

Findings From a Web-based Survey of Degree Programs in Engineering Systems

By Christine Ng

Abstract

Since its creation in 1998, MIT's Engineering Systems Division (ESD) has pursued a dual mission: To define and evolve engineering systems as a new field of study and to transform engineering education and practice. Complementary to this two-fold mission is the emergence and growth of interdisciplinary programs at other universities' engineering schools that address complex engineered systems. The existence and growth of such academic and research programs facilitates knowledge-sharing and collaboration among faculty and students at different universities.

An assessment of the current status of academic programs would better inform ESD's future role in the advancement of education and research in complex engineered systems and promote dialogue about key differences among programs. The 57 universities included in the survey are either members of the Association of American Universities (AAU) or listed in the U.S. News and World Report Top 50 Engineering Graduate Schools. The definition of "engineering systems-like" programs was intentionally kept broad to encompass any technology or engineering-based program seeking to take a more integrative and systems-thinking approach than traditional engineering disciplines. Programs that granted degrees in one or more of the following "knowledge domain areas" were included in the survey: engineering management, industrial engineering, manufacturing, logistics, operations research, systems engineering, systems theory, and technology and policy. Although categorization is useful for characterizing programs, this particular categorization scheme is somewhat arbitrary because it relies on loosely defined terminology. To the extent available online, information was gathered about each program's home department or school, creation date, degree options, degree requirements, faculty structure, student composition, delivery options, specialization areas, and curriculum.

The most popular knowledge domain areas are engineering management, industrial engineering, and systems engineering. The number of engineering management and systems engineering programs has continued to grow since their rise in the 1970s and 1980s, while industrial engineering programs reached a plateau by the 1980s. In the last two decades, the growth of master's degree offerings has far outpaced the growth of other degree options. Often targeted to technical professionals seeking a course-based program, these master's programs frequently incorporate part-time or distance learning options.

Although the vast majority of programs surveyed emphasize the interdisciplinary nature of their degree programs, most programs are sourced from a single department with a dedicated faculty. Most core coursework is completed in the home department, and few universities use dual or joint appointments. There is the question of how broad "engineering systems," or its suite of relevant knowledge domain areas, will become. The programs surveyed still lack common unifying characteristics that allow employers to fully recognize the set of knowledge domain areas as a single field of study.

Based on the strong growth of practice-oriented master's programs, engineering practice seems to be leading the engineering systems field and actively shaping engineering education. Although more universities are considering new Ph.D. programs in engineering systems areas, the current emphasis on engineering practice poses a challenge to universities seeking to strengthen research programs that complement the practice-oriented degree programs while advancing engineering systems as a field. The major challenge in the near-term future may be to perform research which enhances these practice programs without detracting from the educational mission.

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1. Introduction

Since its creation in 1998, MIT's Engineering Systems Division (ESD) has pursued a dual mission: to "define and evolve engineering systems as a new field of study and to transform engineering education and practice." Complementary to this two-fold mission is the emergence and growth of interdisciplinary programs at other universities that address complex engineered systems. The existence and growth of such academic and research programs facilitates knowledge-sharing and collaboration among faculty and students at different universities. An assessment of the current status of academic programs would better inform ESD's future role in the advancement of education and research in complex engineered systems and promote dialogue about key differences among programs.

The next section describes how this survey relates to past surveys and information sources on academic programs. It is followed by an explanation of the web-based methodology used to identify and characterize degree programs. At the heart of the paper are the findings from the web-based assessment, with aggregated data on knowledge domain areas, program start dates, degree types, target student audience, program delivery options, departmental affiliation, faculty structure, and core curricula. The implications of the findings are discussed, followed by brief highlights of academic programs in other countries and questions prompted by this paper's findings.

1.1. Previous surveys and terminology

Other organizations have collected information about academic programs similar to those offered by MIT ESD. In 2001, Portland State University's Engineering and Technology Management Department conducted a survey of Engineering and Technology Management (ETM) programs in the United States. Out of the 265 ETM programs identified, 147 responded to the survey as of 2003. PSU broadly defines ETM programs as those concerned with "the management of technological systems," which includes the management of technological innovation, engineers and scientists, technical organizations, technical projects/programs, resources, technology implementation, and strategy and policy (PSU 2003). Most schools have only one degree program listed. For example, MIT's Technology and Policy Program is included, but the survey does not include the other ESD programs that fit the ETM definition (e.g. Leaders for Manufacturing, System Design and Management).

Professional societies often provide lists of educational programs in their respective areas. INCOSE, the International Council on Systems Engineering, has identified, categorized, and classified 51 distinct SE degree programs offered by 34 U.S. institutions, where "systems engineering" is the sole name for the major. INCOSE also found 73 distinct degree programs at 38 institutions with program names combining "systems engineering" with another area of study (INCOSE 2003a). INFORMS, the Institute for Operations Research and the Management

Sciences, maintains a list of 141 universities with academic programs in operations research/management sciences, situated in engineering and business schools (INFORMS 2004).

Several college guides designed for prospective undergraduate and graduate students offer searchable information about programs in a number of academic categories. For example, Peterson's has a searchable online database of graduate schools and programs categorized in areas such as systems engineering, engineering management, industrial engineering, manufacturing, systems science, and technology and policy (Peterson's 2004). Such guides vary in the level of coverage and detail about each program, because they depend on information submitted to the publisher from the school.

Previous surveys relied mainly on submissions from the schools offering programs in engineering systems or related areas. Although this process may allow for more accurate details about each program, it may neglect programs that do fall into the relevant categories but do not respond to the survey. For instance, some programs that have a major systems engineering component may not have the term in the name of the degree and therefore may be excluded from INCOSE identification. The other surveys and information sources focus on providing detailed information listings for each school or program. The goal of this paper is not to provide a comprehensive list of schools or programs but to attempt a deeper look at a sample of schools by aggregating collected information for the programs surveyed and identifying significant patterns and trends.

The diversity in program and department names posed some difficulty in categorizing programs by specialty area. Some flexibly defined categories have emerged from the terminology used in previous studies and databases, individual programs' characterization of their emphases, and categorizations suggested at past ESD workshops. For example, at the October 2003 Engineering Systems Workshop at MIT, one of the workshop groups categorized four key areas as industrial engineering/operations research/systems analysis, technology policy, engineering management, and systems engineering/technology (ESD 2003). The following "knowledge domain areas" have been selected for this paper: engineering management, industrial engineering, logistics, manufacturing, operations research, systems engineering, systems theory, and technology and policy. Variations exist within each of the domain areas and there is substantial overlap between programs in different domains. However, categorization aids in observing patterns across schools and over time. This categorization scheme is not the only one that could have been used; other schemes that capture the broad scope of engineering systems would have been equally valid.

