MANAGEMENT SCIENCE AND ENGINEERING

Courses offered by the Department of Management Science and Engineering are listed under the subject code MS&E on the (https://explorecourses.stanford.edu/search/? view=catalog&academicYear=&page=0&q=MS%26E&filter-departmentcode-MS%26E=on&filter-coursestatus-Active=on&filter-term-Autumn=on)*Stanford Bulletin's* ExploreCourses web site.

The Department of Management Science and Engineering leads at the interface of engineering, business, and public policy. The department's mission is, through education and research, to advance the design, management, operation, and interaction of technological, economic, and social systems. The department's engineering research strength is integrated with its educational program at the undergraduate, master's, and doctoral levels: graduates of the program are trained as engineers and future leaders in technology, policy, and industry. Research and teaching activities are complemented by an outreach program that encourages the transfer of ideas to the environment of Silicon Valley and beyond.

Management Science and Engineering (MS&E) provides programs of education and research by integrating three basic strengths:

1. depth in conceptual and analytical foundations
2. comprehensive coverage of functional areas of application
3. interaction with other Stanford departments, Silicon Valley industry, and organizations throughout the world.

The analytical and conceptual foundations include decision and risk analysis, dynamic systems, economics, optimization, organizational science, and stochastic systems. The functional areas of application include entrepreneurship, finance, information, marketing, organizational behavior, policy, production, and strategy. Close associations with other engineering departments and with industry enrich the programs by providing opportunities to apply MS&E methods to important problems and by motivating new theoretical developments from practical experience. MS&E's programs also provide a basis for contributing to other areas such as biotechnology, defense policy, environmental policy, information systems, and telecommunications.

Mission of the Undergraduate Program in Management Science and Engineering

The mission of the undergraduate program in Management Science and Engineering is to provide students with the fundamentals of engineering systems analysis so that they are able to plan, design, and implement complex economic and technical management systems. The program builds on foundational courses in calculus and linear algebra. Students complete core courses in mathematical modeling, systems analysis, organization theory, optimization, probability, statistics, ethics, accounting, computer science, and economics, leading to a capstone senior project. To personalize their exploration, students select additional courses from different application areas of the department, with greater emphasis in one of them. The major prepares students for a variety of career paths, including investment banking, management consulting, facilities and process management, or for graduate school in industrial engineering, operations research, business, economics, law, medicine, or public policy.

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to be able:

1. to apply knowledge of mathematics, social science, and engineering;
2. to design and conduct experiments;
3. to design a system and components to meet desired needs;
4. to identify, formulate, and solve engineering problems;
5. to use techniques, skills, and modern engineering tools necessary for engineering practice;
6. to function on multidisciplinary teams;
7. to communicate effectively;
8. to recognize the need for and demonstrate an ability to engage in life-long learning;
9. to obtain the background necessary for admission to top graduate engineering or professional programs;
10. to understand professional and ethical responsibility;
11. to obtain the broad education necessary to understand the impact of engineering solutions in a global and societal context; and
12. to obtain a knowledge of contemporary issues pertinent to the field of management science and engineering.

Graduate Programs in Management Science and Engineering

MS&E offers programs leading to the degrees of Master of Science and Doctor of Philosophy. The department also offers a coterminal B.S./M.S. degree, a dual master's degree in cooperation with each of the other departments in the School of Engineering, and joint master's degrees with the School of Law and the Public Policy Program.

For University coterminal degree program rules and University application forms, see the Registrar's coterminal degrees web site (http://studentaffairs.stanford.edu/registrar/publications/#Coterm).

Applicants for admission as graduate students in MS&E are required to submit the results of the verbal reasoning, quantitative reasoning, and analytical writing sections of the Graduate Record Examination General Test (GRE). The deadline for application to the doctoral program is December 3, 2019, and the deadline for application to the master's program is January 14, 2020.

Except in unusual circumstances, admission is limited to the Autumn Quarter because courses are arranged sequentially with basic courses and prerequisites offered early in the academic year.

Assistantships and Fellowships

A limited number of fellowships and assistantships are awarded each year. Applicants admitted to the doctoral program, who have indicated on their application that they would like to be considered for financial aid, are automatically considered for these assistantships and fellowships. New and returning master's students may apply for course assistantships each quarter, but priority is given to MS&E doctoral students.

Information about loan programs and need-based aid for U.S. citizens and permanent residents can be obtained from the Financial Aid Office.

Learning Outcomes (Graduate)

The M.S. prepares engineers for a lifelong career addressing the critical technical and managerial needs of private and public organizations. The program emphasizes developing analytic abilities, making better decisions, developing and executing strategies while also leading people who innovate. Unlike an M.B.A., our master's program addresses the technical as well as the behavioral challenges of running organizations

and complex systems. We emphasize quantitative analytic skills and an entrepreneurial spirit.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Management Science and Engineering and related fields.

Careers in MS&E

MS&E students are candidates for careers in consulting, product and project management, financial analysis, and work in policy arenas. A significant number join or found start-ups. Many have become leaders in technology-based businesses which have an increasing need for analytically oriented people who understand both business and technology. Other graduates make careers tackling the problems faced by local, national, and international governments by developing new healthcare systems, new energy systems and a more sustainable environment. The major problems of the day demand an ability to integrate the technical, social and economic ways of thinking. This is precisely what the department educates its students to do.

Bachelor of Science in Management Science and Engineering

The program leading to the B.S. degree in Management Science and Engineering (MS&E) is outlined in the School of Engineering section of this bulletin; more information is contained in the School of Engineering's *Handbook for Undergraduate Engineering Programs*. Students are encouraged to plan their academic programs as early as possible, ideally in the freshman or sophomore year. Students should not wait until they are declaring a major to consult with the department's student services staff. This is particularly important for students who would like to study overseas or pursue another major or minor.

The undergraduate curriculum in Management Science and Engineering provides students training in the fundamentals of engineering systems analysis to prepare them to plan, design, and implement complex economic and technological management systems where a scientific or engineering background is necessary or desirable. The major prepares students for a variety of career paths, including investment banking, management consulting, facilities and process management, or for graduate school in industrial engineering, operations research, business, economics, law, medicine, or public policy.

The educational objectives of the undergraduate degree program are:

- *Principles and Skills*—provide students with a basic understanding of management science and engineering principles, including analytical problem solving and communications skills.
- *Preparation for Practice*—prepare students for practice in a field that sees rapid changes in tools, problems, and opportunities.
- *Preparation for Continued Growth*—prepare students for graduate study and self development over an entire career.
- *Preparation for Service*—develop in students the awareness, background, and skills necessary to become responsible citizens, employees, and leaders.

See also the department's undergraduate Learning Outcomes (p.   ) for additional learning objectives.

Students interested in a minor should see the Minor tab in this section.

MS&E also participates with the departments of Computer Science, Mathematics, and Statistics in a program leading to a B.S. in Mathematical and Computational Science. See the "Mathematical and Computational Science (http://exploredegrees.stanford.edu/schoolofhumanitiesandsciences/

mathematicalandcomputationalscience/#bachelorstext)" section of this bulletin.

Core

The program builds on foundational courses in calculus and linear algebra. The department core includes courses in mathematical modeling, systems analysis, organization theory, optimization, probability, statistics, ethics, accounting, computer science, and economics, leading to a capstone senior project. Through the core, students in the program are exposed to the breadth of faculty interests and prepared to study different areas of application of the department's methodologies.

Areas

The major is designed to allow a student to explore all three areas of the department in greater depth.

1. *Finance and Decision:* focuses on the design and analysis of financial and strategic plans.
2. *Operations and Analytics:* focuses on algorithms, theory, and the design and analysis of manufacturing, production, and service systems.
3. *Organizations, Technology, and Policy:* focuses on understanding, design, and analysis of organizations and public policy, particularly technology-based issues.

Management Science and Engineering (MS&E)

Completion of the undergraduate program in Management Science and Engineering leads to the conferral of the Bachelor of Science in Management Science and Engineering.

Requirements

		Units
Mathematics and Science		**43**
Up to ten units of AP/IB Calculus, MATH 19, 20, and/or 21. [1]		10
All required; see SoE Basic Requirements 1 and 2		22
CME 100	Vector Calculus for Engineers	
or MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	
ENGR 108	Introduction to Matrix Methods (formerly CME 103)	
MS&E 120	Introduction to Probability	
MS&E 121	Introduction to Stochastic Modeling	
MS&E 125	Introduction to Applied Statistics	
Select two of the following: [2]		8
CHEM 31B	Chemical Principles II	
CHEM 33	Structure and Reactivity of Organic Molecules	
PHYSICS 41	Mechanics	
or PHYSICS 21	Mechanics, Fluids, and Heat	
PHYSICS 43	Electricity and Magnetism	
or PHYSICS 23	Electricity, Magnetism, and Optics	
BIO 81	Introduction to Ecology	
BIO 82	Genetics	
BIO 83	Biochemistry & Molecular Biology	
BIO 84	Physiology	
BIO 85	Evolution	
BIO 86	Cell Biology	
Math, Science, or Statistics Elective from SoE approved lists. [3]		3
Technology in Society [4]		**3**
Select one of the following; see SoE Basic Requirement 4		

AA 252	Techniques of Failure Analysis	
BIOE 131	Ethics in Bioengineering	
COMM 120W	The Rise of Digital Culture	
CS 181	Computers, Ethics, and Public Policy	
CS 182	Ethics, Public Policy, and Technological Change	
ENGR 117	Expanding Engineering Limits: Culture, Diversity, and Equity	
ENGR 148	Principled Entrepreneurial Decisions	
ME 267	Ethics and Equity in Transportation Systems	
MS&E 193	Technology and National Security: Past, Present, and Future	
POLISCI 114S	International Security in a Changing World	
STS 1	The Public Life of Science and Technology	

Engineering Fundamentals [5]		**12**

Three required; see SoE Basic Requirement 3

CS 106A	Programming Methodology [6]	
MS&E 111	Introduction to Optimization	
or MS&E 111X	Introduction to Optimization (Accelerated)	

Select one of the following:

ENGR 10	Introduction to Engineering Analysis	
ENGR 14	Intro to Solid Mechanics	
ENGR 15	Dynamics	
ENGR 20	Introduction to Chemical Engineering	
ENGR 21	Engineering of Systems	
ENGR 40A	Introductory Electronics	
ENGR 40M	An Intro to Making: What is EE	
ENGR 42	Introduction to Electromagnetics and Its Applications	
ENGR 50	Introduction to Materials Science, Nanotechnology Emphasis	
ENGR 50E	Introduction to Materials Science, Energy Emphasis	
ENGR 50M	Introduction to Materials Science, Biomaterials Emphasis	
ENGR 80	Introduction to Bioengineering (Engineering Living Matter)	
ENGR 90	Environmental Science and Technology	

Engineering Depth [5]		**52**
Core Courses (all six required)		28
CS 106B	Programming Abstractions	
ECON 1	Principles of Economics	
ECON 50	Economic Analysis I	
MS&E 108	Senior Project (WIM)	
MS&E 140	Accounting for Managers and Entrepreneurs	
MS&E 180	Organizations: Theory and Management	
Area Courses (eight required; see below)		24

Depth Areas

Choose eight courses; four courses from a primary area and two courses from each of the other two areas.

Finance and Decision Area

Students choosing F&D as their primary area must take at least two of ECON 51 (or MS&E 241), MS&E 145 (or 245A), and MS&E 152 (or 252).

Introductory (no prerequisites)

ECON 143	Finance, Corporations, and Society	

MS&E 152	Introduction to Decision Analysis	

Intermediate (has prerequisites and/or appropriate for juniors and seniors)

MS&E 145	Introduction to Finance and Investment	
MS&E 146	Corporate Financial Management	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	

Advanced (intended primarily for graduate students, but may be taken by advanced undergraduates)

MS&E 241	Economic Analysis	
MS&E 245A	Investment Science	
MS&E 245B	Advanced Investment Science	
MS&E 246	Financial Risk Analytics	
MS&E 250A	Engineering Risk Analysis	
MS&E 250B	Project Course in Engineering Risk Analysis	

Operations and Analytics Area

Students choosing O&A as their primary area may also include one of CS 161, CS 229, or STATS 202 in their selections.

Methods

MS&E 112	Mathematical Programming and Combinatorial Optimization	
MS&E 135	Networks	
MS&E 213	Introduction to Optimization Theory	
MS&E 223	Simulation	
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	
MS&E 231	Introduction to Computational Social Science	
MS&E 251	Introduction to Stochastic Control with Applications	

Applications

MS&E 130	Information Networks and Services	
MS&E 230	Market Design for Engineers	
MS&E 232	Introduction to Game Theory	
MS&E 232H	Introduction to Game Theory	
MS&E 234	Data Privacy and Ethics	
MS&E 235	Network Structure and Epidemics	
MS&E 260	Introduction to Operations Management	
MS&E 263	Healthcare Operations Management	
MS&E 267	Service Operations and the Design of Marketplaces	
MS&E 330	Law, Order, & Algorithms	
MS&E 463	Healthcare Systems Design	

Organizations, Technology, and Policy Area

Introductory (no prerequisites)

ENGR 148	Principled Entrepreneurial Decisions	
MS&E 193	Technology and National Security: Past, Present, and Future	

Advanced (has prerequisites and/or appropriate for juniors and seniors)

BIOE 177	Inventing the Future	
ENGR 145	Technology Entrepreneurship	
MS&E 175	Innovation, Creativity, and Change	
MS&E 182A	Leading Organizational Change	
MS&E 182B	Leading Organizational Change II	
MS&E 184	Future of Work: Issues in Organizational Learning and Design	
MS&E 185	Global Work	
MS&E 188	Organizing for Good	

MS&E 243	Energy and Environmental Policy Analysis	
MS&E 292	Health Policy Modeling	

[1] Students without AP/IB mathematics credit, who skip MATH 19, 20, and/or 21, may petition to waive up to 10 units of math.

