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Engineering Management—Past, Present, and Future

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1.1 Introduction

1.1.1 Overview of Engineering Management

With the globalization of the manufacturing base, outsourcing of many technical services, the efficiencies derived from advances in information technology (and the subsequent decrease in mid-management positions), and the shifting of our economy to be service-based, the roles of the technical organization and the engineering manager have dramatically changed. The 21st century technical organization must be concerned with:

1. Maintaining an agile, high quality, and profitable business base of products or services in a fluctuating economy,
2. Hiring, managing, and retaining a highly qualified and trained staff of engineers, scientists, and technicians in a rapidly changing technological environment, and
3. Demonstrating a high level of capability maturity.

Engineers often enter the job market not as traditional engineers but as project managers, technical sales, and lead systems engineers (especially within the defense and information management arenas) involved with conceiving, defining, architecting, designing, integrating, marketing, and testing complex and multi-functional information technology centric systems (Abel, 2005). Within five years, for most engineers this has become their primary job function. Combined with the fact that the modern engineering enterprise is now characterized by geographically dispersed and multi-cultural organizations, engineering management (EM) is more relevant than ever. Because of the blurring of boundaries between technical and management roles, engineers must continue to redefine their roles to remain relevant in the modern economy. Like all technical professions, EM has evolved dramatically because of the information age and the interdisciplinary nature and complexity of modern systems.

1.1.2 The History of the Engineering Management Discipline

According to Kocaoglu (1984), EM as a formal degree has existed since the mid 1940s. However, we know that courses in business and management aspects of engineering have been taught since the 1900s. For example, Stevens Institute of Technology founded a Department of Business Engineering in 1902 with the aim to teach students "to become efficient managers" (Clark, 2000). The Massachusetts Institute of Technology offered a degree in industrial management around 1913 (Kocaoglu, 1989). Several EM or EM-type programs grew out of the post World War II industrial expansion to include the University of Washington (1947) and Michigan Technological University (1949). The major growth occurred in the 1960s and 1970s. The first EM department was founded at the University of Missouri – Rolla (UMR now known as Missouri University of Science and Technology) in 1967. UMR also awarded the first PhD in EM in 1984 (Murray and Raper, 1997). The UMR contribution is further discussed by Babcock (2000). Today, there are probably in excess of 85 universities offering undergraduate and graduate degrees in programs named EM in the United Sates. Most EM programs can be categorized as being embedded within an industrial engineering department/program or combined with systems engineering departments/programs. Few undergraduate education EM programs exist because industrial engineering departments have been reluctant to embrace the profession at the undergraduate level. If you include the international programs, those embedded as concentrations within industrial engineering degrees, concentrations within MBAs, and hybrid programs such as engineering administration, systems EM, there are probably hundreds of universities that offer an EM-type degree. Given the recent downturn in MBAs degrees awarded in many programs (*Triad Business Journal*, 2004), EM degrees/programs/department should continue to grow.

At the undergraduate level, there has also been growth in terms of related classes, minors, and certificates that are embedded within traditional degrees. However, the number of undergraduate EM programs has seen little growth. As shown in Table 1.1, the ABET website lists 11 accredited undergraduate programs in the US and five internationally with the word "management" in the program name and only

one has been accredited in the US for the first time in the last five years. Only five use the term "engineering management" exclusively for the program name. A recent American Society for Engineering Education (ASEE) publication on domestic engineering programs lists 23 EM undergraduate programs, which also are summarized in Table 1.1.