2. Methodology

2.1. Criteria for selecting universities

This study was limited to universities meeting at least one of two criteria: (1) membership in the Association of American Universities (AAU), comprised of North American research universities granting Ph.D. degrees, or (2) listing in the top 50 engineering graduate schools, as ranked by the U.S. News and World Report. Membership to AAU is by invitation only; a membership committee selects members based on indicators of the breadth and quality of their research and graduate education (AAU 2004). The U.S. News and World Report annual rankings are based on survey responses from engineering school deans and corporate recruiters (US News 2004). Both of these criteria are intended to capture universities with widely respected reputations in research and education.

The rationale behind limiting the search to AAU member universities and “Top 50” graduate schools was guided by a practical consideration as well as the intended purpose of the study. Conducting a web survey of all universities with relevant programs would have been prohibitively time-consuming. Since this study is motivated by an interest in the future of engineering systems as a field, it was assumed that the most prominent research universities would play the largest role in generating scholarly research, initiating changes in engineering education, and producing future leaders in academia and professional practice.

2.2. Criteria for selecting programs

Once the list of universities was identified, the next step was to establish criteria for the programs. The programs should be degree-granting, offering at least a BS, MS, M.Eng., Ph.D., or their equivalents. Programs offering a non-degree certificate or minor only were not included. An engineering- or science-based academic unit should be the program sponsor or co-sponsor. It is expected that programs are geared toward students with a strong technical background or interest. Although it is recognized that business school programs in operations research and technology management share strong commonalities with their engineering school counterparts, they are outside the scope of this study, which focuses on engineering education. Also, programs studying the societal impacts of technology, like those grounded in history, literature, or sociology, were not included.

2.3. Web-based survey

The survey was initially conducted through the search engine in each university’s main webpage, using combinations of key words such as “engineering,” “systems,” “management,” and “interdisciplinary.” If an engineering systems-like program was identified through the search procedure, program details were collected from the relevant university websites and online course catalogs. This study is intended to be broad enough to encompass programs beyond those labeled explicitly as “systems engineering,” so secondary searches within engineering departments’ webpages were also conducted to look for relevant programs.

To the extent available online, information was gathered about the following:

- Sponsoring academic unit(s)
- Creation and/or accreditation year
- Degrees offered
- Full-time, part-time, or distance learning options
- Specialization/concentration options
- Target student type (educational background and experience)
- Number of students and faculty
- Faculty structure (single dept, other dept, dual/joint appt)
- Core curricular courses

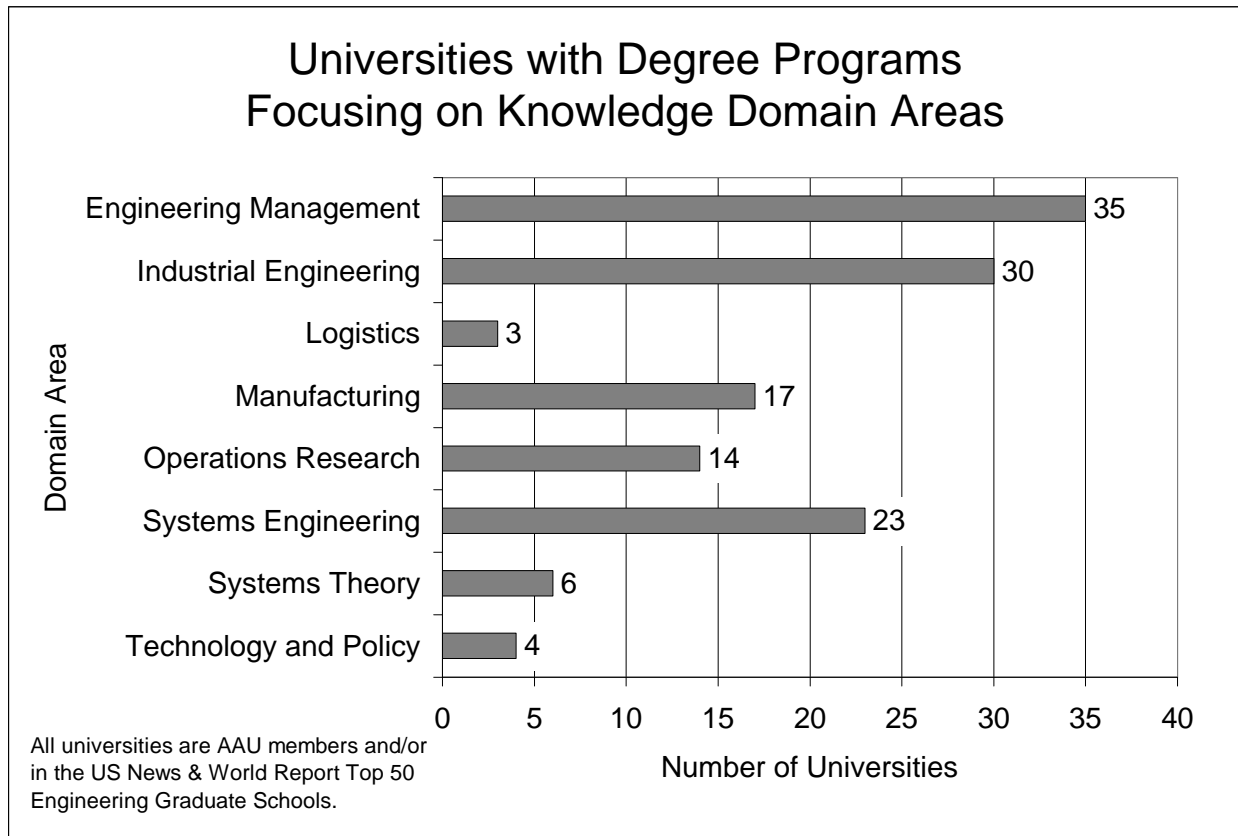
The web-based nature of this study limited the availability of program details to information publicly accessible on the Internet as of January 2004. It was assumed that available degree programs have an online presence, and that the information provided by each university is updated and accurate. This is the information available to prospective students as they investigate degree programs. (The precise URLs that served as the source of information for each program are available by request from the author.) Because many schools did not supply the creation date of their programs, some missing date information was obtained using publicly accessible databases from Peterson's graduate school guide, the Accreditation Board for Engineering and Technology (ABET), and Portland State University's ETM survey. These information sources, as well as the INCOSE and INFORMS academic programs lists, were also consulted to decrease the likelihood of overlooking a relevant program.

3. Findings

The university and program criteria resulted in a list of 71 universities, of which 57 had programs focusing on one or more of the relevant knowledge domain areas. Categorizing a program into one or more of the 8 knowledge domain areas was based on the program title and online description. Most programs had emphases or tracks in several of the knowledge domain areas. However, the online program descriptions usually reflected a program's focus on one, or at most two, domains. For example, a program in "manufacturing management" may be equally concerned with manufacturing and engineering management, and would therefore be intentionally "double-counted" in the manufacturing and engineering management knowledge domains.

There were 130 programs identified among the 57 universities, some within the same department and others in separate departments or schools. Of the 57 universities, 61%, or 35 of them, have engineering management degree programs. Half have industrial engineering programs, and 40% have systems engineering programs.