[2] AP/IB credit for Chemistry and Physics may be used.

[3] Electives must come from the School of Engineering approved list or PSYCH 50 Introduction to Cognitive Neuroscience, may not repeat material from any other requirement, and may not be used to also satisfy an engineering fundamentals or depth requirement. AP/IB credit for Chemistry and Physics may be used if not used above.

[4] A course may only be counted towards one requirement; courses used to satisfy the TiS requirement may not be used to also satisfy a depth area requirement.

[5] Engineering fundamentals plus engineering depth must total a minimum of 60 units. Recommended engineering fundamentals are E25B, E25E, E40A, E40M, and E80. MS&E majors may not use E60, or E70B as engineering fundamentals.

[6] Students may petition to waive CS 106A Programming Methodology after completion of CS 106B Programming Abstraction, and/or ECON 1 Principles of Economics after completion of ECON 50 Economic Analysis I.

[7] All courses taken for the major must be taken for a letter grade. Minimum combined GPA for all courses in Engineering Topics (Engineering Fundamentals and Depth courses) is 2.0.

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu).

Management Science and Engineering (MS&E) Minor

The following courses are required to fulfill the minor requirements:

		Units
Prerequisites (two courses; letter-graded or CR/NC)		
CME 100	Vector Calculus for Engineers	5
or MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	
CS 106A	Programming Methodology	5
Minor requirements (seven courses; all letter-graded)		
MS&E 111	Introduction to Optimization	3-4
or MS&E 111X	Introduction to Optimization (Accelerated)	
MS&E 120	Introduction to Probability [1]	4
MS&E 121	Introduction to Stochastic Modeling	4
MS&E 125	Introduction to Applied Statistics	4
MS&E 180	Organizations: Theory and Management	4
Electives (select any two 100- or 200-level MS&E courses)		6
Recommended courses		
In addition to the required prerequisite and minor courses, it is recommended that students also take the following courses.		
ECON 50	Economic Analysis I	5
MS&E 140	Accounting for Managers and Entrepreneurs (may be used as one of the required electives above)	3-4

[1]   Students completing a calculus-based probability course such as CS 109 or STATS 116 for their major, may substitute another MS&E course for MS&E 120.

Coterminal Program in Management Science and Engineering

This program allows Stanford undergraduates an opportunity to work simultaneously toward a B.S. in Management Science and Engineering or another quantitative major, and an M.S. in Management Science and Engineering.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees/)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Master of Science in Management Science and Engineering

The M.S. degree programs require a minimum of 45 units beyond the equivalent of a B.S. degree at Stanford. All programs represent substantial progress in the major field beyond the bachelor's degree.

University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin.

The master's in Management Science and Engineering prepares engineers for a lifelong career addressing the technical and managerial needs of private and public organizations. The program emphasizes developing analytic abilities, making better decisions, and developing and executing strategies while also leading people who innovate. Unlike an M.B.A., the department's master's program addresses the technical as well as the behavioral challenges of running organizations and complex systems, emphasizing quantitative analytic skills and an entrepreneurial spirit.

MS&E students know math, engineering, as well as behavioral science. They can conduct experiments to design better systems, organizations and work processes. They understand how to analyze data to solve real world problems. They can develop mathematical and computational models to inform action. They know how to surface and examine unarticulated assumptions and root causes. These students can communicate effectively in the team environments found in so many contemporary organizations.

MS&E master's students have breadth as well as depth. All are required to develop competence in optimization and analytics, organizations and decisions, and probability. In addition every student pursues a specialty in one of seven areas:

1. *Financial Analytics:* Students who concentrate in Financial Analytics are prepared for careers requiring analytical rigor and the ability to innovate around market challenges. Example career paths include financial services, risk management, investment management, financial technology and data processing, financial regulation and policy, exchanges and clearing houses, and auditing and compliance. The concentration combines the in-depth study of quantitative techniques with practical, hands-on business problem solving. Students learn to use mathematical models and quantitative tools to solve complex problems in finance practice. The concentration exploits the intellectual ties between finance, operations research, computer science, and engineering. It offers a high level of flexibility and a range of elective courses that allow students to tailor the program to their specific career goals. Required courses immerse students in quantitative methods and deepen their understanding of finance fundamentals. Projects courses feature practical, data-driven team projects and case studies, fostering group learning and interaction with peers.

2. *Operations and Analytics:* The Operations and Analytics track prepares students in the fundamentals and applications that are critical to careers in fields ranging from operations management in the service, healthcare, production, manufacturing, computer, telecommunications, and banking industries, to modern Silicon Valley information technology and data analytics. The program emphasizes a balance between the technical rigor of methodologies with lasting value and insightful modern applications and design challenges in a variety of established and emerging industries and operations environments. It offers a portfolio of courses in probabilistic modeling, optimization, simulation, algorithms, data science, networks, markets, and corresponding applications.

3. *Technology and Engineering Management:* Students who concentrate in Technology and Engineering Management are prepared for careers including product and project management, management consulting, and entrepreneurship. They acquire skills to manage technical organizations, foster innovation, and deal with rapidly evolving technologies and dynamic markets. Specialized coursework is flexible, allowing students to explore and gain depth and understanding of technical organizations to develop a culture of successful innovation and entrepreneurship, along with methods for decision making under uncertainty, financial analysis, and strategic planning.

4. *Computational Social Science:* The Computational Social Science track teaches students how to apply rigorous statistical and computational methods to address problems in economics, sociology, political science, and beyond. The program prepares students for a diverse set of career paths in data science, information technology, and policy analysis. The core coursework covers fundamental statistical concepts, large-scale computation, and network analysis. Through electives, students can explore topics such as experimental design, algorithmic economics, and machine learning.

5. *Decision and Risk Analysis:* Students who specialize in Decision and Risk Analysis are prepared for careers including management consulting, policy analysis, and risk management, applying engineering systems analysis to tackle complex economic and technical management problems in the private and public sectors. They acquire the skills to identify and develop opportunities in uncertain situations while recognizing and hedging the downside risks. Specialized course work includes the mathematical foundations for modeling in dynamic uncertain environments to value and manage uncertain opportunities and risks, applications to public policy, and an opportunity to work on a client project under faculty guidance.

6. *Energy and Environment:* The Energy and Environment track is designed for students interested in energy and environmental issues from the perspectives of public policy, non-governmental organizations, or corporations. This track includes core courses in economic analysis, energy resources, and energy/environmental policy analysis; and an individually designed concentration, typically emphasizing policy, strategy, or technology. Seminars provide insights into current corporate strategy, public policy, and research community developments. Energy/environmental project courses give practice in applying methodologies and concepts.

7. *Health Systems Modeling:* The Health Systems Modeling track is designed for students interested in healthcare operations and policy. The courses in this track emphasize the application of mathematical and economic analysis to problems in public health policy and the design and operation of healthcare services.

The master's degree is designed to be a terminal degree program with a professional focus. The M.S. degree can be earned in one academic year (three academic quarters) of full-time work, although most students choose to complete the program in five academic quarters, or eighteen months, and work as an intern in the Summer Quarter.

Background Requirements

Students are expected to have completed both MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications , or an equivalent multivariable differential calculus course, and CS 106A Programming Methodology, or an equivalent general programming course, before beginning graduate study. These courses do not count toward degree requirements.

Degree Requirements

Students must take a minimum of 45 course units as follows:

- Three core courses (9-12 units)
- Four to six courses in a primary or specialized concentration, not duplicating core courses (12-24 units)
- One project course or two integrated project courses (0-8 units)
- Elective courses (1-24 units; see restrictions below)

Core Courses (three courses required)

Optimization and Analytics (select one)

		Units
MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	
Relevant 200 or 300 level MS&E course in optimization (e.g. 310 or 311) or analytics if a comparable introductory course in optimization or analytics has already been completed.		

Organizations and Decisions (select one)

		Units
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 270	Strategy in Technology-Based Companies	
MS&E 280	Organizational Behavior: Evidence in Action	
Relevant 200 or 300 level MS&E course in organizations or decisions if a comparable introductory course in organizations or decisions has already been completed.		

Probability (select one)

		Units
MS&E 220	Probabilistic Analysis	
MS&E 221	Stochastic Modeling	
Relevant 200 or 300 level MS&E course in probability or stochastics (e.g. 321 or 324) if a comparable introductory course in probability or stochastics has already been completed.		

Primary Concentrations

Computational Social Science (four courses required)

		Units

Select four courses, with at least one from each of the three areas below.

Statistics (select at least one)		
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	
MS&E 327	Topics in Causal Inference	
STATS 202	Data Mining and Analysis	
STATS 203	Introduction to Regression Models and Analysis of Variance	
STATS 305A	Applied Statistics I	
STATS 315A	Modern Applied Statistics: Learning	
STATS 315B	Modern Applied Statistics: Data Mining	
Computation (select at least one)		
MS&E 230	Market Design for Engineers	
MS&E 231	Introduction to Computational Social Science	
CS 224N	Natural Language Processing with Deep Learning	
CS 229	Machine Learning	
CS 246	Mining Massive Data Sets	
STATS 290	Computing for Data Science	
Social Data (select at least one)		
MS&E 232	Introduction to Game Theory	
MS&E 232H	Introduction to Game Theory	
MS&E 234	Data Privacy and Ethics	
MS&E 235	Network Structure and Epidemics	
MS&E 241	Economic Analysis	
MS&E 270	Strategy in Technology-Based Companies	
MS&E 280	Organizational Behavior: Evidence in Action	
MS&E 284	Designing Modern Work Organizations	
MS&E 334	Topics in Social Data	
CS 224W	Machine Learning with Graphs	
ECON 291	Social and Economic Networks	
SOC 369	Social Network Methods	
Recommended Elective Courses		
MS&E 366	Market Design and Resource Allocation in Non-Profit Settings	
COMM 382	Big Data and Causal Inference	
CS 124	From Languages to Information	
CS 147	Introduction to Human-Computer Interaction Design	
CS 224S	Spoken Language Processing	
CS 448B	Data Visualization	
ECON 202N	Microeconomics I For Non-Economics PhDs students	
EDUC 288	Organizational Analysis	

LINGUIST 278	Programming for Linguists	
POLISCI 355C	Causal Inference for Social Science	
POLISCI 452	Machine Learning with Application to Text as Data	
PSYCH 212	Classic and contemporary social psychology research	
PSYCH 238	Wise Interventions	
PSYCH 265	Social Psychology and Social Change	
SOC 214	Economic Sociology	
SOC 218	Social Movements and Collective Action	
SOC 220	Interpersonal Relations	
SOC 224B	Relational Sociology	
SOC 262	The Social Regulation of Markets	
SOC 270	Classics of Modern Social Theory	
STATS 209B	Applications of Causal Inference Methods	
STATS 263	Design of Experiments	
STATS 285	Massive Computational Experiments, Painlessly	

Financial Analytics Concentration (five courses required)

		Units

Financial Theory and Modeling (select one):		
MS&E 245A	Investment Science	
MS&E 245B	Advanced Investment Science	
MS&E 246	Financial Risk Analytics	
Optimization and Analytics (select whichever of optimization or analytics wasn't taken for core):		
MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
or MS&E 310	Linear Programming	
or MS&E 311	Optimization	
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	
Quantitative Methods and Financial Applications (select three):		
MS&E 223	Simulation	
MS&E 245B	Advanced Investment Science (if not used above)	
MS&E 246	Financial Risk Analytics (if not used above)	
MS&E 249	Corporate Financial Management	
MS&E 322	Stochastic Calculus and Control	
MS&E 346	Reinforcement Learning for Stochastic Control Problems in Finance	
MS&E 347	Credit Risk: Modeling and Management	
MS&E 348	Optimization of Uncertainty and Applications in Finance	
MS&E 349	Financial Statistics	
MS&E 448	Big Financial Data and Algorithmic Trading	
STATS 207	Introduction to Time Series Analysis	
STATS 240	Statistical Methods in Finance	
STATS 241	Data-driven Financial Econometrics	

Operations and Analytics Concentration (four courses required)

Units

Required Courses

MS&E 211X	Introduction to Optimization (Accelerated) (whichever of optimization or analytics wasn't taken for core)	
or MS&E 213	Introduction to Optimization Theory	
or MS&E 310	Linear Programming	
or MS&E 311	Optimization	
or MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	
MS&E 221	Stochastic Modeling (any of the following courses may be substituted only if 221 or an equivalent has been taken)	
or MS&E 223	Simulation	
or MS&E 251	Introduction to Stochastic Control with Applications	
or MS&E 321	Stochastic Systems	
or MS&E 324	Stochastic Methods in Engineering	
or MS&E 338	Reinforcement Learning: Frontiers	
or MS&E 351	Dynamic Programming and Stochastic Control	
MS&E 212	Mathematical Programming and Combinatorial Optimization	
or MS&E 232	Introduction to Game Theory	
or MS&E 232H	Introduction to Game Theory	
or MS&E 251	Introduction to Stochastic Control with Applications	
MS&E 260	Introduction to Operations Management	
or MS&E 263	Healthcare Operations Management	
or MS&E 267	Service Operations and the Design of Marketplaces	

Recommended Elective Courses:

MS&E 230	Market Design for Engineers	
MS&E 231	Introduction to Computational Social Science	
MS&E 234	Data Privacy and Ethics	
MS&E 235	Network Structure and Epidemics	
MS&E 241	Economic Analysis	
MS&E 243	Energy and Environmental Policy Analysis	
MS&E 245A	Investment Science	
MS&E 250A	Engineering Risk Analysis	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 292	Health Policy Modeling	

Technology and Engineering Management Concentration (four courses required)

Courses for Core and Concentration must cover each of the three sub-areas below.