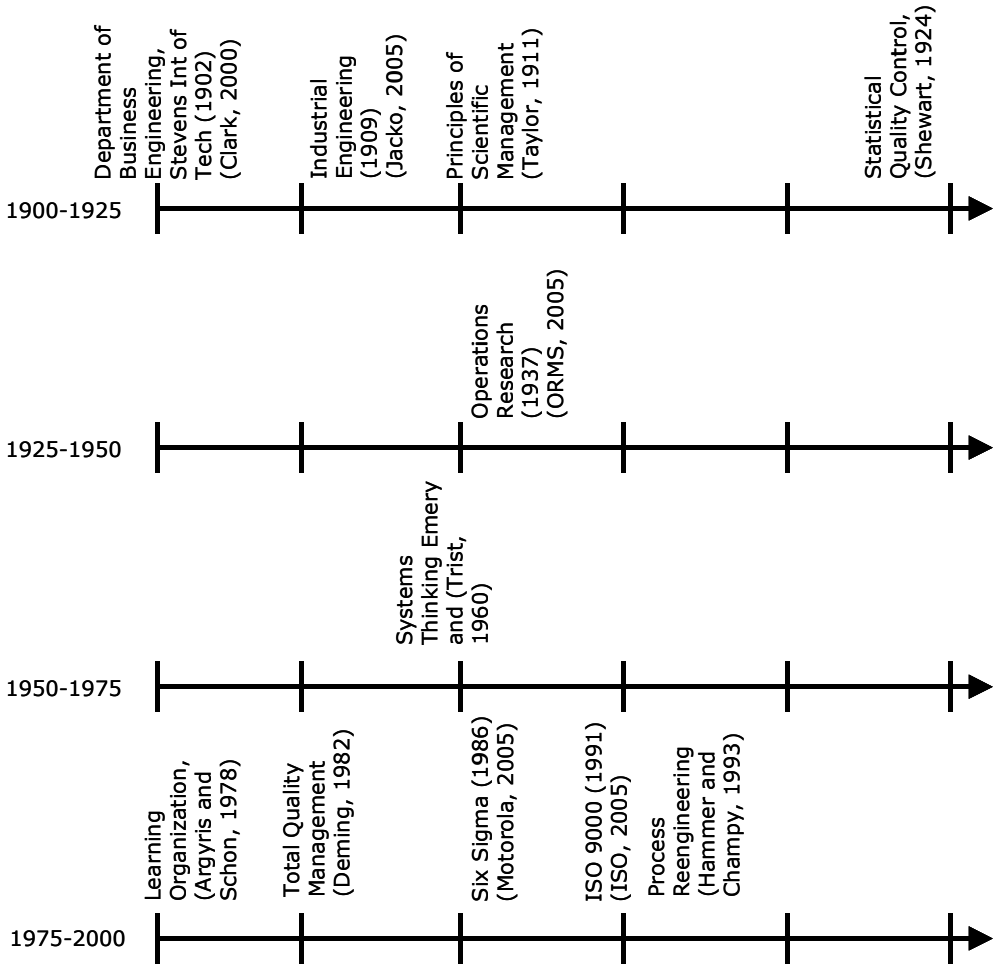
Table 1.1. ABET accredited and ASEE EM Related Programs (from Kaufman et al., 2015)

ABET Accredited EM Programs*	ASEE Listed EM Undergrad Programs
Domestic	University of Arizona
University of Arizona** (2003)	Arizona State University
Clarkson University*** (2009)	California State, Long Beach
University of Connecticut (1978)	California State, Northridge
Missouri University of Science and Technology ** (1979)	University of California – Santa Cruz
	Christian Brothers University
North Dakota State University (1971)	The College of New Jersey
Oklahoma State University (1936)	Colorado School of Mines
University of the Pacific**(2003)	Gonzaga University
Rensselaer Polytechnic Institute (1978)	Illinois Institute of Technology
South Dakota School of Mines and Technology (1991)	Mercer University
	Miami University
Stevens Institute of Technology** (1990)	Missouri University of Science and Tech.
United States Military Academy** (1985)	University of North Carolina - Charlotte
	University of the Pacific
International	NYU Polytechnic School of Engineering
Arab Academy for Science and Technology and Maritime Transport (2009)	University of Portland
	Southern Methodist University
Istanbul Technical University (2009)	St. Mary's University
Kuwait University (2006)	Stevens Institute of Technology
Universidad Autonoma de San Luis Potosi (2012)	University of Tennessee - Chattanooga
University of Sharjah (2010)	United States Military Academy
	University of Vermont

* Programs with "Management" in the name, ** "Engineering Management" programs, *** "Engineering and Management" programs. The number in parenthesis under ABET accredited programs is the year that the program was first accredited.

