective leadership is required to produce engineering innovation. Per Robert Mueller, "Innovation is a uniquely human activity … it is the process by which an invention or an idea is translated into the economy for use. [2] Mueller notes that the necessary ingredients which lead to effective industrial innovativion are:

(1) A need for something new

(2) Creating a concept or idea to meet the need

(3) A champion, or leader ,to help create an idea to fulfill the need

(4) An organizational culture that fosters innovation

(5) Adequate financial resources to produce an innovation

2-2-5. The Innovation Process: ─ The process of engineering innovation has changed greatly in the last half-century. Today, it is apparent, per Peter Drucker [3], it is not just basic science that creates new knowledge. Engineering creates new technological knowledge as the result of its deliberative inventive process, which creates new, or improved, technologies, which lead to new products, systems, processes or operations. Deliberate engineering innovation has become an organized and systematic practice. [3] This is a great change in thinking from the linear research-driven model of the 1945 science policy (Vannevar Bush)[5] which portrayed basic research as the primary driver of engineering practice. This has produced a change from only basic research, to a needs-driven model of engineering for engineering innovation (See Appendices C, D, E).

2-3. SUMMARY

Mid career engineers will require further learning and development, including postgraduate degrees to perform their current jobs, and to grow into senior strategic engineering leaders which will prepare and sustain U.S. industry for a globally competitive future through their leadership, vision, and actions.

As engineers mature throughout their careers and assume greater responsibilities, engineers must learn new skills, develop new abilities, and act in more complex situations. Highly competent engineers never stop learning. The engineer must hone and refresh their skills through lifelong learning and self-direction.

Engineers build upon their accumulated knowledge and experience throughout their careers, The mid level leader/planner must work to become an expert in this/her own domain of engineering leadership, and must work toward developing a holistic systems engineering understanding of their corporate technology through their work experience by attaining postgraduate degrees, along with other means of learning.

Industrial innovation is constrained by the supply, retention, and further professional graduate development of the "innovative capacity" of the professional U.S. Engineering Workforce in America's technology-based industries. Central to this issue is the idea of improved collaboration between America's universities and industry in the professional graduate engineering educational process. To further the graduate education of the nation's engineers who are the primary generators of the nation's technology for competitiveness.

The National Collaborative initiative to produce graduate degree programs at participating universities that are aimed at practicing engineers, will yield new technological advancements relevant to industrial innovation needs of 10 to 1.

Acknowledgment

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"*.[6] 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.[4]

References

1) Norman F. Egbert, N.F., Keating, D.A., DeLoatch, E.M., *Strengthening the United States Engineering Workforce for Innovation: A time for Government and Industry to Invest in a National Competitive Strategy to Revitalize the U.S Engineering Infrastructure for Innovation, American Society for Engineering Education Annual Conference, June 2009.*

2) Mueller, R.K., *The Innovation Ethic,* American Management Association, 1971.

3) Drucker, P., *Managing in a Time of Great Change.*

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

5) Bush, Vannevar, "Science The Endless Frontier". A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development*," July 1945* ...

Appendix: A

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

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

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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

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 Credit 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 Credit 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 Development Project: 6 Credit Hrs.
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).

Total 30 Credit 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 Development Project: 12 Credit Hrs.
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).

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 <u>known laws and data</u> 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 <u>technical judgment</u>, 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 / sociological 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 <u>value judgment</u>, 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 / sociological 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

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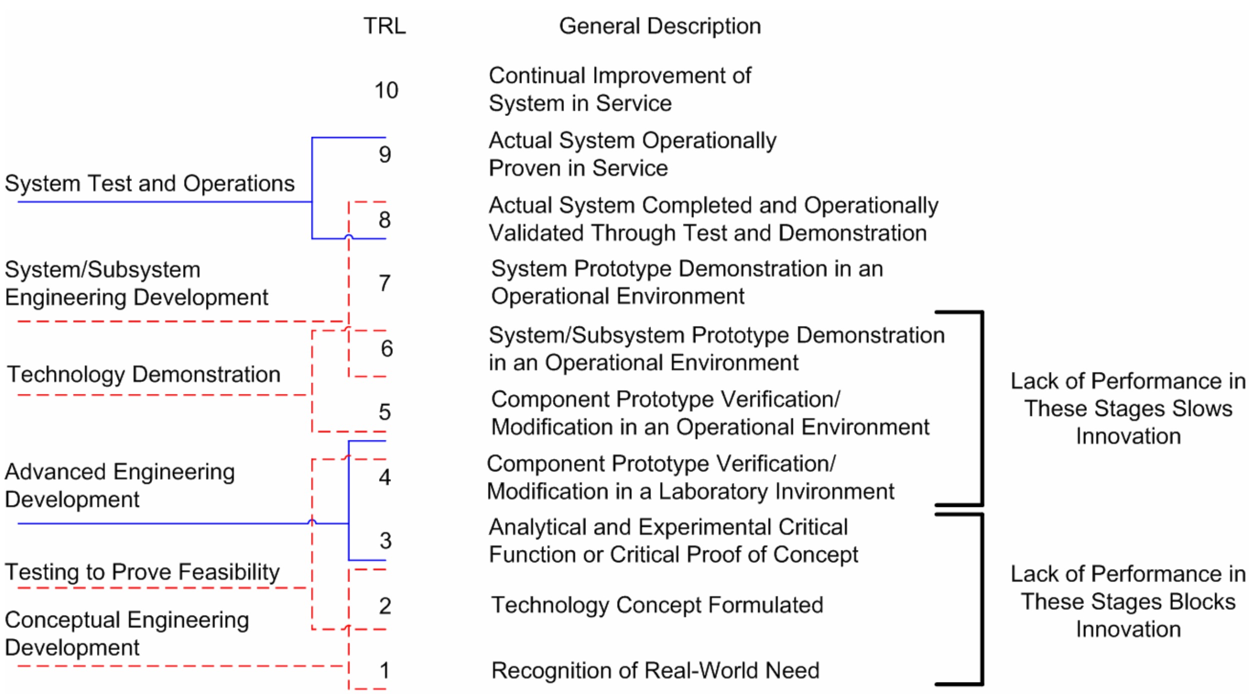
Technology Readiness Level (TRL)



TRL = Technology Readiness Level