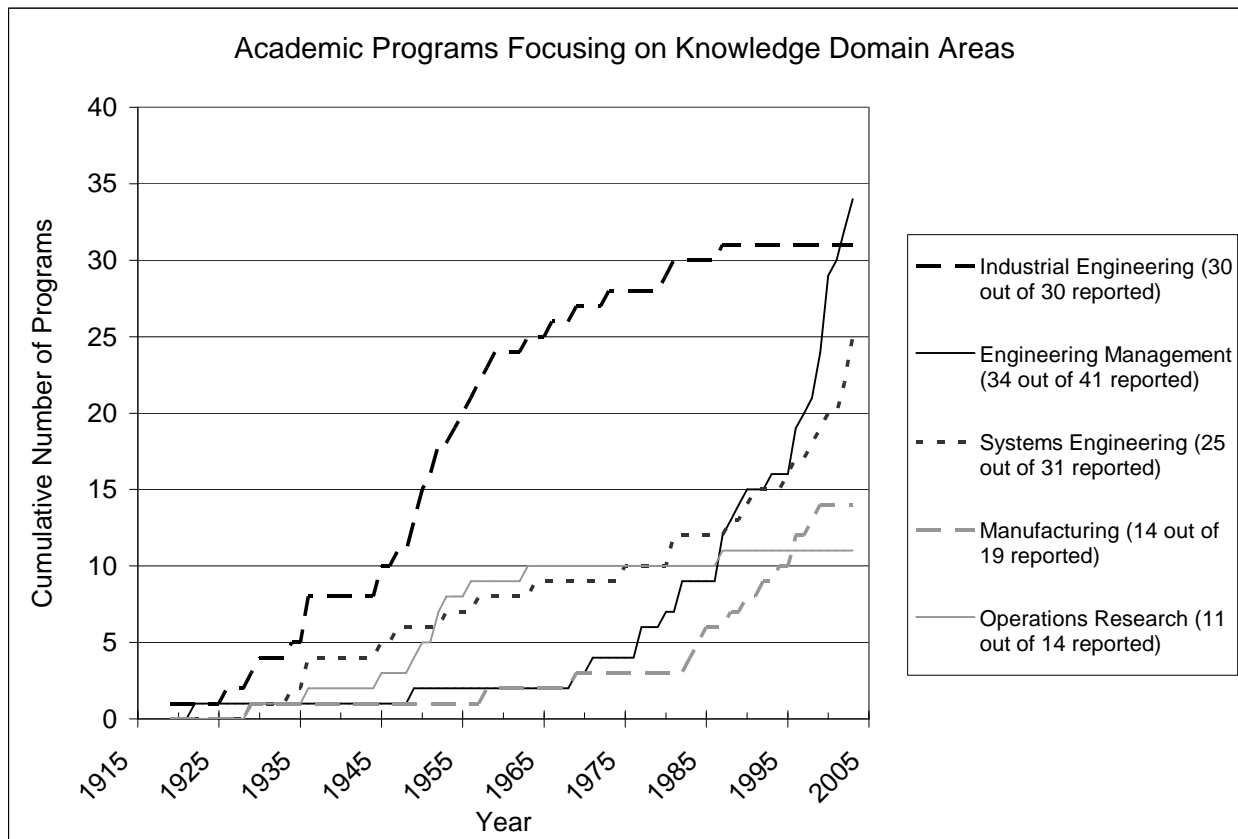
Figure 1



3.1. Evolution of programs in knowledge domain areas

Although information about the creation date of every program was not available, start dates or accreditation dates were identified for over 80% of the programs. Figure 2 shows the cumulative number of programs by knowledge domain over time. In cases where a program's name and description indicate an equal focus in two knowledge domain areas (e.g. industrial and systems engineering), it is included in the count for both areas. As a result, 19 of the 130 programs were assigned to two domain areas in Figure 2. There were not enough degree programs specific to technology and policy, logistics, or systems science to show on Figure 2. Although the operations research programs included in this figure are limited to those in engineering schools, the figure does indicate that the number of programs focused on industrial engineering and/or operations research grew steadily from the 1920s through the 1950s. Few new IE or OR programs have been established in engineering schools since the 1960s, but some of the subsequent growth in systems engineering may be attributed to the renaming and reorganization of industrial engineering programs. Engineering management and manufacturing programs began their rise in the 1970s. The growth of engineering management programs is the most dramatic of current trends, and its upward trend has apparently not yet slowed. A limitation in analyzing these trends is that Figure 2 does not account for programs that may have closed or reorganized before 2003, which would not be observed in a web-based search of current programs.

Figure 2



3.2. Types of Degrees

The vast majority of programs offer master's degrees. The M.S. degree is usually more research-oriented, while the M.Eng. degree is more professionally oriented, often with no research or thesis requirement. For programs created after 1980, the emphasis on master's programs (MS, M.Eng, dual MBA/MS), relative to BS and PhD programs, is even more pronounced, as seen in Table 1. For example, nearly 50% of the existing M.Eng. degree programs were created within the last 25 years, compared to only 16% for BS degrees and 20% for PhD degrees. The full list of degree programs included in this survey is in the appendix.

Table 1: Degrees Offered by Programs

Type(s) of Degree Granted	Number of programs	% of programs with degree	Programs created since 1980	Post-1980 fraction of total
BS	50	38%	9	18%
MS	93	72%	34	37%
M.Eng.	34	26%	16	47%
PhD	55	42%	11	20%
MBA + MS/M.Eng.	17	13%	6	35%
Dual MS	5	4%	0	0%
Other	7	5%	2	29%