The EM profession mirrors both trends in business and education. Early business engineering focused on the civil and mechanical engineering disciplines. As shown in Figure 1.1, with the work Taylor (1911) contributed to the early focus on manufacturing that dominated the discipline through the 1990s. Rapid advances in information technology in the 1980s and organizational changes in all engineering practices led to decline in the specialist engineer and a rise in the generalist engineer. To reflect the shift from manufacturing to turn-key systems integrators in a global economic environment many EM programs are now aligned with systems engineering programs (Farr and Buede, 2003).

Figure 1.1. Management and Educational Trends That Have Affected the EM Field



1.1.3 Definition of Engineering Management

In the literature you find few definitions of EM. Table 1.2 summarizes some the key characteristics common to all definitions of EM. We like the definition presented by Omurtag (1988) or Farr (2008).

The EM field has its roots in the traditional engineering and management disciplines (Waters, 1994). This evolution has helped define the field. In the next section, we discuss the "knowledge" basis for the disciplines.

Table 1.2. Common Characteristics of EM Definitions

Definition	Reference
Engineering management is designing, operating, and continuously improving purposeful systems of people, machines, money, time, information, and energy by integrating engineering and management knowledge, techniques, and skills to achieve desired goals in technological enterprise through concern for the environment, quality, and ethics.	Omurtag (1988)
The engineering manager is distinguished from other managers because he or she posses both the ability to apply engineering principles and a skill in organizing and directing people and projects. He or she is uniquely qualified for two types of jobs; the management of technical functions (such as design or production) in almost any enterprise, or the management of broader functions (such as marketing or top management) in a high technology enterprise.	Babcock and Morse (2002)
Engineering management is the discipline addressed to making and implementing decisions for strategic and operational leadership in current and emerging technologies and their impacts on interrelated systems.	IEEE (1990) and Kocaoglu (1991)
Engineering management is the art and science of planning, organizing, allocating resources, and directing and controlling activities which have a technological component.	American Society for Engineering Management
In today's global business environment, engineer managers integrate hardware, software, people, processes and interfaces to produce economically viable and innovative products and services while ensuring that all pieces of the enterprise are working together.	Farr (2011)

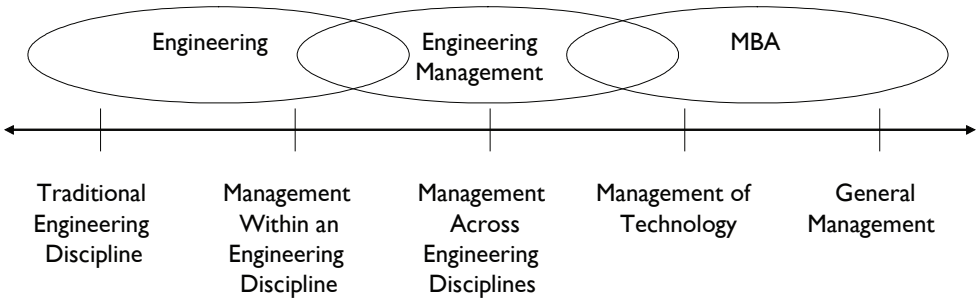
1.2 Present State of the Engineering and Technology Management Field

The present state of the EM field is described by understanding four elements: (a) the contributing disciplines, (b) professional societies, (c) relevant journals, and (d) professional conferences. Through the analysis of the present state conclusions for the future direction are offered: (1) the integration of the three core contributing disciplines of EM needs to continue and (2) the integration of the diverse set of professional societies, journals, and conferences that needs to take place.