Units

Organizations and Strategy (select at least one):

MS&E 265	Introduction to Product Management	
MS&E 270	Strategy in Technology-Based Companies	
MS&E 274	Dynamic Entrepreneurial Strategy	
MS&E 278	Patent Law and Strategy for Innovators and Entrepreneurs	
MS&E 280	Organizational Behavior: Evidence in Action	
MS&E 284	Designing Modern Work Organizations	

Entrepreneurship and Innovation (select at least one):

MS&E 256	Technology Assessment and Regulation of Medical Devices	
MS&E 270	Strategy in Technology-Based Companies	
MS&E 271	Global Entrepreneurial Marketing	
MS&E 272	Entrepreneurship without Borders	
MS&E 273	Venture Creation for the Real Economy	
or CEE 246	Venture Creation for the Real Economy	
MS&E 275	Intelligent Growth in Startups	
MS&E 276	Entrepreneurial Management and Finance	
MS&E 293	Technology and National Security: Past, Present, and Future	
ENGR 245	The Lean LaunchPad: Getting Your Lean Startup Off the Ground	
or MS&E 297	"Hacking for Defense": Solving National Security issues with the Lean Launchpad	
ENGR 248	Principled Entrepreneurial Decisions	

Finance and Decisions (select at least one):

MS&E 240	Accounting for Managers and Entrepreneurs	
MS&E 241	Economic Analysis	
MS&E 245A	Investment Science	
MS&E 245B	Advanced Investment Science	
MS&E 246	Financial Risk Analytics	
MS&E 249	Corporate Financial Management	
MS&E 250A	Engineering Risk Analysis	
MS&E 250B	Project Course in Engineering Risk Analysis	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 254	The Ethical Analyst	
MS&E 355	Influence Diagrams and Probabilistics Networks	

Specialized Concentrations (must have approval of the academic adviser)

Decision and Risk Analysis Concentration (four courses required)

Units

Core Courses are restricted as follows:

MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
MS&E 221	Stochastic Modeling	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	

Required Courses (select two):

MS&E 241	Economic Analysis	
MS&E 250A	Engineering Risk Analysis	
MS&E 251	Introduction to Stochastic Control with Applications	
or EE 263	Introduction to Linear Dynamical Systems	
MS&E 355	Influence Diagrams and Probabilistics Networks	

Policy Course (select one):

MS&E 243	Energy and Environmental Policy Analysis	
MS&E 292	Health Policy Modeling	

MS&E 293	Technology and National Security: Past, Present, and Future
Project Course (select one):	
MS&E 250B	Project Course in Engineering Risk Analysis
MS&E 297	"Hacking for Defense": Solving National Security issues with the Lean Launchpad

Energy and Environment Concentration (six courses required)

		Units
Required Courses:		
MS&E 241	Economic Analysis	
MS&E 243	Energy and Environmental Policy Analysis	
CEE 207A	Understanding Energy	
or CEE 273S	Electricity Economics	
or ENERGY 291	Optimization of Energy Systems	

Three additional courses from energy, policy, or strategy areas below.

Policy:		
MS&E 292	Health Policy Modeling	
MS&E 293	Technology and National Security: Past, Present, and Future	
MS&E 394	Advanced Methods in Modeling for Climate and Energy Policy	
ECON 251	Natural Resource and Energy Economics	
Strategy:		
MS&E 270	Strategy in Technology-Based Companies	
MS&E 271	Global Entrepreneurial Marketing	
MS&E 272	Entrepreneurship without Borders	
MS&E 273	Venture Creation for the Real Economy	
MS&E 274	Dynamic Entrepreneurial Strategy	
MS&E 275	Intelligent Growth in Startups	
MS&E 276	Entrepreneurial Management and Finance	
MS&E 278	Patent Law and Strategy for Innovators and Entrepreneurs	
Energy:		
ENERGY 102	Fundamentals of Renewable Power	
ENERGY 104	Sustainable Energy for 9 Billion	
ME 370A	Energy Systems I: Thermodynamics	
ME 370B	Energy Systems II: Modeling and Advanced Concepts	
PHYSICS 240	Introduction to the Physics of Energy	
PHYSICS 241	Introduction to Nuclear Energy	
Recommended Seminars:		
MS&E 441	Policy and Economics Research Roundtable	
MS&E 472	Entrepreneurial Thought Leaders' Seminar	
ECON 341	Public Economics and Environmental Economics Seminar	
ENERGY 301	The Energy Seminar	
Recommended Elective Courses:		
MS&E 201	Dynamic Systems	
MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
MS&E 251	Introduction to Stochastic Control with Applications	
ECON 206	World Food Economy	

ECON 209	Economic, Legal, and Political Analysis of Climate-Change Policy
ECON 250	Environmental Economics
ECON 270	Intermediate Econometrics I
ECON 278	Behavioral and Experimental Economics I
ENVRES 222	Climate Law and Policy
or ENVRES 226	Energy Law
MGTECON 603	Econometric Methods I
PUBLPOL 353A	Science and Technology Policy

Health Systems Modeling and Policy Concentration (four courses required)

		Units
Required Courses (select four)		
MS&E 263	Healthcare Operations Management	
MS&E 292	Health Policy Modeling	
MS&E 463	Healthcare Systems Design	
HRP 263	Advanced Decision Science Methods and Modeling in Health	
HRP 392	Analysis of Costs, Risks, and Benefits of Health Care	
Recommended Elective Courses:		
MS&E 256	Technology Assessment and Regulation of Medical Devices	
HRP 256	Economics of Health and Medical Care	
HRP 391	Health Law: Finance and Insurance	

Projects (may duplicate Core and/or Concentration courses)

Select one project course or two integrated project courses.

		Units
Project Courses		
MS&E 250B	Project Course in Engineering Risk Analysis	3
MS&E 348	Optimization of Uncertainty and Applications in Finance	3
MS&E 448	Big Financial Data and Algorithmic Trading	3
MS&E 463	Healthcare Systems Design	3-4
Integrated Project Courses		
ENGR 248	Principled Entrepreneurial Decisions	3
MS&E 201	Dynamic Systems	3
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality	3
MS&E 243	Energy and Environmental Policy Analysis	3
MS&E 245A	Investment Science	3-4
MS&E 245B	Advanced Investment Science	3
MS&E 246	Financial Risk Analytics	3
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	3-4
MS&E 256	Technology Assessment and Regulation of Medical Devices	3
MS&E 260	Introduction to Operations Management	3
MS&E 265	Introduction to Product Management	3
MS&E 270	Strategy in Technology-Based Companies	3-4
MS&E 271	Global Entrepreneurial Marketing	3-4
MS&E 272	Entrepreneurship without Borders	3-4
MS&E 274	Dynamic Entrepreneurial Strategy	3
MS&E 275	Intelligent Growth in Startups	3

MS&E 280	Organizational Behavior: Evidence in Action	3-4
MS&E 284	Designing Modern Work Organizations	3
MS&E 311	Optimization	3
MS&E 338	Reinforcement Learning: Frontiers	3
MS&E 347	Credit Risk: Modeling and Management	3
MS&E 349	Financial Statistics	3
MS&E 355	Influence Diagrams and Probabilistics Networks	3

Additional Requirements

1. At least 45 units must be in courses numbered 100 and above.
2. The degree program must be completed with a grade point average (GPA) of 3.0 or higher.
3. At least 27 units must be in courses numbered 200 and above in MS&E, taken for a letter grade and a minimum of two units each.
4. At least 36 letter-graded units must be in MS&E or closely related fields. Closely related fields include any department in the School of Engineering, mathematics, statistics, economics, sociology, or business.
5. A maximum of 4 units of directed or individual study units may count toward the letter-grade requirement.
6. All courses used to satisfy core, concentration, or project requirements must be taken for a letter grade.
7. A maximum of three units of 1-unit courses such as seminars, colloquia, workshops, in any department, including MS&E 208A, B, C, and D Practical Training, and MS&E 208E Part-Time Practical Training.
8. A maximum of 18 non-degree option (NDO) units through the Stanford Center for Professional Development (SCPD).
9. Courses taken in Health and Human Performance (e.g. Athletics, Club Sports, Kinesiology, Leadership Innovations, Lifeworks, Outdoor Education, Physical Education, and Wellness Education) may not be applied toward the degree.

Professional Education

The Stanford Center for Professional Development (SCPD) provides opportunities for employees of some local and remote companies to take courses at Stanford.

The Honors Cooperative Program (HCP) provides opportunities for fully employed working professionals to earn an M.S. degree, over a longer period, by taking one or two courses per academic quarter. Some courses are only offered on campus; HCP students may attend those courses at Stanford to meet the degree requirements. It is possible to complete this program as a remote HCP student although the remote offerings are limited. Students must apply for a degree program through the standard application process, and must meet the standard application deadlines.

The non-degree option (NDO) program allows industry students with the opportunity to take Stanford graduate courses on a part-time basis without having to be formally admitted to a degree program. NDO students enroll as distance learners where up to 18 units of graduate credit earned may later be applied toward a degree program (if admitted). Students who have completed an undergraduate degree with a minimum of a 3.0 grade point average, may apply to take MS&E courses online each quarter through the Stanford Center for Professional Development. Completion of multivariable calculus and linear algebra is required for most MS&E courses and graduate certificates. For additional information about the NDO application process and deadlines, see the SCPD web site (http://scpd.stanford.edu/non-degree-option-program/), or contact SCPD at (650) 725-3000.

Certificate

The department offers a certificate program within the framework of the NDO program. A certificate can be obtained by completing three MS&E core courses, plus one MS&E elective course for a total of four courses. For further information, see http://scpd.stanford.edu/programs/graduate-certificates.

Dual Master's Degree Program

The dual degree program enables a small group of graduate students to obtain two master's degrees simultaneously. Students complete the course requirements for each department. A total of 90 units is required to complete the dual master's degree.

Admission

For the dual degree, admission to two departments is required, but is coordinated by designated members of both admissions committees who make recommendations to the committees of their respective departments. Students may apply to only one department initially. After the first quarter at Stanford, students may apply to be admitted to the second department.

Advising

Every student in the dual degree program has one adviser in each department.

Joint MS&E and Law Degrees

The School of Law and the Department of Management Science and Engineering offer joint degree programs leading to a J.D. degree and an M.S. degree in MS&E, or to a J.D. and Ph.D. in MS&E. These programs are designed for students who wish to prepare themselves for careers in areas relating to both law and to the decision making, policy making, and problem solving knowledge and skills developed in the MS&E program. Students interested in either joint degree program must apply and gain admission separately to the School of Law and the Department of Management Science and Engineering and, as an additional step, must secure consent from both academic units to pursue degrees in those units as part of a joint degree program. Interest in either joint degree program should be noted on the student's admission applications and may be considered by the admission committee of each program. Alternatively, an enrolled student in either the Law School or MS&E may apply for admission to the other program and for joint degree status in both academic units after commencing study in either program.

Joint degree students may elect to begin their course of study in either the School of Law or MS&E. Students are assigned to a joint program committee composed of at least one faculty member from Law and one from MS&E. This committee plans the student's program jointly with the student. Students must be enrolled full time in the Law School for the first year of law studies, and it is recommended that students devote exclusively one Autumn Quarter to the MS&E M.S. program to initiate their MS&E work. After that time, enrollment may be in MS&E or Law, and students may choose courses from either program regardless of where enrolled. A candidate in the joint J.D./Ph.D. program should spend a substantial amount of full time residency in MS&E. Students must satisfy the requirements for both the J.D. and the M.S. or Ph.D. degrees as specified in this bulletin or by the School of Law. The Law School may approve courses from MS&E or courses in the student's MS&E program from outside of the Department of Management Science and Engineering that may count toward the J.D. degree, and MS&E may approve courses from the Law School that may count toward the M.S. or Ph.D. degree in MS&E. In either case, approval may consist of a list applicable to all joint degree students or may be tailored to each individual student's program. The lists may differ depending on whether the student is pursuing an M.S. or a Ph.D. in MS&E.

In the case of a J.D./M.S. program, no more than 45 units of approved courses may be counted toward both degrees. In the case of a J.D./Ph.D. program, no more than 54 units of approved courses may be counted toward both degrees. In either case, no more than 36 units of courses that originate outside the Law School may count toward the law degree. To the extent that courses under this joint degree program originate outside the Law School but count toward the law degree, the law credits permitted under Section 17(1) of the Law School Regulations are reduced on a unit-per-unit basis, but not below zero. The maximum number of law school credits that may be counted toward the M.S. in MS&E is the greater of: (a) 18 units in the case of the M.S., or (b) the maximum number of hours from courses outside the department that an M.S. candidate in MS&E is permitted to count toward the applicable degree under general departmental guidelines or under departmental rules that apply in the case of a particular student.

Tuition and financial aid arrangements are normally through the school in which the student is then enrolled.

Joint MS&E and Master of Public Policy Degree

M.S. MS&E students who wish to apply their analytical and management skills to the field of public policy can simultaneously pursue a master degree in MS&E and a master degree in Public Policy. The MPP is a two-year degree program, but M.S. MS&E students who pursue the joint program can earn both degrees in a minimum of two years, depending on prior preparation and elective choices, by counting up to 45 quarter units of course work toward both degrees. After admission to the Department of Management Science and Engineering, incoming or current M.S. students request that their application file be forwarded to the MPP program director for review.

Students in the joint program normally will spend most of their first year taking MS&E core courses. The second year is typically devoted to the MPP core, concentration, and practicum. The joint degree requires 90 quarter units. Tuition for the first year of study is paid at the Graduate Engineering rate, the remaining time at the graduate rate.

Doctor of Philosophy in Management Science and Engineering

University requirements for the Ph.D. degree are described in the "Graduate Degrees" section of this bulletin.