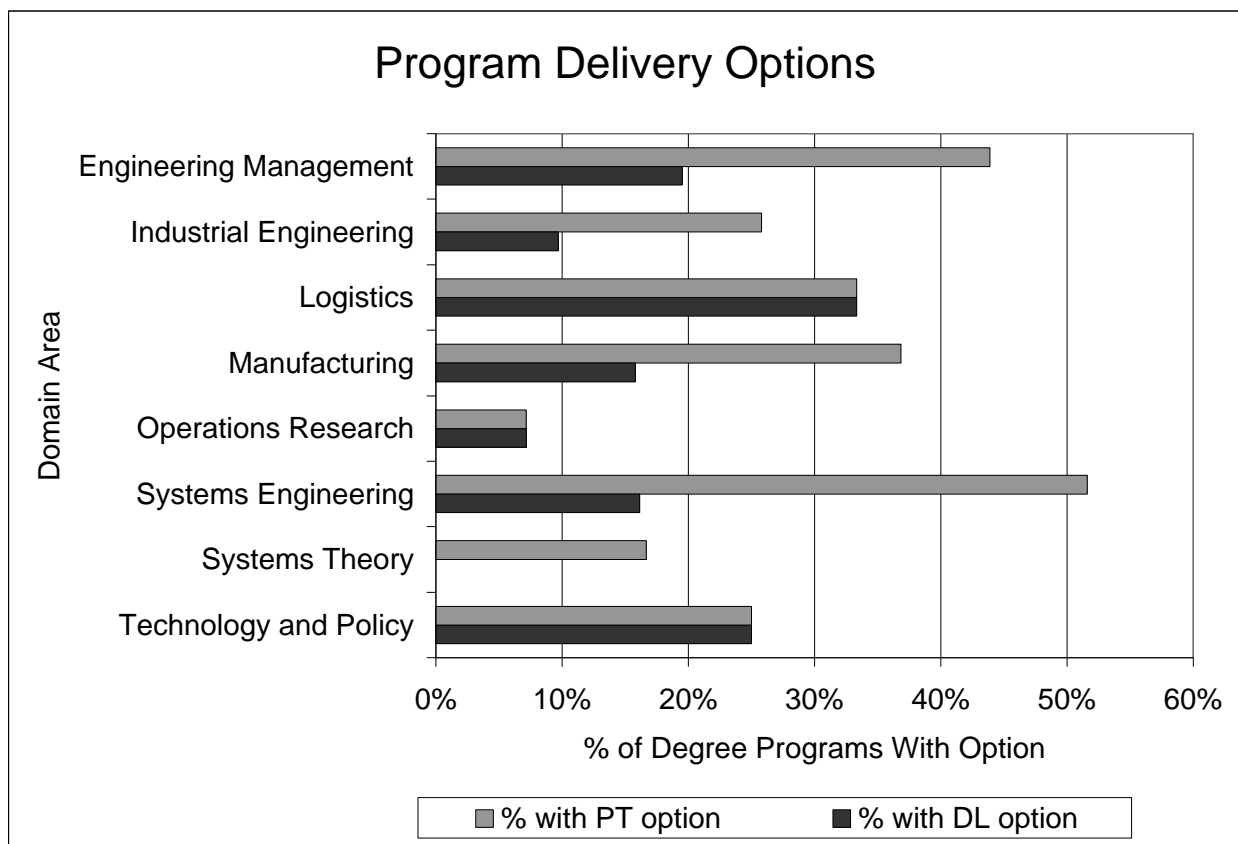
3.3. Target Student Audience

Of the 130 programs included in this study, 120 offer graduate degrees. About two-thirds of those graduate programs do not require work experience. The remaining one-third that do require at least 2 to 3 years of work experience tend to be those focusing on engineering management, and to a lesser extent, manufacturing. Over 90% of the graduate programs require incoming students to have an undergraduate technical degree in engineering, science, or mathematics.

3.4. Program delivery

Many of the degrees cater specifically to working professionals. Courses are offered in the evenings and weekends, often supplemented with online material, and usually result in an M.Eng. degree. Instead of requiring a thesis or independent research, they emphasize coursework, and feature a team-based project or capstone course. The engineering management, systems engineering, and manufacturing degrees have more part-time options; they are also newer programs compared to the traditional industrial engineering and operations research programs. Interest in offering flexible degree options to working professionals reflects the growing popularity of the more practice-oriented M.Eng. degree.

Figure 3



3.5. Departmental Affiliation

A large portion of the programs pertaining to engineering systems are sponsored by departments specializing in industrial engineering, mechanical engineering, and manufacturing. Two-thirds of the programs are sponsored by a single academic department. Of those programs, a significant fraction is sponsored by an “Industrial and Systems Engineering” department. The remaining third of the programs is interdepartmental within an engineering school or between engineering and business schools. MIT’s ESD, TPP, and MLog programs are categorized as

sponsored by the engineering school, while LFM and SDM are treated as programs jointly sponsored by the engineering and business schools.

Table 2: Departmental Affiliation of Programs

Sponsoring Academic Department/Unit	Programs
Industrial & Systems Engineering	26
Engineering and business schools (joint)	22
Engineering (interdepartmental)	18
Industrial, or Industrial Engineering & Operations Research	16
Mechanical, or Mechanical & Industrial Engineering	11
Engineering & Management	7
Electrical Engineering & Computer Science	6
Manufacturing, or Manufacturing & Industrial Engineering	5
Civil & Environmental Engineering	3
Agricultural Engineering	2
Engineering & Policy	2
Other Systems Engineering combinations	9
Other engineering	3

Many Industrial and Systems Engineering departments evolved from Industrial Engineering departments, adopting the new name to reflect the “systems” aspect of their research (i.e. Georgia Tech, Rutgers, University of Florida). For example, Virginia Tech’s Industrial and Systems Engineering Department has undergone several name changes over the past 80+ years:

Name evolution of the Industrial and Systems Engineering Department at Virginia Tech

1920	Commercial Engineering
1929	Industrial Engineering
1972	Industrial Engineering and Operations Research
1990	Industrial and Systems Engineering

The program that stood out with particular variety in its sponsoring departments is University of Pennsylvania’s Systems Engineering program. At different points in its 50-year history, the SE program has been associated with civil engineering and electrical engineering, and twice in a stand-alone SE department. This program’s evolution exemplifies the ongoing reappraisal and redefinition of systems research and education.

Sponsoring departments of the Systems Engineering program at the University of Pennsylvania

1953	Systems Engineering graduate program created.
1973	Department of Systems Engineering
1986	Civil Engineering + Systems Engineering → Department of Systems
1994	Department of Systems → Department of Systems Engineering
2002	Electrical Engineering + Systems Engineering → Department of Electrical and Systems Engineering

3.6. Faculty Structure

Almost two-thirds of the programs have dedicated faculty from a single home department, such as Industrial and Systems Engineering. In those cases, students take their core classes and many of their electives in one department. A significant number of programs rely on affiliated faculty members from multiple departments and schools. Relatively few schools use a mixture of faculty from home and multiple departments. Even fewer use joint or dual appointments. Of the 9 programs (represented by the last three rows of Table 3) that include faculty with joint or dual appointments, 5 are the MIT ESD programs (ESD, LFM, SDM, TPP, MLOG).