1.2.1 The Connection of the Engineering Management Discipline to Other Disciplines

To understand the EM discipline we need to understand how the discipline relates to other disciplines. In reviewing the history of EM, we assert that EM has evolved from the engineering and management disciplines. EM is the bridge between the engineering and management disciplines. Consistent with the definitions provided in the previous section, we view engineering manager as the "bridge" (Hicks, Utely, and Westbrook, 1999) between the traditional disciplines of science/engineering and management (see Figure 1.2).

Figure 1.2. Engineering Management as the Bridge Between Engineering and Management



In reviewing the journals, professional societies, and conferences, five disciplines contribute to defining three different perspectives on the EM field. The five discipline groups are as follows:

1. **Engineering disciplines**. The core engineering disciplines in which the discipline focuses on the engineering and design process unique to a domain (e.g., civil, traditional industrial, mechanical, electrical).
2. **Discipline specific engineering management**. The EM discipline that focuses on the management process for a specific engineering discipline (e.g., management of the civil engineering process, management of the industrial engineering process).
3. **Generalist engineering management**. The EM discipline that focuses on the fundamental EM process across many engineering disciplines.
4. **Management of technology**. The business or management discipline that focuses on managing the creation, development, and use of technology (Badaway, 1998).
5. **General management**. The management discipline that focuses on the management of any organization.

Given these descriptions, three perspectives to EM are: (1) discipline specific EM, (2) generalist EM, and (3) management of technology. Industrial engineering could be considered to be part of the overlap between engineering and EM in Figure 1.2. As will become evident in the rest of this section, the EM field continues to support this view. The EM discipline emerges from five unique sets of journals, professional societies, and conferences to provide three unique perspectives to the field.

1.2.2 Engineering Management Related Professional Societies

Consistent with the three perspectives of the EM field we categorize the different professional societies related to EM. As has been completed before (Sarchet and Baker, 1995), Table 1.3 summarizes the different professional societies. In addition to the three perspectives to EM we have added three other categories for completeness: (1) disciplines associated with processes and tools used by the engineering manager, (2) general management, and (3) engineering education. Engineering disciplines and societies associated with the Accreditation Board for Engineering and Technology (ABET) were used as the source for the engineering programs. All of the engineering discipline professional societies are not included, just the societies with an associated EM group or division. We share these professional societies to help the reader understand the different avenues for actively participating and contributing to the profession. The EM discipline is supported with six groups of professional journals.

1.2.3 Engineering Management Related Journals

Consistent with the three perspectives of the EM field, we review and categorize the different journals related to EM. Table 1.4 summarizes the journals related to EM. For completeness, in addition to the three perspectives to EM we have added three other categories: (1) disciplines associated with processes and tools used by the engineering manager, (2) general management and (3) engineering education. We share these related journals to help the reader understand where to go to for knowledge and to contribute to the knowledge of the profession. This list is not meant to be an exhaustive list. The EM discipline emerges from six unique sets of journals.

Table 1.3. Professional Societies Associated with the EM Discipline

Group	Professional Societies
Engineering Management within an Engineering Discipline	• American Society of Civil Engineers (ASCE) (www.asce.org) • IEEE Engineering Management Society (IEEE EMS) (www.ieee.org/ems) • Institute of Industrial Engineers (IIE) (www.iienet.org) • Institute of Industrial Engineers (IIE)- Society for Engineering & Management Systems (SEMS) (www.iienet.org) • Society of Petroleum Engineers (SPE) (www.spe.org) • Society of Manufacturing Engineers (SME) (www.sme.org) • American Society for Mechanical Engineering (ASME) (asme.org)
Disciplines Associated with Processes and Tools Used by the Engineering Manager	• Association for the Advancement of Cost Engineering (AACE) (aacei.org) • International Council of Systems Engineering (INCOSE) (www.incose.org) • Project Management Institute (PMI) (www.pmi.org)
Engineering Management Across Disciplines	• American Society for Engineering Management (ASEM) (www.asem.org) • Canadian Society for Engineering Management (CSEM) (www.csem-scgi.ca/index.html)
Management of Technology	• International Association for Management of Technology (IAMOT) (www.iamot.org) • Product Development Management Association (PDMA) (www.pdma.org)
General Management	• Academy of Management (AM) (www.aomonline.org) • Institute for Operations Research and the Management Sciences (INFORMS) (www.informs.org)
Engineering Education	• American Society of Engineering Education (ASEE) (www.asee.org)