The Ph.D. degree in MS&E is intended for students primarily interested in a career of research and teaching, or high-level technical work in universities, industry, or government. The program requires three years of full-time graduate study, at least two years of which must be at Stanford. Typically, however, students take four to five years after entering the program to complete all Ph.D. requirements. The Ph.D. is organized around the expectation that the students acquire a certain breadth across all areas of the department, and depth in one of them. The current areas are:

- Computational Social Science
- Decision Analysis and Risk Analysis
- Energy and Environment
- Quantitative Finance
- Health Systems Modeling and Policy
- National Security Policy
- Operations Management
- Optimization and Stochastics
- Organizations
- Strategy, Innovation, and Entrepreneurship

Doctoral students are required to take a number of courses, both to pass a qualifying exam in one of these areas, and to complete a dissertation based on research which must make an original contribution to knowledge.

Each student admitted to the Ph.D. program must satisfy a breadth requirement and pass a qualification procedure. The purpose of the qualification procedure is to assess the student's command of the field and to evaluate his or her potential to complete a high-quality dissertation in a timely manner. The student must complete specified course work in one of the areas of the department.

The qualification decision is based on the student's course work and grade point average (GPA), on the one or two preliminary papers prepared by the student with close guidance from two faculty members, at least one of whom must be an MS&E faculty member, the student's performance in an area examination or defense of the written paper(s), and an overall assessment by the faculty of the student's ability to conduct high-quality Ph.D. research. Considering this evidence, the department faculty vote on advancing the student to candidacy in the department at large. The Ph.D. requires a minimum of 135 units, up to 45 units of which may be transferred from another graduate program.

All courses used to satisfy breadth and depth requirements must be taken for a letter grade, if the letter graded option is available. Prior to candidacy, at least 3 units of work must be taken with each of four Stanford faculty members. Finally, the student must pass a University oral examination and complete a Ph.D. dissertation. During the course of the Ph.D. program, students who do not have a master's degree are strongly encouraged to complete one, either in MS&E or in another Stanford department.

Breadth Requirement

All first year students are required to attend and participate in MS&E 302 Fundamental Concepts in Management Science and Engineering, which meets in the Autumn Quarter.

Each course session is devoted to a specific MS&E Ph.D. research area. At a given session several advanced Ph.D. students in that area make carefully prepared presentations designed for first-year doctoral students regardless of area. The presentations are devoted to: (a) illuminating how people in the area being explored that day think about and approach problems, and (b) illustrating what can and cannot be done when addressing problems by deploying the knowledge, perspectives, and skills acquired by those who specialize in the area in question.

Faculty in the focal area of the week comment on the student presentations. The rest of the session is devoted to questions posed and comments made by the first year Ph.D. students.

During the last two weeks of the quarter, groups of first year students make presentations on how they would approach a problem drawing on two or more of the perspectives to which they have been exposed earlier in the class.

Attendance is mandatory and performance is assessed on the basis of the quality of the students' presentations and class participation

Qualification Procedure Requirements

The qualification procedure is based on depth in an area of the student's choice and preparation for dissertation research. The qualification process must be completed by the end of the month of May of the student's second year of graduate study in the department. The performance of all doctoral students is reviewed every year at a department faculty meeting at the end of May or beginning of June. Ph.D. qualification decisions are made at that time and individual feedback is provided.

The Ph.D. qualification requirements comprise these elements:

1. *Courses and GPA:* Students must complete the depth requirements of one of the areas of the MS&E department. (The Ph.D. area course requirements are below).
   All courses used to satisfy depth requirements must be taken for a letter grade, if the letter graded option is available. Course substitutions may be approved by the doctoral program adviser or the MS&E dissertation adviser on the candidacy form or on a request for graduate course waiver/substitution form. A student must maintain a GPA of at least 3.4 in the set of all courses taken by the student within the department. The GPA is computed on the basis of the nominal number of units for which each course is offered.

2. *Paper(s):* A student may choose between two options. The first option involves one paper supervised by a primary faculty adviser and a second faculty reader. This paper should be written in two quarters.   The second option involves two shorter sequential tutorials, with two different faculty advisers. Each tutorial should be completed in one quarter. In both options, the student chooses the faculty adviser(s)/reader with the faculty members' consent. There must be two faculty members, at least one of whom must be an MS&E faculty member, supervising and evaluating this requirement for advancement to candidacy. The paper/tutorials must be completed before the Spring Quarter of the student's second year of graduate study in the department if the student's qualifying exam is during the Spring Quarter, and before the end of May of that year otherwise.

3. *Area Qualification:* In addition, during the second year, a student must pass an examination in one of the areas of the MS&E department, or defense of the written paper(s). The student chooses the area/program in which to take the examination. This area examination is written, oral, or both, at the discretion of the area faculty administering the exam. Most areas offer the qualifying exam only once per year, which may be early in the second year.

Degree Progress and Student Responsibility
Each doctoral student's progress is reviewed annually by the MS&E faculty. Typically, this occurs at a faculty meeting at the end of Spring Quarter, and an appropriate email notification is sent over the summer to the student and their adviser. It shall be the responsibility of the student to initiate each required step in completing the Ph.D. program.

1. To maintain good standing in the degree program, first-year students must:
   a. complete 30 units, including MS&E 302 and doctoral courses taught by faculty in their research area;
   b. develop relationships with faculty members who can potentially serve as dissertation adviser or reading committee member. A faculty member is more likely to accept the responsibility of supervising the research of a student whom he or she knows fairly well than a student whose abilities, initiative, and originality the faculty member knows less well. It is recommended that students participate in research rotations with MS&E and related faculty to facilitate the development of these relationships.

2. To maintain good standing in the degree program second-year students must:
   a. submit a candidacy form signed by at least one MS&E faculty member with whom they have or will complete research rotations, tutorials, or papers, and listing the course requirements agreed upon by both the student and the program adviser;
   b. complete at least two one-quarter research rotations or tutorials, or one two-quarter research rotation, tutorial, or research paper, continuing to develop relationships with faculty members who might serve as dissertation adviser or reading committee member;
   c. complete 30 units, including most, if not all, of the required courses listed on the candidacy form;
   d. pass an area qualifying exam;
   e. be advanced to candidacy by the faculty.

3. To maintain good standing in the degree program, third-year students must:
   a. submit a progress form listing the dissertation topic and signed by the dissertation adviser (if the dissertation adviser is not an MS&E faculty member, the form must also be signed by an MS&E faculty member who agrees to be on the student's reading committee, as well as the student's point of contact within the department);
   b. complete 30 units, including any remaining depth courses.

4. To maintain good standing in the degree program, fourth-year students must:
   a. select a reading committee (a dissertation adviser and two readers) with at least one member from the student's major department, and submit the reading committee form signed by each member on the reading committee;
   b. make satisfactory progress on their dissertation as determined by their dissertation adviser;
   c. if the student has not transferred any previous graduate units to Stanford, complete 30 dissertation units.

5. To maintain good standing in the degree program beyond the fourth year, students must make satisfactory progress on their dissertation as determined by their dissertation adviser and approved by the faculty. Indeed, the dissertation adviser will have to present the case to (and seek approval for good standing of the student from) the faculty in the annual faculty meeting for student review. It should be noted that each student inherently has to pass the oral examination (see below) and submit their dissertation before their candidacy expires.

Additionally, to remain in good standing, and to remain eligible for funding, students must perform well in all assistantship positions.

Any special cases, for a student to remain in good standing based on extenuating circumstances, must be presented to and approved by the whole faculty.

Oral Examination
As administered in this department, the University oral examination is a defense of the dissertation; however, the candidate should be prepared to answer any question raised by any members of the Academic Council who choose to be present. The examining committee consists of the three members of the reading committee as well as a fourth faculty member and an orals chair. The chair must be an Academic Council member and may not be affiliated with either the Department of Management Science and Engineering nor any department in which the student's adviser has a regular appointment; emeriti professors are eligible to serve as an orals chair. It is the responsibility of the student's adviser to find an appropriate orals chair. The University oral examination may be scheduled after the dissertation reading committee has given tentative approval to the dissertation.

The student must be enrolled in the quarter of their oral examination. Students should schedule three hours for the oral examination, which usually consists of a 45-minute public presentation, followed by closed-session questioning of the examinee by the committee, and committee deliberation. The student needs to reserve a room, and meet with the student services manager to complete the oral examination schedule and pick up other paper work. This paperwork, along with an abstract, needs to be delivered to the orals chair at least one week prior to the oral examination.

Course Requirements
Computational Social Science
The Computational Social Science track teaches students how to apply rigorous statistical and computational methods to address problems in economics, sociology, political science and beyond. The core course work covers fundamental statistical concepts, large-scale computation, and network analysis. Through electives, students can explore topics

such as experimental design, algorithmic economics, and machine learning.

Select four courses, with at least one from each of the three areas below.

Statistics (select at least one)	
MS&E 226	Fundamentals of Data Science: Prediction, Inference, Causality
MS&E 327	Topics in Causal Inference
STATS 202	Data Mining and Analysis
STATS 203	Introduction to Regression Models and Analysis of Variance
STATS 305A	Applied Statistics I
STATS 315A	Modern Applied Statistics: Learning
STATS 315B	Modern Applied Statistics: Data Mining

Computation (select at least one)	
MS&E 230	Market Design for Engineers
MS&E 231	Introduction to Computational Social Science
CS 224N	Natural Language Processing with Deep Learning
CS 229	Machine Learning
CS 246	Mining Massive Data Sets
STATS 290	Computing for Data Science

Social Data (select at least one)	
MS&E 232	Introduction to Game Theory
MS&E 232H	Introduction to Game Theory
MS&E 234	Data Privacy and Ethics
MS&E 235	Network Structure and Epidemics
MS&E 241	Economic Analysis
MS&E 270	Strategy in Technology-Based Companies
MS&E 280	Organizational Behavior: Evidence in Action
MS&E 284	Designing Modern Work Organizations
MS&E 334	Topics in Social Data
CS 224W	Machine Learning with Graphs
ECON 291	Social and Economic Networks
SOC 369	Social Network Methods

Recommended:	
MS&E 366	Market Design and Resource Allocation in Non-Profit Settings
COMM 382	Big Data and Causal Inference
CS 124	From Languages to Information
CS 147	Introduction to Human-Computer Interaction Design
CS 224S	Spoken Language Processing
CS 448B	Data Visualization
ECON 202N	Microeconomics I For Non-Economics PhDs students
EDUC 288	Organizational Analysis
LINGUIST 278	Programming for Linguists
POLISCI 355C	Causal Inference for Social Science
POLISCI 452	Machine Learning with Application to Text as Data
PSYCH 212	Classic and contemporary social psychology research
PSYCH 238	Wise Interventions
PSYCH 265	Social Psychology and Social Change
SOC 214	Economic Sociology
SOC 218	Social Movements and Collective Action
SOC 220	Interpersonal Relations
SOC 224B	Relational Sociology
SOC 262	The Social Regulation of Markets
SOC 270	Classics of Modern Social Theory
STATS 209B	Applications of Causal Inference Methods
STATS 263	Design of Experiments
STATS 285	Massive Computational Experiments, Painlessly

Computational Social Science Qualifying Procedure

The student does two quarter-length tutorials with CSS faculty. At the end of these tutorials, the student must make a 45-minute presentation of one of their tutorials to a committee of three CSS faculty members. The student can do both tutorials with the same faculty member, in which case the presentation can be of the two tutorials together, and another committee member must be kept informed of the student's progress on a regular basis during the two quarters. The presentation should take place in the Spring Quarter of the student's second year, or earlier. The presentation must include original research or promising directions towards original research. During this presentation, the student must also provide the name of their chosen focus area, and the list of courses that the student has completed and intends to complete in the core as well as in the chosen focus area. The committee then makes a recommendation to the CSS area and the MS&E department regarding qualification of the student for the Ph.D. program in CSS.

Decision Analysis and Risk Analysis

Prerequisites:	
CS 106A	Programming Methodology
CME 100	Vector Calculus for Engineers
ENGR 108	Introduction to Matrix Methods (formerly CME 103)

Required:	
MS&E 201	Dynamic Systems
or EE 263	Introduction to Linear Dynamical Systems
MS&E 211	Introduction to Optimization
or MS&E 211X	Introduction to Optimization (Accelerated)
or MS&E 213	Introduction to Optimization Theory
or MS&E 311	Optimization
MS&E 220	Probabilistic Analysis
MS&E 221	Stochastic Modeling
or STATS 217	Introduction to Stochastic Processes I
MS&E 223	Simulation
MS&E 241	Economic Analysis
MS&E 250A	Engineering Risk Analysis
MS&E 250B	Project Course in Engineering Risk Analysis
MS&E 251	Introduction to Stochastic Control with Applications
or MS&E 351	Dynamic Programming and Stochastic Control
MS&E 252	Decision Analysis I: Foundations of Decision Analysis
MS&E 352	Decision Analysis II: Professional Decision Analysis
MS&E 353	Decision Analysis III: Frontiers of Decision Analysis
MS&E 355	Influence Diagrams and Probabilistics Networks

Recommended:	
MS&E 245A	Investment Science
MS&E 254	The Ethical Analyst
MS&E 270	Strategy in Technology-Based Companies

MS&E 280	Organizational Behavior: Evidence in Action	
MS&E 321	Stochastic Systems	
or STATS 218	Introduction to Stochastic Processes II	
CS 228	Probabilistic Graphical Models: Principles and Techniques	
CS 270	Modeling Biomedical Systems	
ECON 286	Game Theory and Economic Applications	
ECON 290	Multiperson Decision Theory	
STATS 200	Introduction to Statistical Inference	
or STATS 202	Data Mining and Analysis	
or ECON 271	Intermediate Econometrics II	

Quantitative Finance

The finance area focuses on the quantitative and statistical study of financial risks, institutions, markets, and technology. Students take courses in probability, statistics, optimization, finance, economics, and computational mathematics as well as a variety of other courses. Recent dissertation topics include studies of machine learning methods for risk management; systemic financial risk; algorithmic trading; optimal order execution; large-scale portfolio optimization; mortgage markets; and statistical testing of financial models. Ph.D. students in the area typically are affiliated with the Center for Financial and Risk Analytics (CFRA).