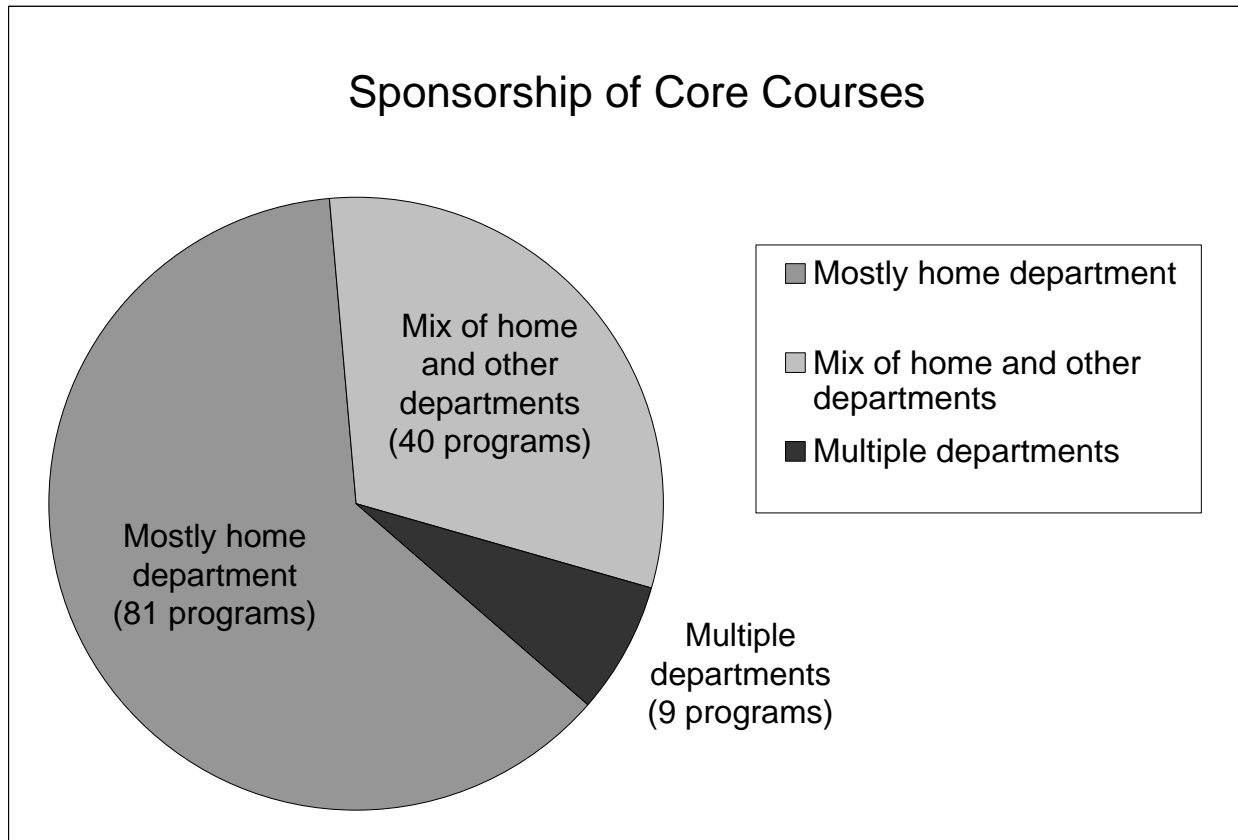
Table 3: Faculty Structure

Faculty Structure	Number of Programs
Single home dept	77
Multiple dept	30
Mix of home & multiple	14
Joint/dual	2
Single home dept + Joint/dual	2
Multiple dept + Joint /dual	5

3.7. Core curriculum

Categorization of the sponsorship of each program’s core courses is based on the coursework requirements listed on the program websites. Department-specific course codes provide a reasonable indication of each core course’s sponsoring department. Core course sponsorship mirrors the structure of the program administration. Programs that have a single home department usually require their students to take most or all of their core coursework in the home department, with some flexibility for elective courses in other departments. Since 77 of the programs are sponsored by a single department or academic unit, it is not surprising that 81 programs rely on a home department for administering most of the core courses (Figure 4). One-third of the programs rely on both their home department and other departments for their core curricular offerings. The MIT ESD programs fall into this category. The few programs that do not have a discernable “dominant” department take their core courses from multiple departments. These 9 programs are all genuinely “interdepartmental” in the sense that they are jointly sponsored by multiple departments or colleges. For example, the MIT Operations Research program falls into this category.

Figure 4



The core curriculum course titles listed next indicate the level of diversity in programs focusing on the same knowledge domains. There is also significant overlap of course types between different domains. For example, there are required courses in optimization and simulation in programs of virtually every knowledge domain.

Sample Graduate-level Core Curriculum Course Titles for Selected Knowledge Domains

Engineering Management

Marketing; Intellectual Property, Business Law, and Entrepreneurship; Finance in High Tech Industries; Management in High Tech Industries (Duke)

Engineering Probability and Statistics; Financial and Managerial Accounting; Operations Management; Systems Optimization and Analysis for Manufacturing; Total Quality Management; Communication for Managers; Economic Analysis for Business Decisions; Strategic Management; Proseminar in Manufacturing; Seminar in Management & Ethics; Organizational Processes; Marketing; Informational Technology as an Integrating Force in Manufacturing; Product Design and Development; Organizational Leadership and Change; Manufacturing Strategy (MIT)

(at least 5 required) Dynamic Systems or Stochastic Decision Models; Linear and Nonlinear Optimization, Stochastic Modeling or Simulation; Economic Analysis; Decision Analysis or Risk Analysis; Industrial Accounting or Investment Science or Introduction to Finance; Production Systems; Organizational Behavior and Management; Global Entrepreneurship Marketing; Strategy in Technology-based Companies (Stanford)

Managing People and Organizations; Art and Science of Negotiations; Advanced Marketing Management; Legal Issues for Engineering Managers; Management of Projects and Processes; Strategic Design and Risk Analysis; System Design Metrics; Engineering Economics (UT Austin)

Systems Engineering

Models of Human-Machine Systems, Real-Time Interactive Simulation, Design of Human-Integrated Systems, Understanding and Supporting Human Decision Making (Georgia Tech)

Introduction to Systems Engineering, Introduction to Project Management; Project Planning and Control, Software Engineering Management, System Conceptual Design, System Design and Integration, System Test and Evaluation, Systems Engineering Project (Johns-Hopkins)

System Architecture, System Engineering, System and Project Management, Engineering Risk-Benefit Analysis, Financial & Managerial Accounting, Marketing Management, Operations Management, Organizational Processes, Systems Optimization (MIT)

Systems Engineering Principles; System Modeling and Analysis; Systems Engineering Design Project; Human Factors in Systems Engineering; Systems Financial and Contract Management; Systems Life Cycle Cost Estimation; Quality Management in Systems (University of Maryland at College Park)

Industrial Engineering

Optimization; Stochastic Models; PhD Concentration in Optimization, Stochastic Models, Financial Engineering, or Supply Chain Management and Logistics (Columbia)

Course groups: Economic Analysis and Decision Making; Human Factors and Ergonomics; Manufacturing Systems; Production Systems; Systems Analysis & Optimization; Computer Science, Mathematics, and Statistics (NC State)

Linear Programming; Nonlinear Programming; Stochastic Processes; Mathematical Probability (Texas A&M)

Manufacturing

Technology, Operations and Competitive Strategy; Production Planning and Resource Allocation; Automation and Production Systems; Agile Organizations and Manufacturing Systems (Lehigh)

Concurrent Engineering; Global Strategic Management of Technological Innovation; Information Technology and Systems for Enterprise Engineering; Quality Control and Reliability; Discrete-Event Simulation (RPI)

Manufacturing or Dynamic Systems Theory; Software for Design and Control in Manufacturing Systems; Manufacturing Management; Engineered Materials (Boston University)

3.8. Selected Program Profiles

The variety in the surveyed programs’ origins, size, breadth, research areas, and course offerings is impressive, but not surprising, given the range of knowledge domains spanned by engineering systems. Although most universities have single stand-alone programs, this section draws attention to universities that host a portfolio of programs under one academic unit. Taking a closer look at three of these “program portfolios” offers an opportunity for comparison to ESD’s own program portfolio.