Table 1.4. Journals Associated with the Engineering Management Discipline

Group	Journals
Engineering Management within an Engineering Discipline	• *Journal of Management in Engineering* • *Leadership and Management in Engineering* • *The Journal of Construction Engineering and Management*
Disciplines Associated with Processes and Tools Used by the Engineering Manager	• *Cost Engineering* • *International Journal of Project Management* • *Journal of Systems Engineering* • *Project Management Journal* • *The Engineering Economist*
Engineering Management Across Disciplines	• *IEEE Transactions on Engineering Management* • *Engineering Management Review* • *Engineering Management Journal* (ASEM) • *The Engineering Management Journal* (IEE IN UK)
Management of Technology	• *International Journal of Technology Management* • *Journal of Engineering & Technology Management* • *Journal of High Technology Management* • *Journal of Product Innovation Management* • *Technological Forecasting and Social Change* • *Technovation* • *R&D Management* • *Research Policy* • *Research Technology Management* • *Technological Analysis and Strategic Management*
General Management	• *Academy of Management Review* • *Academy of Management Journal* • *Administrative Science Quarterly* • *California Management Review* • *Decision Analysis* • *Harvard Business Review* • *Information Technology & People* • *Interfaces* • *International Journal of Operations & Production Management* • *International Journal of Quality & Reliability Management* • *International Journal of Service Industry Management* • *Management Decision* • *Management Review* • *Management Science* • *Manufacturing & Service Operations Management* • *National Productivity Review* • *Organization Science* • *Sloan Management Review*
Engineering Education	• *Journal of Engineering Education* • *IEEE Transactions on Engineering Education*

1.2.4 Engineering Management Related Conferences

Consistent with the three perspectives of the EM field we reviewed and categorized the different professional conferences related to EM. Table 1.5 summarizes these conferences. We would like to share these related conferences to help the reader understand where to go to for knowledge and to contribute to the knowledge of the profession. This list of conference is not meant to be exhaustive, rather a starting place. The EM discipline emerges from six unique sets of conferences.

Table 1.5. Professional Conferences Associated with the EM Discipline

Group	Conferences
Engineering Management within an Engineering Discipline	• American Society of Civil Engineers (ASCE) (www.asce.org) • Institute of Industrial Engineers (IIE) (www.iienet.org)
Disciplines Associated with Processes and Tools Used by the Engineering Manager	• International Council of Systems Engineering (INCOSE) (www.incose.org) • Project Management Institute (PMI) (www.pmi.org)
Engineering Management Across Disciplines	• American Society for Engineering Management (ASEM) (www.asem.org) • IEEE Engineering Management Society (IEEE EMS) (www.ieee.org/ems) • PICMET (www.picmet.org)
Management of Technology	• International Association for Management of Technology (IAMOT) (www.iamot.org) • PICMET (www.picmet.org) • Product Development Management Association (PDMA) (www.pdma.org)
General Management	• Academy of Management (AM) (www.aomonline.org) • Institute for Operations Research and the Management Sciences (INFORMS) (www.informs.org)
Engineering Education	• American Society of Engineering Education (ASEE) (www.asee.org) • Masters of Engineering Management Programs Consortium (http://www.mempc.org) • Accreditation Board of Engineering and Technology (http://www.abet.org)