Prerequisites (may be waived based on prior coursework)

Mathematics		
MATH 113	Linear Algebra and Matrix Theory	
MATH 115	Functions of a Real Variable	
or MATH 171	Fundamental Concepts of Analysis	

Probability		
MS&E 220	Probabilistic Analysis	
or STATS 116	Theory of Probability	
MS&E 221	Stochastic Modeling	

Statistics		
STATS 110	Statistical Methods in Engineering and the Physical Sciences	

Programming		
CS 106A	Programming Methodology	

Economics		
MS&E 241	Economic Analysis	
or ECON 50	Economic Analysis I	

Required Core Courses

Optimization		
MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
or MS&E 310	Linear Programming	
or MS&E 311	Optimization	

Stochastics		
MS&E 321	Stochastic Systems	
or MS&E 322	Stochastic Calculus and Control	

Statistics		
STATS 200	Introduction to Statistical Inference	
or STATS 305A	Applied Statistics I	
or STATS 315A	Modern Applied Statistics: Learning	

Numerical Methods		
MS&E 223	Simulation	
or CME 200	Linear Algebra with Application to Engineering Computations	
or CME 206	Introduction to Numerical Methods for Engineering	

Strongly Recommended		
STATS 300A	Theory of Statistics I	
STATS 310A	Theory of Probability I	
Elective Courses (select at least 4)		
MS&E 245A	Investment Science	
MS&E 245B	Advanced Investment Science	
MS&E 246	Financial Risk Analytics	
MS&E 347	Credit Risk: Modeling and Management	
MS&E 348	Optimization of Uncertainty and Applications in Finance	
MS&E 349	Financial Statistics	
ECON 236	Financial Economics I	
ECON 237	Financial Economics II	
ECON 273	Advanced Econometrics I	
ECON 274	Advanced Econometrics II	
FINANCE 625	Empirical Asset Pricing	
MATH 238	Mathematical Finance	
STATS 240	Statistical Methods in Finance	
STATS 243	Risk Analytics and Management in Finance and Insurance	
STATS 315B	Modern Applied Statistics: Data Mining	

Students should discuss their course schedule with their dissertation advisers. Other courses in MS&E, Economics, Finance, Scientific Computing, or Statistics at the MS&E 300-level (or comparable in other departments) may be chosen after consulting with the dissertation adviser.

Quantitative Finance Qualifying Procedure

In addition to beginning an appropriate course program, students must pass two quarters of tutorial and an oral examination to obtain qualification. The tutorials emphasize basic research skills. The oral examination emphasizes command of basic concepts as represented in the required courses as well as the modeling of practical situations.

Energy and Environment Policy (see Policy and Strategy)
Health Policy (see Policy and Strategy)
National Security Policy (see Decision Analysis and Risk Analysis)
Operations Management

Foundation courses (may be waived based on prior coursework):

MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
MS&E 241	Economic Analysis	
or ECON 202N	Microeconomics I For Non-Economics PhDs students	
MS&E 260	Introduction to Operations Management	

Methodology courses (all):

MS&E 221	Stochastic Modeling	
or STATS 217	Introduction to Stochastic Processes I	
MS&E 223	Simulation	
or STATS 362	Topic: Monte Carlo	
MS&E 251	Introduction to Stochastic Control with Applications	
or MS&E 351	Dynamic Programming and Stochastic Control	
MS&E 311	Optimization	
or EE 364A	Convex Optimization I	
MS&E 321	Stochastic Systems	

OM research courses (any four):

MS&E 365	Mechanism and Market Design	

Faculty-approved GSB OIT Ph.D. courses (about six are offered every two years).

Optimization and Stochastics

Prerequisites:

MS&E 220	Probabilistic Analysis
or STATS 116	Theory of Probability
MS&E 221	Stochastic Modeling
or STATS 217	Introduction to Stochastic Processes I
MS&E 241	Economic Analysis
or ECON 50	Economic Analysis I
CS 106A	Programming Methodology
MATH 113	Linear Algebra and Matrix Theory
MATH 115	Functions of a Real Variable
or MATH 171	Fundamental Concepts of Analysis

Strongly Recommended:

CME 108	Introduction to Scientific Computing
STATS 200	Introduction to Statistical Inference
STATS 203	Introduction to Regression Models and Analysis of Variance

Core (four courses):

MS&E 310	Linear Programming
MS&E 321	Stochastic Systems
Two of the following four courses:	
MS&E 311	Optimization
MS&E 316	Discrete Mathematics and Algorithms
MS&E 337	Network Structure and Epidemics
STATS 310A	Theory of Probability I
Three to four courses in some coherent area of specialization.	

In addition to the four core courses, students should take at least four 3-4 unit courses in some coherent area of specialization. The area of specialization may be methodological; examples include (but are not limited to) optimization, stochastic systems, stochastic control, algorithms, economic analysis, statistical inference, scientific computing, etc. The area of specialization could also have a significant modeling and application component, such as (but not limited to) information services, telecommunications, financial engineering, supply chains, health care, energy, etc. Independent of the choice of specialization, students are encouraged to take a range of courses covering methodology, modeling, and applications. Any MS&E courses satisfying this requirement must be at the 300-level, while courses outside MS&E must be at a comparable level. Students are expected to earn a letter grade of A- or better in all courses counted for the requirements. A student's plan for completing these requirements must be discussed with and approved by their faculty adviser by the beginning of Autumn Quarter of their second year.

Optimization and Stochastics Qualifying Procedure

Students take the area qualifying exam at the beginning of their second year of study. The qualifying exam consists of two written exams: one in Optimization and one in Stochastic Systems. The first exam covers the material in MS&E 310 and related prerequisites. The second exam covers the material in MS&E 321 and related prerequisites.

The student does two quarter-length tutorials with Optimization and Stochastics faculty (or affiliated faculty). A written report approved by the supervising faculty member is required on each tutorial. In addition, at the end of the second year, students are expected to make a 30-minute presentation to the broader Optimization and Stochastics faculty. The presentation must include original research or promising directions towards original research. The student can do both tutorials with the same faculty member; in this case a single written report is sufficient, and the presentation can be of the two tutorials together.

Organizations, Strategy, Innovation, and Entrepreneurship

Foundation in Organizational Behavior (five courses):

MS&E 389	Seminar on Organizational Theory

Plus three of the following, which must include at least one 37x course and one 38x course:

MS&E 370	Current Topics in Strategy, Innovation and Entrepreneurship
MS&E 371	Innovation and Strategic Change
MS&E 372	Entrepreneurship Doctoral Research Seminar
MS&E 376	Strategy Doctoral Research Seminar
MS&E 384	Groups and Teams

Statistics and Research Methods (examples; three courses required)

MS&E 231	Introduction to Computational Social Science
PSYCH 252	Statistical Methods for Behavioral and Social Sciences
SOC 381	Sociological Methodology I: Introduction
SOC 382	Sociological Methodology II: Principles of Regression Analysis
SOC 383	Sociological Methodology III: Models for Discrete Outcomes
SOC 384	New Models and Methods in the Social Sciences

In their first two years in the Ph.D. program, all students are expected to work with faculty on research. To ensure an early start, all students must work at least 25% of their time in their first year as a research assistant with a faculty member. Students on fellowships can earn course credit for the work. With approval from the students' adviser, one quarter of the requirement may be fulfilled by working as a Course Assistant (CA).

Ph.D. students in organizational behavior must take 3 courses in statistics and research methods. Two of these courses must be statistics courses.

Ph.D. students are required to take a minimum of 2 advanced-content courses chosen with input from their adviser.

Students are expected to complete a yearly plan, of no more than two typed pages in length, detailing the student's plans for the next year in terms of education (e.g., courses and seminars), research (e.g., RAships), and teaching (e.g., TAships). This plan should be provided to the students' academic adviser for review no later than May 15 each calendar year.

Policy and Strategy

The Policy and Strategy (P&S) Area addresses policy and strategy questions in a variety of organizational and societal settings. In order to approach interdisciplinary research questions in application domains as diverse as energy, environment, health, information technology, innovation, and government regulation, P&S faculty members rely on a broad range of analytical and empirical tools, such as decision analysis, optimization and operations research methods, formal economic modeling, econometrics, case studies, and simulation. After having been exposed to foundational knowledge of economics, strategy, and organizational theory, doctoral students in the P&S Area can select from a variety of courses to deepen their understanding of the specific application domains. The P&S Area's mission is to provide a first-class learning and research environment preparing doctoral students for careers at research universities, government institutions, and in the private sector.

Foundation in Policy and Strategy (three):

MS&E 241	Economic Analysis

MS&E 376	Strategy Doctoral Research Seminar	
or MS&E 390	Doctoral Research Seminar in Health Systems Modeling	
or MS&E 391	Doctoral Research Seminar in Energy-Environmental Systems Modeling and Analysis	
Statistics and Research Methods (three):		
MS&E 201	Dynamic Systems	
MS&E 211	Introduction to Optimization	
or MS&E 211X	Introduction to Optimization (Accelerated)	
or MS&E 213	Introduction to Optimization Theory	
MS&E 212	Mathematical Programming and Combinatorial Optimization	
MS&E 221	Stochastic Modeling	
MS&E 223	Simulation	
MS&E 352	Decision Analysis II: Professional Decision Analysis	
PSYCH 252	Statistical Methods for Behavioral and Social Sciences	
SOC 383	Sociological Methodology III: Models for Discrete Outcomes	
SOC 384	New Models and Methods in the Social Sciences	

The student must select a program of four or more electives including disciplinary depth courses that reflects his or her interests and this approved by the Policy and Strategy faculty. The following are a number of sample programs:

Sample Program: Modeling Emphasis		
Research Methods		
MS&E 201	Dynamic Systems	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 311	Optimization	
MS&E 321	Stochastic Systems	
Domain Depth		
MS&E 292	Health Policy Modeling	
HRP 392	Analysis of Costs, Risks, and Benefits of Health Care	
Two of the following:		
MS&E 263	Healthcare Operations Management	
MS&E 463	Healthcare Systems Design	
HRP 256	Economics of Health and Medical Care	
HRP 263	Advanced Decision Science Methods and Modeling in Health	
Sample Program: Economics Emphasis		
Research Methods		
ECON 282	Contracts, Information, and Incentives	
ECON 286	Game Theory and Economic Applications	
Domain Depth		
ECON 257	Industrial Organization 1	
ECON 285	Matching and Market Design	
Sample Program: Strategy Emphasis		
Research Methods		
MS&E 408	Directed Reading and Research (Methods Apprenticeship)	
SOC 369	Social Network Methods	
Domain Depth		
MS&E 371	Innovation and Strategic Change	
MS&E 376	Strategy Doctoral Research Seminar	
SOC 314	Economic Sociology	

Sample Program: Risk Analysis Emphasis		
Research Methods		
MS&E 250A	Engineering Risk Analysis	
MS&E 251	Introduction to Stochastic Control with Applications	
MS&E 252	Decision Analysis I: Foundations of Decision Analysis	
MS&E 355	Influence Diagrams and Probabilistics Networks	
Domain Depth		
MS&E 250B	Project Course in Engineering Risk Analysis	
MS&E 353	Decision Analysis III: Frontiers of Decision Analysis	

Students are expected to complete a yearly plan, of no more than two typed pages in length, detailing the student's plans for the next year in terms of education (e.g., courses and seminars), research (e.g., RAships), and teaching (e.g., TAships). This plan should be provided to the students' academic adviser for review no later than May 15 each calendar year.

Policy and Strategy Qualifying Procedure

Advancement to Ph.D. candidacy is determined at the end of the student's second year of studies, based on the following three components:

1. the student's overall grade point average in the program (a GPA of 3.5 or higher is required);
2. a second-year research paper that is written by the student under the supervision of a faculty member, and that is presented to examining faculty members in the second year;
3. a written and an oral qualifying examination taken by the student in the spring quarter of the second year.

Ph.D. Minor in Management Science and Engineering

Students pursuing a Ph.D. in another department who wish to receive a Ph.D. minor in Management Science and Engineering should consult the MS&E student services office. A minor in MS&E may be obtained by completing 20 units of approved graduate-level MS&E courses, of which at least 6 units must be at the 300-level. Courses approved for the minor must form a coherent program, and include a breadth of courses from across the department. The program must include a minimum of 16 letter-graded units, and a minimum grade point average of 3.3 must be achieved in these courses.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (http://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a "credit" or "satisfactory" grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements
Grading

The Department of Management Science and Engineering counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory), which are normally offered for a letter grade, towards satisfaction of undergraduate degree requirements that otherwise require a letter grade.

Graduate Degree Requirements
Grading

The Department of Management Science and Engineering counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory), which are normally offered for a letter grade, towards satisfaction of graduate degree requirements that otherwise require a letter grade.

Graduate Advising Expectations

The Department of Management Science and Engineering is committed to providing academic advising in support of graduate student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Every student is assigned a faculty program adviser based on their stated area within the department. Faculty program advisers guide all students in key areas such as selecting courses, navigating policies and degree requirements, and exploring academic opportunities and professional pathways. Faculty program advisers additionally guide doctoral students in designing and conducting research, and development of teaching pedagogy. Faculty program advisers and students meet regularly, and the faculty program adviser may initiate a meeting with any student deemed to be in academic or research distress.

Doctoral students are encouraged to explore research activities in several research groups/labs during their first academic year, and to declare candidacy with a faculty dissertation adviser by the end of their second year in the program. Students may align with faculty across the department. This faculty dissertation adviser supersedes the faculty program adviser in assuming primary responsibility for advising and mentoring the student. When the faculty dissertation adviser is from outside our department, the student must also identify a faculty research adviser from MS&E to provide guidance on departmental requirements, core coursework, and opportunities. We encourage students to decide on their thesis committee within one year after start of candidacy in order to avail themselves of advice from multiple faculty members on the reading committee. MS&E conducts an annual review of all doctoral students' progress on degree progress milestones and research. Research input is solicited and an individual progress report spelling out the forthcoming milestones and any remedial action needed to maintain status is sent to the student via email.