Georgia Institute of Technology – School of Industrial and Systems Engineering (ISE)	
Date Established	1945 (some programs added later)
Programs and Degrees	Industrial Engineering (BS, MS) Industrial and Systems Engineering (MS, PhD) Operations Research (BS) International Logistics (Executive MS) Statistics* (MS) Health Systems* (MS) Quantitative and Computational Finance* (MS)
Student Enrollment	1200 undergraduates 250 MS students 200 PhD students
Faculty	65 full-time, 9 part-time faculty
Research Emphases	Optimization, stochastic systems, manufacturing and logistics, simulation, economic decision analysis, engineering statistics, natural systems, and human-integrated systems
Other attributes	MS thesis required for the Industrial and Systems Engineering program only.

* Not included in the survey results, but shown here to illustrate the full ISE offerings.

Rensselaer Polytechnic Institute – Department of Decision Sciences and Engineering Systems	
Date Established	1987
Programs and Degrees	Decision Sciences and Engineering Systems (PhD) Industrial and Management Engineering (BS, MS, PhD) Manufacturing Systems Engineering (MS, MEng) Operations Research and Statistics (MS, MEng)
Student Enrollment	50 MS students 39 PhD students
Faculty	24 full-time faculty
Research Emphases	Manufacturing and service systems, data mining and decision support systems
Other attributes	Part-time option available for all master’s degree programs.

University of Southern California – Department of Industrial and Systems Engineering	
Date Established	1957 (with major revisions to some MS programs in 2003)
Programs and Degrees	Industrial and Systems Engineering (BS, MS, MS+MBA, MEng, PhD) Engineering Management (MS) Manufacturing Engineering (MS) Operations Research Engineering (MS) Product Development Engineering (MS) Systems Architecture and Engineering (MS)
Student Enrollment	17 undergraduates ~190 MS students (not including Product Development Engineering MS) 15 PhD students
Faculty	14 tenure track faculty, 3 research faculty, 5 adjunct faculty, 10 lecturers
Research Emphases	Technology development, software, supply chains, manufacturing and engineering management.
Other Attributes	No MS thesis requirements. All programs can be pursued part-time, and distance learning options are available for the MS in Engineering Management, Product Development Engineering, and Systems Architecture and Engineering.

Massachusetts Institute of Technology – Engineering Systems Division	
Date Established	1998 (although most individual programs predate the creation of ESD)
Programs and Degrees	Engineering Systems (SM, PhD) Leaders for Manufacturing (SM+MBA) System Design and Management (SM) Technology and Policy (SM) Logistics (MEng)
Student Enrollment	~340 master's students 39 PhD students
Faculty	39 full-time, dual or joint-appointed faculty
Research Emphases	Complex, technology-based products (i.e., automobiles, airplanes, etc.) and systems (i.e., transportation, telecommunications, energy, etc.)
Other Attributes	MS thesis required for all programs. Part-time, distance-learning option available for System Design and Management.

The three academic units at the Georgia Institute of Technology (Georgia Tech), Rensselaer Polytechnic Institute (RPI), and University of Southern California are single departments. (At Georgia Tech, a “school” is the academic equivalent of a department.) This differs structurally from MIT’s Engineering Systems Division, which is not a department, but a division comprised of faculty with dual appointments in ESD and a department. This structural difference translates to differences in the hosting of the core courses. At Georgia Tech, RPI, and USC, the home department sponsors the majority of core courses, whereas MIT ESD programs use a combination of core courses from ESD and various departments.

3.9. Summary of findings

In summary, the main findings from the web-based survey are:

- The most popular knowledge domain areas covered by the programs surveyed are engineering management, industrial engineering, and systems engineering.
- Since the 1970s, there has been a surge in the number of engineering management and systems engineering programs, which still show signs of continued growth.
- Master's degrees are the most common degree offered, and many of them are professionally oriented. In the last two decades, the growth of master's degree offerings has far outpaced the growth of other degree options.
- Systems engineering and engineering management programs have led the way in offering part-time degree options. The more traditional programs in industrial engineering and operations research are less likely to have part-time or distance learning options.
- Although a technical background is a prerequisite for all but a few graduate programs, two-thirds of the programs surveyed do not explicitly require work experience. Those that do require at least 2-3 years of work experience are typically engineering management programs.
- Two-thirds of the programs are sponsored by a single department, most frequently a department associated with industrial engineering, mechanical engineering, manufacturing, or a combination of those disciplines. Programs sponsored by more than one department are usually administered through an engineering college-wide collaboration or a joint effort by the engineering and business schools.
- Substantial renaming and reorganization of traditional industrial engineering departments have occurred to formally incorporate systems engineering.
- Most programs rely on faculty appointed to a single department, and require students to take the majority of their core courses in the home department.

4. Discussion

4.1. Implications of survey findings

The tremendous growth of master's degree programs in the engineering management and systems engineering knowledge domain areas demonstrates the high demand for education beyond the bounds of traditional engineering disciplines. These programs, which are usually coursework-based, are designed to prepare technically trained professionals to take on management roles.

The growth in the number of PhD programs has not been as strong. Out of the 56 programs identified as beginning after 1980, only 11 offer a PhD degree, compared to 50 offering a master's degree. This is an important discrepancy to note because much of the scholarly research would be expected to come from PhD programs, and to some extent, research-based master's degree programs. While broad, interdisciplinary systems-thinking capability seems to be gaining traction in professional practice and training, the parallel development in academic research does not appear to be as rapid or widespread. The existing PhD programs are largely in industrial engineering and operations research, which do provide some research basis for the expanding academic activity.

Education and research in engineering systems trace some of their historical roots to industrial engineering programs established in the first half of the 20th century. Most programs in engineering systems knowledge domains are sponsored by a department with "industrial engineering" in its name. The ubiquity of industrial engineering may make it difficult to distinguish engineering systems, or even systems engineering, as a distinct field. For example, even though many programs offer degrees in "industrial and systems engineering," it is not always clear whether the degree is an evolved version of a traditional industrial engineering program or a new entity. Because many programs grew out of traditional industrial engineering programs, engineering management and systems engineering continue to be closely tied to manufacturing applications. However, there is definitely movement towards other applied systems areas outside of manufacturing. Some systems engineering programs now also specialize in civil infrastructure (UC Berkeley, University of Minnesota, University of Pennsylvania) and biotechnology/health care applications (Michigan State, Georgia Tech, University of Toronto).