1.2.5 The Future of the Engineering Management Discipline

The intent of this section is to develop a framework to continue the conversation about the future of EM. The intent is not to define the agenda, but rather provide the structure from which further conversations can be developed. In reviewing the past and present of EM and the emerging issues facing the world, the discipline of EM offers a unique ability to make lasting contributions (Sarchet and Baker, 1989). To define strategic issues we first understand three items: (1) a description of trends and challenges facing the EM organization, (2) a model of the EM discipline from a perspective of knowledge roles, and (3) a description of global outcomes for the stakeholders of the EM discipline. By taking these three perspectives we can better understand and define the emerging issues facing the discipline.

1.3 Emerging Engineering Management Related Trends, Drivers, and Challenges

Barkema, Baum, and Mannix (2002) defined a set of trends defining management challenges. These challenges included: greater diversity; greater synchronization requirements; greater time pacing requirements;

faster decision-making, learning, and innovation; faster newness and obsolescence of knowledge; more frequent environmental discontinuities; faster industry life-cycles; greater risk of competency traps; and faster newness and obsolescence of organizations. The challenges are being driven by the increased globalization of the knowledge economy and the increasing complexity of the systems. Technology managers are facing challenges managing in this domain. Engineering managers face challenges that include: (1) strategic planning for technology products, (2) new product project selection, (3) organizational learning about technology, and (4) technology core competencies (Scott, 1998). During the 2003 annual conference of the American Society for Engineering Management (ASEM), a session was held with both practicing and academic EM participants on defining the challenges associated with EM. During this session the participants identified challenges in three groups: (1) business environment trends and challenges, (2) organizational trends and challenges, and (3) engineering management/manager trends and challenges (Utley, Farrington, and Kotnour, 2003). The business environment trends and challenges included:

- Globalization,
- Short-term profit focused,
- Increased regulatory/environmental stewardship/ethical focus, and
- Changing demographics of the workforce.

These trends create further trends and challenges for the technical organization:

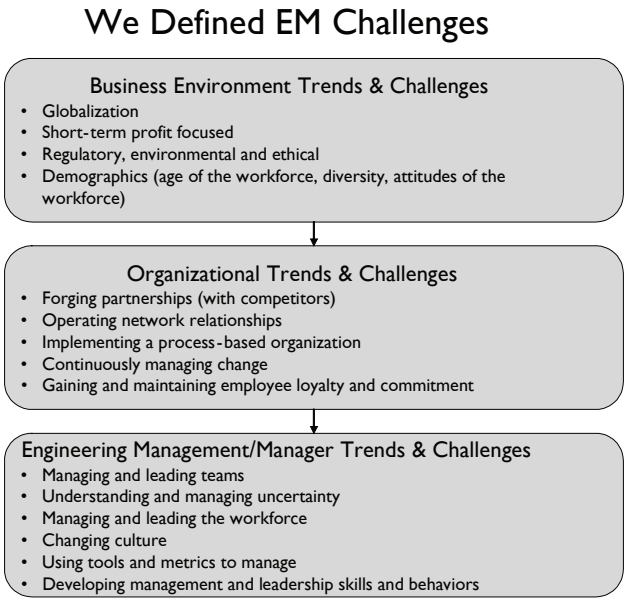
- Forging partnerships,
- Operating networks of relationships,
- Implementing a process-based organization,
- Continuously managing change, and
- Gaining/maintain employee loyalty and commitment.

The engineering manager then faces of the challenges of operating in this environment. Specific challenges include:

- Managing and leading teams,
- Understanding and managing uncertainty,
- Managing and leading the workforce,
- Changing culture,
- Using tools and metrics to manage, and
- Developing the needed management and leadership skills and behaviors.