Master students are encouraged to explore courses from across the department, and with multiple MS&E faculty members. Students may request a new adviser from MS&E Student Services staff as their interests clarify. Master's students are encouraged to meet with their adviser on a regular basis, to discuss their program goals and objectives, course selection, career goals, and academic and industry opportunities.

The MS&E student services staff are also an important part of the advising team. They inform students and advisers about University and department requirements, procedures, opportunities, and maintain the official records of adviser assignments and course approvals. Students are encouraged to talk with both the faculty program adviser and the student services office as they consider courses.

Students are active contributors to the advising relationship and we urge them to proactively seek academic and professional guidance and take responsibility for informing themselves of policies and degree requirements for their graduate program. We therefore expect students to read regular communication from the Registrar's office and Student Services regarding upcoming academic deadlines and policy updates, and to be responsible for complying with the university and program requirements.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Emeriti: (Professors) James L. Adams, Stephen R. Barley, Richard W. Cottle, B. Curtis Eaves, Warren H. Hausman, Frederick S. Hillier, Ronald A. Howard, Donald L. Iglehart, David G. Luenberger, Michael M. May, William J. Perry, David A. Thompson; *(Associate Professor)* Samuel S. Chiu; *(Professors, Research)* Siegfried S. Hecker, Walter Murray, Michael A. Saunders; *(Professor, Teaching)* Robert E. McGinn

Chair: Pamela J. Hinds

Director of Graduate Studies: Riitta Katila

Director of Undergraduate Studies: Ross D. Shachter

Professors: Nicholas Bambos, Jose Blanchet, Margaret L. Brandeau, Kathleen M. Eisenhardt, Kay Giesecke, Peter W. Glynn, Ashish Goel, Pamela J. Hinds, Ramesh Johari, Riitta Katila, M. Elisabeth Paté-Cornell, Amin Saberi, Robert I. Sutton, James L. Sweeney, Benjamin Van Roy, Yinyu Ye

Associate Professors: Itai Ashlagi, Charles E. Eesley, Ross D. Shachter, Edison T. S. Tse

Assistant Professors: Guillaume W. Basse, Sharad Goel, Irene Y. Lo, Markus Pelger, Aaron Sidford, Johan Ugander, Melissa A. Valentine

Professor (Research): John P. Weyant

Professor (Teaching): Thomas H. Byers

Professor of the Practice: Tina L. Seelig

Courtesy Professors: Stephen P. Boyd, Paul Milgrom, Douglas K. Owens, Alvin Roth

Courses

MS&E 20. Discrete Probability Concepts And Models. 4 Units.
Fundamental concepts and tools for the analysis of problems under uncertainty, focusing on structuring, model building, and analysis. Examples from legal, social, medical, and physical problems. Topics include axioms of probability, probability trees, belief networks, random variables, conditioning, and expectation. The course is fast-paced, but it has no prerequisites.

MS&E 33N. How We Decide: Social Choice in the Age of Algorithms. 4 Units.

The digital revolution arrived with the promise of improving human life, including through its ability to transform the way in which we make social decisions. But one of the most common critiques today is that unstructured interactions in social media and online platforms have actually set us back by spreading fake news, amplifying polarization, and failing to aggregate our diverse views and opinions into collective choices that move our society forward. nnHow should social decisions be made in the age of algorithms? We will approach this question through the lens of social choice theory, and connect this theory from economics and political science to the potential design of algorithms that aggregate our diverse preferences and information. We will review various systems of preference and information aggregation in small groups as well as large societies, including voting systems, bargaining protocols, and methods of deliberation. We will also describe decision making problems that arise in modern applications, such as distributed systems like blockchains and Wikipedia, as well as applications of topical interest such as the assignment of children to schools, the design of congressional districts, and the direct involvement of communities in participatory budgeting. nnA key objective of the class will be to get students to think about how social choice theory can be applied to real-life problems through the design of algorithms. There are no prerequisites, but students should come prepared to use high school level mathematics and deductive reasoning.
Same as: POLISCI 33N

MS&E 52. Introduction to Decision Making. 3-4 Units.

How to ensure focus, discipline, and passion when making important decisions. Comprehensive examples illustrate Decision Analysis fundamentals. Consulting case studies highlight practical solutions for real decisions. Topics: declaring when and how to make a decision, framing and structuring the decision basis, defining values and preferences, creating alternative strategies, assessing unbiased probabilistic judgments, developing appropriate risk/reward and portfolio models, evaluating doable strategies across the range of uncertain future scenarios, analyzing relevant sensitivities, determining the value of additional information, and addressing the qualitative aspects of communication and commitment to implementation. Required for all students are three problem sets, three in-class exams, and a take-home final exam. Students taking the course for 4 units of credit must also complete and present a team project that analyzes a decision currently being made by an organization of their choice. Not intended for MS&E majors.

MS&E 73SI. ASES Entrepreneurship Bootcamp. 1 Unit.

Practicum designed to introduce freshmen and sophomores to design thinking and entrepreneurship. Students learn how to conduct user interviews, identifynmarket opportunities, find product-market fit, and develop pitch decks. Concludes with a fast-paced problem-solving session and a 'demo day'-style pitch event, in which students pitch their projects to Silicon Valley venture capitalists (VCs), entrepreneurs, and investors. Students interact with highly experienced speakers, gain mentorship from upperclassmen and VCs, and develop a worldwide entrepreneurship network, both in and out of Silicon Valley. No background knowledge or experience is necessary, only willingness to work hard, get your hands dirty, and learn. Limited enrollment. Application required: https://tinyurl.com/bootcamp2021.

MS&E 79SI. Values and Principles in the Workplace: PEAK Fellows. 1 Unit.

Extension of the PEAK Fellows program. Serves as an opportunity for students to explore what it means to create and work for principled, entrepreneurial businesses. Through readings and peer-led discussions, students will definentheir personal set of values and principles to serve as a guide in shaping future teams and workplaces. Prerequisite: admission to PEAK Fellows Program. See https://stvp.stanford.edu/peak-fellows.

MS&E 92. Introduction to Health Policy Modeling. 3 Units.

The application of mathematical models to problems in health policy. Estimating the benefits, harms, costs, and uncertainties of a health policy or intervention. Understanding concepts of cost-effectiveness analysis. Developing decision models that capture the tradeoffs between policy alternatives. Examples include disease screening, prevention, and treatment, combating the opioid epidemic, and protecting the blood supply. As a course project, students will develop a simple decision model to evaluate a current health policy problem.

MS&E 92Q. International Environmental Policy. 3 Units.

Preference to sophomores. Science, economics, and politics of international environmental policy. Current negotiations on global climate change, including actors and potential solutions. Sources include briefing materials used in international negotiations and the U.S. Congress.

MS&E 108. Senior Project. 5 Units.

Restricted to MS&E majors in their senior year. Students carry out a major project in groups of four, applying techniques and concepts learned in the major. Project work includes problem identification and definition, data collection and synthesis, modeling, development of feasible solutions, and presentation of results. Service Learning Course (certified by Haas Center). Satisfies the WIM requirement for MS&E majors.

MS&E 111. Introduction to Optimization. 3-4 Units.

Formulation and computational analysis of linear, quadratic, and other convex optimization problems. Applications in machine learning, operations, marketing, finance, and economics. Prerequisite: CME 100 or MATH 51.
Same as: ENGR 62, MS&E 211

MS&E 111X. Introduction to Optimization (Accelerated). 3-4 Units.

Optimization theory and modeling. The role of prices, duality, optimality conditions, and algorithms in finding and recognizing solutions. Perspectives: problem formulation, analytical theory, computational methods, and recent applications in engineering, finance, and economics. Theories: finite dimensional derivatives, convexity, optimality, duality, and sensitivity. Methods: simplex and interior-point, gradient, Newton, and barrier. Prerequisite: CME 100 or MATH 51 or equivalent.
Same as: ENGR 62X, MS&E 211X

MS&E 112. Mathematical Programming and Combinatorial Optimization. 3 Units.

Combinatorial and mathematical programming (integer and non-linear) techniques for optimization. Topics: linear program duality and LP solvers; integer programming; combinatorial optimization problems on networks including minimum spanning trees, shortest paths, and network flows; matching and assignment problems; dynamic programming; linear approximations to convex programs; NP-completeness. Hands-on exercises. Prerequisites: basic concepts in linear algebra, probability theory, CS 106A or X.
Same as: MS&E 212

MS&E 120. Introduction to Probability. 4 Units.

Probability is the foundation behind many important disciplines including statistics, machine learning, risk analysis, stochastic modeling and optimization. This course provides an in-depth undergraduate-level introduction to fundamental ideas and tools of probability. Topics include: the foundations (sample spaces, random variables, probability distributions, conditioning, independence, expectation, variance), a systematic study of the most important univariate and multivariate distributions (Normal, Multivariate Normal, Binomial, Poisson, etc...), as well as a peek at some limit theorems (basic law of large numbers and central limit theorem) and, time permitting, some elementary markov chain theory. Prerequisite: CME 100 or MATH 51.

MS&E 121. Introduction to Stochastic Modeling. 4 Units.

Stochastic processes and models in operations research. Discrete and continuous time parameter Markov chains. Queuing theory, inventory theory, simulation. Prerequisite: 120, 125, or equivalents.

MS&E 125. Introduction to Applied Statistics. 4 Units.
An increasing amount of data is now generated in a variety of disciplines, ranging from finance and economics, to the natural and social sciences. Making use of this information, however, requires both statistical tools and an understanding of how the substantive scientific questions should drive the analysis. In this hands-on course, we learn to explore and analyze real-world datasets. We cover techniques for summarizing and describing data, methods for statistical inference, and principles for effectively communicating results. Prerequisite: 120, CS 106A, or equivalents.

MS&E 130. Information Networks and Services. 3 Units.
Architecture of the Internet and performance engineering of computer systems and networks. Switching, routing and shortest path algorithms. Congestion management and queueing networks. Peer-to-peer networking. Wireless and mobile networking. Information service engineering and management. Search engines and recommendation systems. Reputation systems and social networking technologies. Security and trust. Information markets. Select special topics and case studies. Prerequisites: 111, 120, and CS 106A.

MS&E 135. Networks. 3 Units.
This course provides an introduction to how networks underly our social, technological, and natural worlds, with an emphasis on developing intuitions for broadly applicable concepts in network analysis. The course will include: an introduction to graph theory and graph concepts; social networks; information networks; the aggregate behavior of markets and crowds; network dynamics; information diffusion; the implications of popular concepts such as "six degrees of separation", the "friendship paradox", and the "wisdom of crowds".

MS&E 140. Accounting for Managers and Entrepreneurs. 3-4 Units.
Non-majors and minors who have taken or are taking elementary accounting should not enroll. Introduction to accounting concepts and the operating characteristics of accounting systems. The principles of financial and cost accounting, design of accounting systems, techniques of analysis, and cost control. Interpretation and use of accounting information for decision making. Designed for the user of accounting information and not as an introduction to a professional accounting career. Enrollment limited. Admission by order of enrollment.
Same as: MS&E 240

MS&E 145. Introduction to Finance and Investment. 4 Units.
Introduction to modern quantitative finance and investments. The course focuses on the basic principles underlying financial decision making which are applicable to all forms of investment: stocks, bonds, real estate, corporate finance, etc., and how they are applied in practice. Topics: interest rates; evaluating investments: present value and internal rate of return; fixed-income markets: bonds, yield, duration, portfolio immunization; term structure of interest rates; measuring risk: volatility, value at risk, conditional value at risk; designing optimal security portfolios; the capital asset pricing model, arbitrage pricing theory. Group projects involving financial market data. No prior knowledge of finance required. Prerequisite: basic preparation in probability, statistics, and optimization.

MS&E 146. Corporate Financial Management. 3-4 Units.
Key functions of finance in both large and small companies, and the core concepts and key analytic tools that provide their foundation. Making financing decisions, evaluating investments, and managing cashflow, profitability and risk. Designing performance metrics to effectively measure and align the activities of functional groups and individuals within the firm. Structuring relationships with key customers, partners and suppliers. Prerequisite: 145, 245A, or equivalent.
Same as: MS&E 249

MS&E 148. Ethics of Finance. 2 Units.
Explores the ethical reasoning needed to make banking, insurance and financial services safer, fairer and more positively impactful. Weighs tradeoffs in how money is created, privileging some, under-privileging others, using market mechanisms for transforming and trading financial risk, return, maturity and asset types. Technology is changing banks, financial markets, insurance and money. Like technology for medicine, finance is being rebuilt as machine learned code, algorithmic investment rules and regulatory monitoring. Risk models can be built to detect fraud and ethical lapses, or to open doors for them. Investment valuation models can optimize short term or long term returns, by optimizing or ignoring environmental and social impacts. Transparency or opacity can be the norm. Transforming finance through engineering requires finding, applying and evolving codes of professional conduct to make sure that engineers use their skills within legal and ethical norms. Daily, financial engineers focus on two horizons: on the floor, we stand on the bare minimum standards of conduct, and on the ceiling, we aim for higher ethical goals that generate discoveries celebrated though individual fulfillment and TED Talks. Stanford engineers, computer scientists, data scientists, mathematicians and other professionals are building systems for lending, investment and portfolio management decisions that determine future economic and social growth. This course uses the case method to preview intersecting codes of conduct, legal hurdles and ethical impact opportunities, and creates as a safe academic setting for seeing career-limiting ethical stop signs (red lights) and previewing ¿what¿s my life all about¿ events, as unexpected threats or surprising ah-ha moments. Guest speakers will highlight real life situations, lawsuits and other events where ethics of financial engineering was a predominant theme, stumbling block or humanitarian opportunity.