A major finding from this study is that most programs still rely on traditional academic administrative structures, with core courses and faculty sourced from a single department. Although the interdisciplinary nature of these programs implied that the curriculum and faculty would be very interdepartmental, this is not the case for the majority of the programs. Most programs encourage students to take electives outside the department, but the instructors of those electives are usually not formally affiliated with the programs. The practice of joint and dual faculty appointments is rare; universities that do choose this option (e.g. MIT, Carnegie Mellon, University of Maryland) have few peer institutions with which to compare their experiences. Their level of success with interdepartmental faculty structures may well determine whether other universities start using joint and dual appointments.

4.2. Engineering systems education outside the U.S.

Although this study focused on U.S. universities (and two Canadian universities), there has also been considerable activity in the development of academic degree programs abroad. The international interest and development of master's programs in engineering management parallel the trends in the U.S. Meanwhile, there appears to be greater development of technology policy programs internationally than in the U.S. Many universities are responding to the demand from industry for master's graduates with more management and systems thinking skills. For European universities in particular, innovation and technology management are key areas of research. The programs described below are far from comprehensive, but they attempt to highlight several existing international programs.

In the UK and many other European countries, graduate work traditionally consists of research only, with no coursework requirement. However, following some educational reforms, the UK witnessed a huge growth in the number of course-based master's programs in the 1990s, paving the way for an increase in professional master's degrees (NSF 2000). The University of Warwick offers 8 full-time and part-time master's degree programs through its Manufacturing Group, designed for professional engineers working with manufacturing and service systems. The degree programs arose from the Integrated Engineering Business Management Programme, an industry-academia collaboration that began in 1981. Throughout the 1990s, Warwick established part-time versions of its degree programs in collaboration with local universities in Thailand, South Africa, India, Hong Kong, and Malaysia (Warwick 2004). University of Sheffield's Department of Automatic Control and Systems Engineering has existed since 1968, but it was not until 2000 that it began to develop a part-time master's degree (MSc) in Control and Systems Engineering, to meet industry demand for flexible and professionally oriented degree options (University of Sheffield 2003). In 2002, Cambridge University launched a 9-month MPhil in Technology Policy, developed in collaboration with faculty from MIT's Technology and Policy Program. While the MPhil is offered through the business school, the engineering department is substantially involved in curriculum development and teaching. The program's primary purpose is to prepare students for leadership in industry and government, but there is the option for continuing for a PhD within the business school (JIMS 2003).

French universities offer graduate-level training for professional engineering practice in the area of engineering management. France's prestigious Grandes Écoles system offers the 5-year Diplôme d'Ingénieur, which is comparable to an engineering bachelor's degree combined with a master's degree in engineering management; most degree-holders pursue professional careers. The Groupe des Écoles des Mines offers 8 M.S. degree programs geared toward English-speaking international students, including one in the Management of Logistic and Production Systems. The 1.5-year course-based programs also include a 5-month industrial internship (GEM 2002).

A number of Dutch universities have established programs in the engineering management and technology and policy knowledge domain areas. In 1987, Utrecht University established a Department of Science, Technology, and Society, rooted in the science disciplines of chemistry, biology, physics, and astronomy. The research agenda and master's degree programmes are oriented more toward energy, environmental, and land use applications (Utrecht 2003). Since 1997, the Delft University of Technology in the Netherlands has had a Faculty of

Technology Policy Management (analogous to a department), which offers 2-year MSc degrees in Management of Technology; Engineering and Policy Analysis; Systems Engineering, Policy Analysis, and Management (SEPAM). Research is divided into two themes: Infrastructure and Services, and Technology and Innovation. To be launched in 2004, the newly created Information Architecture and Transportation, Infrastructure, and Logistics programs will be offered jointly with the other engineering faculties (TBM 2003). Eindhoven University has a Subdepartment of Technology and Policy, which offers a B.S. in Technology and Society, and a M.S. in Technology and Policy, created in 1983. The subdepartment's research, conducted in the Eindhoven Center of Innovation Studies, is focused on technology flows, the knowledge economy, and socio-economic performance (Eindhoven 2003).

The Instituto Superior Técnico in Portugal has a master's degree program in Engineering Policy and Management of Technology. Designed for engineering professionals, it emphasizes technology policy, innovation, commercialization, knowledge management, and sustainability (IST 2004). The Swiss Federal Institute of Technology's industrial engineering program dates back to 1929. Since the 1990s, the program has offered Technology & Innovation Management and Logistics & Information Management concentrations (ETHZ 2003)

In Japan, a master's degree is seen as means to provide specialized training for technical professionals entering industry, and demand for master's graduates is expected to exceed the supply (NSF 2000). In 1985, Tottori University established the first Social Systems Engineering department in the country. "Social engineering systems" refer to "any type of social engineering complex such as a city or region, transportation, enterprise or information network." The department conducts research in two areas: (1) applied systems engineering, which consists of information systems engineering, system theory, system design and planning, and regional planning and development, and (2) infrastructure systems engineering. At its inception, the department offered an undergraduate degree only, but in 1989, it added a master's program. There is also a related doctoral program in Engineering of Social Development, which is also concerned with sociotechnical systems (Tottori 2004). Like many U.S. universities that incorporated the term "systems" when renaming their industrial engineering departments, Japan's Waseda University renamed their Industrial Management Department, established in 1936, the "Industrial and Management Systems Department" in 1996 (Waseda 2004a). Newly created in 1998, their Multidisciplinary Studies Division offers an undergraduate program in Science and Technology Policy, which allows students to pursue thesis research during their third and four years in environmental systems, economic planning, social engineering, scientific technology policy and international cooperation (Waseda 2004b).

For over 20 years, the Royal Melbourne Institute of Technology (RMIT) has offered an M.Eng. in Systems Engineering through its Department of Aerospace, Mechanical and Manufacturing Engineering. SE is actually the oldest graduate engineering program at RMIT. Since the late 1990s, RMIT has even offered a version of its SE program to graduate students at the Vietnam National University (RMIT 2004). The University of South Australia's Systems Engineering and Evaluation Centre (UniSA SEEC), established in 1999, recently launched a coursework-based M.Eng. degree program in Systems Engineering to accompany their existing research-oriented master's and Ph.D. programs. As of 2003, SEEC was planning a new M.Eng. in engineering management and a professional doctorate (SEEC 2004).

4.3. Future trends in the U.S.

As discussed in the previous section, many new academic programs have been initiated around the world since the 1990s. In the meantime, U.S. institutions have continued to expand their graduate degree options and interdisciplinary research opportunities. A few programs already offering master's degrees are considering a Ph.D. option as well. Cornell University, which has been offering its Systems Engineering M.Eng degree through the Engineering College since 1998, is contemplating the creation of a Systems Engineering Ph.D. degree (Roundy 2003). Reflecting the strong industrial influence on many of the surveyed programs, Pennsylvania State University has plans for a part-time Doctor of Engineering degree in Systems and Software Engineering. According to the description of the proposed degree, doctoral students will work on "industrially significant" research (Penn State 2004).