Figure 1.3 summarizes these challenges. These trends and challenges offer the strategic context for the EM discipline. For example, the discipline needs to become more global and integrative across disciplines. The EM discipline must define a body of knowledge that provides the knowledge needed by the engineering manager to be successful in the challenging environment.

Figure 1.3. Challenges for the Technical Organization and Engineering Manager



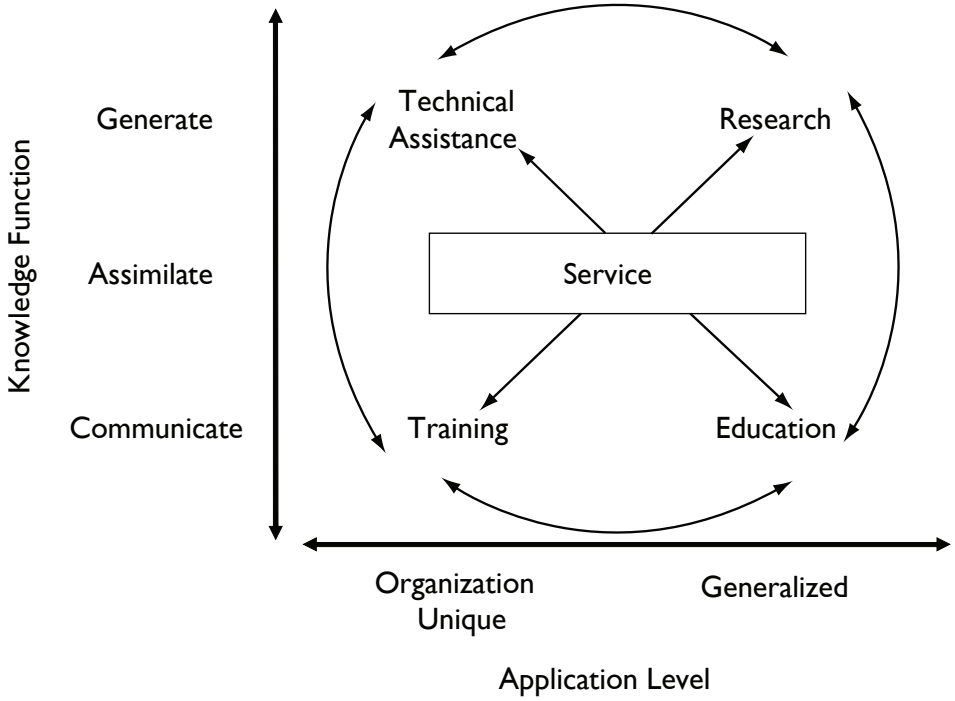
1.4 Engineering Management Discipline's Knowledge Roles

The EM discipline plays five knowledge roles (Boyer, 1990; Kotnour, 2001). The roles are based on the knowledge management function (i.e., generate, assimilate, or communicate) and application of the knowledge (i.e., generalist/across many organizations or organization specific). As can be seen in Figure 1.4, each of these roles supports the other roles. The challenge for the EM discipline is in integrating these five roles. The five roles are:

1. **Research**: The process of generating generalized knowledge. This knowledge can be applied to many different domains and does not necessarily solve an organization's unique problem. This knowledge serves as the content and basis for the other roles.
2. **Education**: The process of teaching students knowledge that can be applied to many different domains or applications. The education roles pulls content from the other roles.
3. **Training**: The process of transferring knowledge to a unique domain, application, or organization. In training, the discipline's knowledge is used to provide specific application insights.
4. **Technical assistance**: The process of working with an organization to solve a specific performance challenge. This technical assistance support creates knowledge unique to an organization. This unique knowledge can be used to generalize from for research or used as case studies in training or education classes.
5. **Service**: The set of activities to provide support to the university, profession, and society. The service role also provides an overarching or governance function for the discipline. The service or professional society role helps to assimilate the knowledge through conferences and journals.