MS&E 149. Hedge Fund Management. 1-2 Unit.
Introduction to hedge fund management. Students actively manage the $1MM Stanford Kudla Fund employing Equity Long/Short, Macro and Quantitative Investment Strategies. Modeled after a hedge fund partnership culture, participation involves significant time commitment, passion for investing, and uncommon teamwork and communication skills. Open to advanced undergraduate and graduate students with continuing participation expectation. Limited to 12 students. Enrollment by application and permission of Instructor.May be repeat for credit.

MS&E 152. Introduction to Decision Analysis. 3-4 Units.
How to make good decisions in a complex, dynamic, and uncertain world. People often make decisions that on close examination they regard as wrong. Decision analysis uses a structured conversation based on actional thought to obtain clarity of action in a wide variety of domains. Topics: distinctions, possibilities and probabilities, relevance, value of information and experimentation, relevance and decision diagrams, risk attitude. Prerequisites: high school algebra and basic spreadsheet skills.

MS&E 175. Innovation, Creativity, and Change. 3-4 Units.
Problem solving in organizations; creativity and innovation skills; thinking tools; creative organizations, teams, individuals, and communities. Limited enrollment.

MS&E 178. The Spirit of Entrepreneurship. 2 Units.
Is there more to entrepreneurship than inventing the better mouse trap? This course uses the speakers from the Entrepreneurial Thought Leader seminar (MS&E472) to drive research and discussion about what makes an entrepreneur successful. Topics include venture financing, business models, and interpersonal dynamics in the startup environment. Students meet before and after MS&E 472 to prepare for and debrief after the sessions. Enrollment limited to 60 students. Application available at first class session.

MS&E 180. Organizations: Theory and Management. 4 Units.
For undergraduates only; preference to MS&E majors. Classical and contemporary organization theory; the behavior of individuals, groups, and organizations. Limited enrollment. Students must attend and complete an application at the first class session.

MS&E 182A. Leading Organizational Change. 4 Units.
This course blends lecture, case discussions, readings about pertinent research, and hands-on projects to learn about what leaders and senior teams can do to bring about broad-based change in complex organizations. Topics include the role of the CEO and the senior team, organizational growth and scaling, organizational culture, organizational design, and innovation. The course focuses in particular on the causes and cures for dysfunctional organizational friction, and the related question what organizations ought to make difficult or impossible to do. Limited enrollment. For juniors and seniors, with preference given to students who have taken MS&E 180.

MS&E 182B. Leading Organizational Change II. 4 Units.
Project-based course for students who wish to explore focused intellectual topics or applied questions pertinent to leading organizational change. Work is done in groups of three to four students that are formed prior to the start of class. Prerequisite: At least one student in each group shall have completed MS&E 182A.

MS&E 184. Future of Work: Issues in Organizational Learning and Design. 4 Units.
For over 100 years much of our economic activity was accomplished in bureaucratic organizations. Many theories of management and work design were developed for those settings. Today, economic activities are being reconfigured using new technologies such as online labor markets, crowdsourcing platforms, data, automation, and robotics. We will update and extend theories of management and work design, building from these original theories to explore how work and organizations are changing. Enrollment Limited. Prerequisite: 180.

MS&E 185. Global Work. 4 Units.
Issues, challenges, and opportunities facing workers, teams, and organizations working across national boundaries. Topics include geographic distance, time zones, language and cultural differences, technologies to support distant collaboration, team dynamics, and corporate strategy. Limited enrollment. Recommended: 180.

MS&E 188. Organizing for Good. 4 Units.
Grand challenges of our time will demand entirely new ways of thinking about when, how, and under what conditions organizations are "doing good" and what effects that has. Focus is on the role of organizations in society, the ways that organizations can "do good," the challenges organizations face in attempting to "do good", limitations to current ways of organizing, alternative ways to organize and lead organizations that are "good," and the role and responsibilities of individuals in organizations. Students will reflect on and refine their own values and purpose to identify ways in which they can ¿do good.¿ This course has been designated as a Cardinal Course by the Haas Center for Public Service.

MS&E 193. Technology and National Security: Past, Present, and Future. 3-4 Units.
Explores the relation between technology, war, and national security policy from early history to modern day, focusing on current U.S. national security challenges and the role that technology plays in shaping our understanding and response to these challenges. Topics include the interplay between technology and modes of warfare; dominant and emerging technologies such as nuclear weapons, cyber, sensors, stealth, and biological; security challenges to the U.S.; and the U.S. response and adaptation to new technologies of military significance.
Same as: INTLPOL 256, MS&E 293

MS&E 201. Dynamic Systems. 3 Units.
Dynamic System: Provides a solid foundation in understanding and modeling the dynamics of change. Differential equations are used as a mathematical language to facilitate discussions on dynamic phenomena. Develop mathematical tools to analyze the dynamic models, and use such tools to think about and manage the dynamics of change. The course covers the notions of equilibrium, stability, growth and limit cycle of dynamic systems and discussed in terms of examples in product market penetration, business competition, ecology and spread of epidemics. The course gives an introduction to Catastrophe Theory, which provides a mathematical model for certain discontinuous phenomena like the crash of the stock market and the extinction of species. The course concludes with optimal control theory and differential games. Optimal economic growth model and optimal dynamic pricing are used to illustrate how the optimal control theory is applied to economic modeling analysis and business application. A platform competition model is used to illustrate how different games can be used to do dynamic competitive analysis. Required a project in dynamic system modeling. Pre-requisite: calculus and linear algebra.

MS&E 202. Topics in Management Science and Engineering. 1 Unit.
Topics in Management Science and Engineering. Restricted to MS&E MS students.

MS&E 208A. Practical Training. 1 Unit.
MS&E students obtain employment in a relevant industrial or research activity to enhance professional experience, consistent with the degree program they are pursuing. Students submit a statement showing relevance to degree program along with offer letter to the Student Services Office before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. Students may take each course once. To receive a permission code to enroll, please submit this form: https://forms.gle/bFtMtwJMyaCJRhkf8 with statement and offer letter.

MS&E 208B. Practical Training. 1 Unit.
MS&E students obtain employment in a relevant industrial or research activity to enhance professional experience, consistent with the degree program they are pursuing. Students submit a statement showing relevance to degree program along with offer letter to the Student Services Office before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. Students may take each course once. To receive a permission code to enroll, please submit this form: https://forms.gle/bFtMtwJMyaCJRhkf8 with statement and offer letter.

MS&E 208C. Practical Training. 1 Unit.
MS&E students obtain employment in a relevant industrial or research activity to enhance professional experience, consistent with the degree program they are pursuing. Students submit a statement showing relevance to degree program along with offer letter to the Student Services Office before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. Students may take each course once. To receive a permission code to enroll, please submit this form: https://forms.gle/bFtMtwJMyaCJRhkf8 with statement and offer letter.

MS&E 208D. Practical Training. 1 Unit.
MS&E students obtain employment in a relevant industrial or research activity to enhance professional experience, consistent with the degree program they are pursuing. Students submit a statement showing relevance to degree program along with offer letter to the Student Services Office before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. Students may take each course once. To receive a permission code to enroll, please submit this form: https://forms.gle/bFtMtwJMyaCJRhkf8 with statement and offer letter.

MS&E 208E. Part-Time Practical Training. 1 Unit.
MS&E students obtain employment in a relevant industrial or research activity to enhance professional experience, consistent with the degree program they are pursuing. Students submit a statement showing relevance to degree program along with offer letter to the Student Services Office before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. Course may be repeated for credit. To receive a permission code to enroll, please submit this form: https://forms.gle/bFtMtwJMyaCJRhkf8 with statement and offer letter.

MS&E 211. Introduction to Optimization. 3-4 Units.
Formulation and computational analysis of linear, quadratic, and other convex optimization problems. Applications in machine learning, operations, marketing, finance, and economics. Prerequisite: CME 100 or MATH 51.
Same as: ENGR 62, MS&E 111

MS&E 211X. Introduction to Optimization (Accelerated). 3-4 Units.
Optimization theory and modeling. The role of prices, duality, optimality conditions, and algorithms in finding and recognizing solutions. Perspectives: problem formulation, analytical theory, computational methods, and recent applications in engineering, finance, and economics. Theories: finite dimensional derivatives, convexity, optimality, duality, and sensitivity. Methods: simplex and interior-point, gradient, Newton, and barrier. Prerequisite: CME 100 or MATH 51 or equivalent.
Same as: ENGR 62X, MS&E 111X

MS&E 212. Mathematical Programming and Combinatorial Optimization. 3 Units.
Combinatorial and mathematical programming (integer and non-linear) techniques for optimization. Topics: linear program duality and LP solvers; integer programming; combinatorial optimization problems on networks including minimum spanning trees, shortest paths, and network flows; matching and assignment problems; dynamic programming; linear approximations to convex programs; NP-completeness. Hands-on exercises. Prerequisites: basic concepts in linear algebra, probability theory, CS 106A or X.
Same as: MS&E 112

MS&E 213. Introduction to Optimization Theory. 3 Units.
Introduction of core algorithmic techniques and proof strategies that underlie the best known provable guarantees for minimizing high dimensional convex functions. Focus on broad canonical optimization problems and survey results for efficiently solving them, ultimately providing the theoretical foundation for further study in optimization. In particular, focus will be on first-order methods for both smooth and non-smooth convex function minimization as well as methods for structured convex function minimization, discussing algorithms such as gradient descent, accelerated gradient descent, mirror descent, Newton's method, interior point methods, and more. Prerequisite: multivariable calculus and linear algebra.
Same as: CS 269O

MS&E 220. Probabilistic Analysis. 3-4 Units.
Concepts and tools for the analysis of problems under uncertainty, focusing on structuring, model building, and analysis. Examples from legal, social, medical, and physical problems. Topics include axioms of probability, probability trees, random variables, distributions, conditioning, expectation, change of variables, and limit theorems. Prerequisite: multivariable calculus and some linear algebra.

MS&E 221. Stochastic Modeling. 3 Units.
Focus is on time-dependent random phenomena. Topics: discrete time Markov chains, Markov jump processes, queueing theory, and applications. Emphasis on model-building, computation, and related calibration and statistical issues. Prerequisite: 220 or equivalent, or consent of instructor.

MS&E 223. Simulation. 3 Units.
Discrete-event systems, generation of uniform and non-uniform random numbers, Monte Carlo methods, programming techniques for simulation, statistical analysis of simulation output, efficiency-improvement techniques, decision making using simulation, applications to systems in computer science, engineering, finance, and operations research. Prerequisites: working knowledge of a programming language such as C, C++, Java, Python, or FORTRAN; calculus-base probability; and basic statistical methods.

MS&E 226. Fundamentals of Data Science: Prediction, Inference, Causality. 3 Units.
This course is about understanding "small data": these are datasets that allow interaction, visualization, exploration, and analysis on a local machine. The material provides an introduction to applied data analysis, with an emphasis on providing a conceptual framework for thinking about data from both statistical and machine learning perspectives. Topics will be drawn from the following list, depending on time constraints and class interest: approaches to data analysis: statistics (frequentist, Bayesian) and machine learning; binary classification; regression; bootstrapping; causal inference and experimental design; multiple hypothesis testing. Class lectures will be supplemented by data-driven problem sets and a project. Prerequisites: CME 100 or MATH 51; 120, 220 or STATS 116; experience with R at the level of CME/STATS 195 or equivalent.

MS&E 230. Market Design for Engineers. 3 Units.
Markets are everywhere around us but don't always achieve desired goals. Market failures occur due to a variety of frictions and need design to be fixed. The design of marketplace varies depending on the type of goods and possible transactions. This course will cover methods and classic results to analyze the behavior of a marketplace, whether it is successful and how to fix it, building especially on game theoretic tools. The course will further explore the trade-offs between efficiency and equitable outcomes and how to reach desired outcomes. Applications include matching students to schools, college admissions and the failure the desire to balance equity and merit, assigning vaccines, assigning interns to hospitals, assigning organs to patients, auction designs and pricing, information design, online platforms, allocation of food, transportation, and emissions. The course is intended for undergraduates, masters, but also PhD students who are interested in exposure to market design. Prerequisites: basic mathematical maturity at the level of Math 51, and probability at the level of MS&E 120, 220 or EE 178.

MS&E 231. Introduction to Computational Social Science. 3 Units.
With a vast amount of data now collected on our online and offline actions -- from what we buy, to where we travel, to who we interact with -- we have an unprecedented opportunity to study complex social systems. This opportunity, however, comes with scientific, engineering, and ethical challenges. In this hands-on course, we develop ideas from computer science and statistics to address problems in sociology, economics, political science, and beyond. We cover techniques for collecting and parsing data, methods for large-scale machine learning, and principles for effectively communicating results. To see how these techniques are applied in practice, we discuss recent research findings in a variety of areas. Prerequisites: introductory course in applied statistics, and experience coding in R, Python, or another high-level language.
Same as: SOC 278

MS&E 232. Introduction to Game Theory. 3 Units.
Examines foundations of strategic environments with a focus on game theoretic analysis. Provides a solid background to game theory as well as topics in behavioral game theory and the design of marketplaces. Introduction to analytic tools to model and analyze strategic interactions as well as engineer the incentives and rules in marketplaces to obtain desired outcomes. Technical material includes non-cooperative and cooperative games, behavioral game theory, equilibrium analysis, repeated games, social choice, mechanism and auction design, and matching markets. Exposure to a wide range of applications. Lectures, presentations, and discussion. Prerequisites: basic mathematical maturity at the level of Math 51, and probability at the level of MS&E 120 or EE 178.