Purdue University is establishing 8 new interdisciplinary "signature areas" among its Schools of Engineering: (1) advanced materials & manufacturing; (2) global sustainable industrial systems; (3) Information, communications, and perception technologies; (4) Intelligent infrastructure systems; (5) Nanotechnologies & nanophotonics; (6) Renewable energy & power systems; (7) System of systems; (8) Tissue & cellular engineering. These 8 areas have a strong "systems" theme, and graduate students from various engineering programs and 75 new faculty hires are expected to conduct research in the eight areas (Purdue 2004). The University of Virginia has had a Center for Risk Management of Engineering Systems since 1987. It is not a degree-granting unit, but a cross-disciplinary research center focusing on infrastructure, transportation, and security (UVa 2003).

Although non-degree granting research centers were not the focus of this study, the slow growth of Ph.D. programs relative to master's degree programs and the reliance on single departments to administer interdisciplinary programs suggests the following possibility: Research units may be outpacing academic programs in development as intellectual centers of interdisciplinary research in engineering systems.

5. Future research questions

There are many more possible directions for deeper assessments of academic programs concerned with complex engineered systems. The web-based approach used here captures the programs as they existed in January 2004, or at the latest update of the program's website. Tracking changes to specific programs over time would inform the understanding of the growth and challenges facing engineering systems programs. Web searches occasionally led to archived webpages of discontinued programs. For example, starting in the 1970s, Washington University in St. Louis had an M.S. program in Technology and Human Affairs in its Department of Engineering and Policy, but now both the program and department are gone. Stanford University once offered a Manufacturing Systems Engineering M.S. degree through the Mechanical Engineering and Management Science and Engineering Departments, but as of 2002, Stanford was no longer accepting applications for this program, according to the ME Graduate Handbook (Stanford 2002). Further research, including interviews with faculty members, would help in understanding the reasons behind the discontinuation, merging, or reorganization of programs and provide valuable lessons to existing academic programs.

Questions remain regarding how broad engineering systems will become and whether engineering systems is a field in itself, or an umbrella term for multiple fields. Identifying key unifying characteristics is important, but narrowing the definition of the field may limit its impact on engineering education and practice. While this study does not include business school-specific programs or the more social science-based “science, technology, and society” programs, further investigation into these programs would deepen the understanding of educational trends and highlight potential synergies with engineering education.

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Appendix: List of Programs Surveyed

	University	Degree Program
1	Boston University	Manufacturing Engineering Systems Engineering
2	California Institute of Technology	Control and Dynamical Systems
3	Carnegie Mellon University	Engineering and Public Policy
4	Case Western Reserve University	Engineering and Management Systems and Control Engineering
5	Columbia University	Industrial Engineering Operations Research
6	Cornell University	Operations Research and Engineering Systems Engineering
7	Dartmouth College	Engineering Management
8	Duke University	Engineering Management
9	Georgia Institute of Technology	Executive Master of Science in International Logistics Industrial Engineering Industrial and Systems Engineering Operations Research
10	Harvard University	Operations Research, Systems and Control
11	Indiana University	Engineering Management
12	Iowa State University	Executive Engineer's Dual Master's Degree Industrial Engineering Systems Engineering
13	Johns Hopkins University	Systems Engineering
14	Lehigh University	Global Manufacturing Logistics Industrial Engineering Information and Systems Engineering Integrated Business and Engineering Manufacturing Systems Engineering Master of Business Administration and Engineering
15	Massachusetts Institute of Technology	Engineering Systems Leaders for Manufacturing Logistics Operations Research System Design and Management Technology and Policy
16	McGill University (Canada)	Manufacturing Management
17	Michigan State University	Biosystems Engineering Technology Systems Management
18	North Carolina State University	Industrial Engineering Integrated Manufacturing Systems Engineering Operations Research

19	Northwestern University	Dynamics of Complex Systems in Science and Engineering Engineering Management Industrial Engineering and Management Science
20	Ohio State University	Engineering Management Industrial and Systems Engineering Manufacturing Science
21	Pennsylvania State University	Industrial Engineering Manufacturing Systems Engineering Quality and Manufacturing Management Systems Engineering
22	Princeton University	Operations Research and Financial Engineering
23	Purdue University	Industrial Engineering Interdisciplinary Engineering
24	Rensselaer Polytechnic Institute	Decision Sciences and Engineering Sciences Industrial and Management Engineering Manufacturing Systems Engineering Operations Research and Statistics
25	Rice University	MBA/ME Program
26	Rutgers, State University of New Jersey	Industrial and Systems Engineering
27	Stanford University	Management Science and Engineering
28	SUNY, University of Buffalo	Engineering Management Industrial Engineering
29	SUNY, Stony Brook University	Technological Systems Management
30	Syracuse University	Engineering Management Manufacturing Engineering
31	Texas A&M University	Engineering Systems Management Industrial Engineering Systems Engineering
32	Tulane University	Engineering Management
33	University of Arizona	Systems Engineering
34	University of California, Berkeley	Industrial Engineering and Operations Research Systems Engineering
35	University of California, Davis	Engineering and Management
36	University of Colorado, Boulder	Engineering Management
37	University of Florida	Industrial and Systems Engineering Outreach Engineering Management
38	University of Illinois, Urbana-Champaign	General Engineering Industrial Engineering Systems and Entrepreneurial Engineering
39	University of Iowa	Industrial Engineering
40	University of Kansas	Engineering Management
41	University of Maryland, College Park	Systems Engineering

42	University of Massachusetts, Amherst	Engineering Management Industrial Engineering and Operations Research Manufacturing Engineering
43	University of Michigan, Ann Arbor	Industrial and Operations Engineering
44	University of Minnesota, Twin Cities	Industrial Engineering Infrastructure Systems Engineering Management of Technology
45	University of Missouri, Columbia	Industrial and Manufacturing Systems Engineering
46	University of Nebraska, Lincoln	Engineering Management Industrial and Management Systems Engineering Manufacturing Systems
47	University of Pennsylvania	Civil Engineering Systems Environmental Systems Management and Technology Systems Engineering Systems Science and Engineering
48	University of Pittsburgh	Industrial Engineering
49	University of Southern California	Engineering Management Manufacturing Engineering Operations Research Engineering Product Development Engineering Systems Architecture and Engineering
50	University of Texas, Austin	Engineering and Public Affairs Engineering Management Operations Research and /Industrial Engineering
51	University of Toronto (Canada)	Industrial Engineering Industrial Master's Program in Design and Manufacturing Integrated Manufacturing Jeffrey Skoll BASc/MBA
52	University of Virginia	Systems Engineering Systems and Information Engineering
53	University of Washington	Industrial Engineering Manufacturing Engineering
54	University of Wisconsin, Madison	Manufacturing Systems Engineering Industrial Engineering
55	Vanderbilt University	Management of Technology
56	Virginia Tech	Engineering Administration Human Factors Engineering and Ergonomics Management Systems Engineering Manufacturing Systems Engineering Operations Research Systems Engineering
57	Washington University in St. Louis	Engineering Management Systems Science and Engineering

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