These five knowledge roles are needed to provide positive outcomes for the EM discipline's stakeholders. The strategic issue facing the EM discipline is on how to integrate these five roles across the global and diverse set of contributing disciplines, professional societies, journals, and conference of EM. The intent of the rest of this chapter is to define specific challenges facing the EM discipline.

Figure 1.4. Five Knowledge Roles of the EM Discipline



1.5 Engineering Management Discipline Stakeholder Needs

To raise a set of questions to help determine the agenda for the future of the EM discipline, we must first understand the discipline's stakeholders and needs. The stakeholders are the set of individuals or groups who impact and are impacted by the profession. Table 1.6 summarizes the needs of the EM disciplines stakeholders. These outcomes can provide the overarching guidance or goals for the discipline.

Table 1.6. EM Discipline's Stakeholder Needs

Stakeholder	Desired Outcome	Engineering Management Discipline's Contribution in Helping the Stakeholder Achieve their Desired Outcome
Society	• Strong, stable society • Useful products and services	• Provide graduates who are functional and make a difference
High-tech organizations	• Success in growing their business	• Provide educated graduates • Provide real-time knowledge to improve organizational performance
Profession	• Enhanced professionalism and profession	• Provide service to the professional societies and active students/graduates
Practicing engineering manager and engineering team	• Success in the workplace	• Provide real-time knowledge to improve individual, team, and organizational performance
Professional engineer	• Maintain professional certification	• Provide real-time knowledge to improve individual performance • Offer opportunities to complete professional registration requirements
University community	• Enhance the reputation of the university	• Provide an outlet (i.e., conferences and scholarly journals) for faculty to professionally grow and gain recognition for academic programs
Student	• Productive, working member of society	• Provide educational and work experiences to enable them to be a life-long learner • Provide a connection to employers and graduate schools
Faculty	• Enhanced reputation and freedom to intellectually explore	• Provide the infrastructure and outlets for conducting teaching, research, and service
Accreditation institutions	• Meet the desired outcomes of the accreditation process	• Define the bodies of knowledge and characteristics of the EM discipline • Systematically implement the accreditation process

1.6 Conclusions and Summary

The intent of this chapter was to review the history and current state of the EM discipline as a foundation to help define the future of the discipline. We have presented a review of the history of the profession and also presented several definitions. To further describe the current state of the profession we have summarized relevant professional organizations, publications, and technical societies. However, the main contribution of this chapter is to present emerging trends, knowledge roles, and stakeholder needs for the profession along with strategic issues that will affect the future of EM and engineering education.

We offer four conclusions from this work. First, the EM profession is at a critical juncture in its maturation. Unlike many traditional engineering professions, EM has been agile and responsive to changes in

the global economic community. This can mainly be attributed to our main role as continuing education for engineers and scientists. In practice, we have had to be on the leading edge of managerial trends to produce competitive products and services. In order to remain relevant, we have had to adapt our skill sets. However, the role of EM is changing from both an educational and practical perspective. Most EM programs are run very similar to MBA programs with adjunct faculty. EM education is becoming more accepted within most universities. Unfortunately, few universities have standalone EM programs at the undergraduate and graduate levels staffed with mainly full-time faculty. The number of undergraduate programs has experienced steady growth. From a practicing EM perspective, the challenges in many ways are more daunting. Rapid changes in business practices require a continual self-evaluation and retraining to remain relevant.

Second, the EM profession needs to build an integrated approach of teaching, research, technical assistance, training, and service. From this integration, the discipline will continue to grow and make significant contributions. Third, to draw this synergy, the EM profession must also recognize the complementary perspectives that different contributing fields can bring. These complementary perspectives will help develop and transfer the knowledge needed to address the challenges of the technical environment and technical organization. Fourth, the EM professional societies offer a key mechanism to foster collaboration across disciplines. The leadership for the profession needs to come from active participation from the discipline itself and the leadership of the professional societies.

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