MS&E 232H. Introduction to Game Theory. 3 Units.
Game theory uses mathematical models to study strategic interactions and situations of conflict and cooperation between rational decision-makers. This course provides an accelerated introduction to tools, models and computation in non-cooperative and cooperative game theory. Technical material includes normal and extensive form games, zero-sum games, Nash equilibrium and other solution concepts, repeated games, games with incomplete information, auctions and mechanism design, the core, and Shapley value. Exploration of applications of this material through playing stylized in-class and class-wide games and analyzing real-life applications. Prerequisites: mathematical maturity at the level of MATH51, and probability at the level of MS&E 120, or equivalent.
Same as: Accelerated

MS&E 234. Data Privacy and Ethics. 3 Units.
This course engages with ethical challenges in the modern practice of data science. The three main focuses are data privacy, personalization and targeting algorithms, and online experimentation. The focus on privacy raises both practical and theoretical considerations. As part of the module on experimentation, students are required to complete the Stanford IRB training for social and behavioral research. The course assumes a strong technical familiarity with the practice of machine learning and and data science. Recommended: 221, 226, CS 161, or equivalents.

MS&E 235. Network Structure and Epidemics. 3 Units.
Explores the underlying network structure of social, economic, and technological world using techniques from graph theory and economics, as well as machine learning and data analysis. Prerequisite: 226, CME 195, or equivalents. Recommended: 212.
Same as: MS&E 337

MS&E 240. Accounting for Managers and Entrepreneurs. 3-4 Units.
Non-majors and minors who have taken or are taking elementary accounting should not enroll. Introduction to accounting concepts and the operating characteristics of accounting systems. The principles of financial and cost accounting, design of accounting systems, techniques of analysis, and cost control. Interpretation and use of accounting information for decision making. Designed for the user of accounting information and not as an introduction to a professional accounting career. Enrollment limited. Admission by order of enrollment.
Same as: MS&E 140

MS&E 241. Economic Analysis. 3-4 Units.
Principal methods of economic analysis of the production activities of firms, including production technologies, cost and profit, and perfect and imperfect competition; individual choice, including preferences and demand; and the market-based system, including price formation, efficiency, and welfare. Practical applications of the methods presented. Recommended: 211, ECON 50.

MS&E 243. Energy and Environmental Policy Analysis. 3 Units.
Concepts, methods, and applications. Energy/environmental policy issues such as automobile fuel economy regulation, global climate change, research and development policy, and environmental benefit assessment. Group project. Prerequisite: MS&E 241 or ECON 50.

MS&E 245A. Investment Science. 3-4 Units.
Basic concepts of modern quantitative finance and investments. Focus is on the financial theory and empirical evidence that are useful for investment decisions. Topics: basic interest rates; evaluating investments: present value and internal rate of return; fixed-income markets: bonds, yield, duration, portfolio immunization; term structure of interest rates; measuring risk: volatility and value at risk; designing optimal portfolios; risk-return tradeoff: capital asset pricing model and extensions. No prior knowledge of finance is required. Concepts are applied in a stock market simulation with real data. Prerequisite: basic preparation in probability, statistics, and optimization.

MS&E 245B. Advanced Investment Science. 3 Units.
Formerly MS&E 342. Topics: forwards and futures contracts, continuous and discrete time models of stock price behavior, geometric Brownian motion, Ito's lemma, basic options theory, Black-Scholes equation, advanced options techniques, models and applications of stochastic interest rate processes, and optimal portfolio growth. Computational issues and general theory. Teams work on independent projects. Prerequisite: 245A.

MS&E 246. Financial Risk Analytics. 3 Units.
Practical introduction to financial risk analytics. The focus is on data-driven modeling, computation, and statistical estimation of credit and market risks. Case studies based on real data will be emphasized throughout the course. Topics include mortgage risk, asset-backed securities, commercial lending, consumer delinquencies, online lending, derivatives risk. Tools from machine learning and statistics will be developed. Data sources will be discussed. The course is intended to enable students to design and implement risk analytics tools in practice. Prerequisites: MS&E 245A or similar, some background in probability and statistics, working knowledge of R, Matlab, or similar computational/statistical package.

MS&E 249. Corporate Financial Management. 3-4 Units.
Key functions of finance in both large and small companies, and the core concepts and key analytic tools that provide their foundation. Making financing decisions, evaluating investments, and managing cashflow, profitability and risk. Designing performance metrics to effectively measure and align the activities of functional groups and individuals within the firm. Structuring relationships with key customers, partners and suppliers. Prerequisite: 145, 245A, or equivalent.
Same as: MS&E 146

MS&E 250A. Engineering Risk Analysis. 3 Units.
The techniques of analysis of engineering systems for risk management decisions involving trade-offs (technical, human, environmental aspects). Elements of decision analysis; probabilistic risk analysis (fault trees, event trees, systems dynamics); economic analysis of failure consequences (human safety and long-term economic discounting); and case studies such as space systems, nuclear power plants, and medical systems. Public and private sectors. Prerequisites: probability, decision analysis, stochastic processes, and convex optimization.

MS&E 250B. Project Course in Engineering Risk Analysis. 3 Units.
Students, individually or in groups, choose, define, formulate, and resolve a real risk management problem, preferably from a local firm or institution. Oral presentation and report required. Scope of the project is adapted to the number of students involved. Three phases: risk assessment, communication, and management. Emphasis is on the use of probability for the treatment of uncertainties and sensitivity to problem boundaries. Limited enrollment. Prerequisites: MS&E 250A and consent of instructor.

MS&E 251. Introduction to Stochastic Control with Applications. 3 Units.
Focuses on conceptual foundation and algorithmic methodology of Dynamic Programming and Stochastic Control with applications to engineering, operations research, management science and other fields. Elaborates on the concept of probing, learning and control of stochastic systems, and addresses the practical application of the concept and methodology through the use of approximations. Prerequisites: 201, 221, or equivalents.
Same as: EE 266

MS&E 252. Decision Analysis I: Foundations of Decision Analysis. 3-4 Units.
Coherent approach to decision making, using the metaphor of developing a structured conversation having desirable properties, and producing actional thought that leads to clarity of action. Socratic instruction; computational problem sessions. Emphasis is on creation of distinctions, representation of uncertainty by probability, development of alternatives, specification of preference, and the role of these elements in creating a normative approach to decisions. Information gathering opportunities in terms of a value measure. Relevance and decision diagrams to represent inference and decision. Principles are applied to decisions in business, technology, law, and medicine. Prerequisite: 220 or equivalent.

MS&E 254. The Ethical Analyst. 1-3 Unit.
We raise awareness of ethically sensitive situations and provide principles and tools for forming coherent ethical judgments regarding individual, government, or organizational actions. Students learn ethical theories and tools from which they create their own personal ethical codes and test them against established ethical principles, class discussion, homework, class presentations, and situations from work and life. The course addresses personal life, human action and relations in society, technology, medicine, coercion, harming, stealing, imposition of risk, deception, and other ethical issues.

MS&E 256. Technology Assessment and Regulation of Medical Devices. 3 Units.
Regulatory approval and reimbursement for new health technologies are critical success factors for product commercialization. This course explores the regulatory and payer environment in the U.S. and abroad, as well as common methods of health technology assessment. Students will learn frameworks to identify factors relevant to the adoption of new health technologies, and the management of those factors in the design and development phases of bringing a product to market through case studies, guest speakers from government (FDA) and industry, and a course project.
Same as: BIOE 256

MS&E 256A. Technology Assessment and Regulation of Medical Devices. 1 Unit.
Regulatory approval and reimbursement for new medical technologies as a key component of product commercialization. The regulatory and payer environment in the U.S. and abroad, and common methods of health technology assessment. Framework to identify factors relevant to adoption of new medical devices, and the management of those factors in the design and development phases. Case studies; guest speakers from government (FDA) and industry.

MS&E 260. Introduction to Operations Management. 3 Units.
Operations management focuses on the effective planning, scheduling, and control of manufacturing and service entities. This course introduces students to a broad range of key issues in operations management. Topics include determination of optimal facility location, production planning, optimal timing and sizing of capacity expansion, and inventory control. Prerequisites: basic knowledge of Excel spreadsheets, probability.

MS&E 263. Healthcare Operations Management. 3 Units.
US health care spending is approximately 18% of GDP, growing rapidly, and driven in large part by prices and waste rather than quality and access. New approaches for improving health care delivery are urgently needed. This class focuses on the use of analytical tools to support efficient health care delivery. Topics include case studies on capacity planning, resource allocation, and scheduling. Methods include queueing, optimization, and simulation. Prerequisites: basic knowledge of Excel, probability, and optimization. For students in the Schools of Medicine, Business, and Law the course includes a variant of the curriculum with less emphasis on the technical material.
Same as: PEDS 263

MS&E 265. Introduction to Product Management. 3 Units.
Product Managers define a product's functional requirements and lead cross functional teams responsible for development, launch, and ongoing improvement. Uses a learning-by-doing approach covering the following topics: changing role of a PM at different stages of the product life cycle; techniques to understand customer needs and validate demand; user experience design and testing; role of detailed product specifications; waterfall and agile methods of software development. Group projects involve the specification of a technology product though the skills taught are useful for a variety of product roles. No prior knowledge of design, engineering, or computer science required. Limited enrollment.

MS&E 267. Service Operations and the Design of Marketplaces. 3 Units.
The service sector accounts for approximately 80% of GDP and employment in the US. It is therefore imperative to develop efficient and effective operations of services. The management of service operations can require quite different constraints and objectives than manufacturing operations. The course examines both traditional and new approaches for achieving operational competitiveness in service businesses including (online) marketplaces. Topics include the service concept and operations strategy, the design of effective service delivery systems, capacity management, queuing, quality, revenue management as well as concepts from the design of marketplaces such as matching, congestion and auctions.

MS&E 270. Strategy in Technology-Based Companies. 3-4 Units.
For graduate students only. Introduction to the basic concepts of strategy, with emphasis on high technology firms. Topics: competitive positioning, resource-based perspectives, co-opetition and standards setting, and complexity/evolutionary perspectives. Limited enrollment. Students must attendnand complete an application at the first class session.

MS&E 271. Global Entrepreneurial Marketing. 3-4 Units.
Introduces core marketing concepts to bring a new product or service to market and build for its success. Geared to both entrepreneurs and intrapreneurs alike who have a passion for innovation. Course themes include: Identifying markets and opportunities, defining the offering and customer experience, creating demand, generating revenue, and measuring success. The team-based final focuses on developing a go-to-market strategy based on concepts from the course. Learn about managing self, building culture and teams, strategically think about your contribution as entrepreneur or intrapreuneur to an organization, community or society at large. Highly experiential and project based. Limited enrollment.

MS&E 272. Entrepreneurship without Borders. 3-4 Units.
How and why does access to entrepreneurial opportunities vary by geographic borders, racial/gender borders, or other barriers created by where or who you are? What kinds of inequalities are created by limited access to capital or education and what role does entrepreneurship play in upward mobility in societies globally? What are the unique issues involved in creating a successful startup in Europe, Latin America, Africa, China or India? What is entrepreneurial leadership in a venture that spans country borders? Is Silicon Valley-style entrepreneurship possible in other places? How does an entrepreneur act differently when creating a company in a less-developed institutional environment? Learn through forming teams, a mentor-guided startup project focused on developing students' startups in international markets, case studies, research on the unequal access to wealth creation and innovation via entrepreneurship, while also networking with top entrepreneurs and venture capitalists who work across borders.

MS&E 273. Venture Creation for the Real Economy. 3-4 Units.
A project-based course where teams of 4 prepare their entrepreneurial venture for fundraising and launch. Students acquire the experience of an early-stage entrepreneur as they progress through stages of team building, opportunity assessment, product-market fit analysis, business model architecture, go-to market strategy, product planning, financial modelling, and fundraising planning. The course structure includes weekly workshops, guest presentations from seasoned entrepreneurs, weekly meetings with the teaching team, and one-on-one support from a dedicated industry mentor. The experience culminates in three pitches to panels of VCs and other industry experts. By the end of the class, successful students will be equipped with the knowledge and network to create impactful business ideas, many of which have been launched from this class. Open to all Stanford students. No prerequisites. For more information, visit the course website: https://web.stanford.edu/class/msande273. Enrolment by application: https://web.stanford.edu/class/msande273/apply.
Same as: CEE 246

MS&E 274. Dynamic Entrepreneurial Strategy. 3 Units.
Dynamic Entrepreneurial Strategy: Primarily for graduate students. How entrepreneurial strategy focuses on creating structural change or responding to change induced externally. Grabber-holder dynamics as an analytical framework for developing entrepreneurial strategy to increase success in creating and shaping the diffusion of new technology or product innovation dynamics. Topics: First mover versus follower advantage in an emerging market; latecomer advantage and strategy in a mature market; strategy to break through stagnation; and strategy to turn danger into opportunity. Modeling, case studies, and term project.

MS&E 275. Intelligent Growth in Startups. 3 Units.
Explore the foundational and strategic elements needed for startups to be designed for "venture scale" at inception. Themes include controversial and disruptive insights, competitive analysis, network effects, organizational design, and capital deployment. Case studies, expert guests, and experiential learning projects will be used. Primarily for graduate students. Limited enrollment. Admission by application. Recommended: basic accounting.

MS&E 276. Entrepreneurial Management and Finance. 3 Units.
For graduate students only, with a preference for engineering and science majors. Emphasis on managing high-growth, early-stage enterprises, especially those with innovation-based products and services. Students work in teams to develop skills and approaches necessary to becoming effective entrepreneurial leaders and managers. Topics include assessing risk, understanding business models, analyzing key operational metrics, modeling cash flow and capital requirements, evaluating sources of financing, structuring and negotiating investments, managing organizational culture and incentives, managing the interplay between ownership and growth, and handling adversity and failure. Limited enrollment. Admission by application. Prerequisite: basic accounting.

MS&E 277A. Entrepreneurial Leadership. 3 Units.
This course sequence is part of the Accel Leadership Program which accepts 24 technically-minded students from across Stanford. The program focuses on how to lead entrepreneurial ventures, with a focus on startup strategy, organizational structure, securing resources, operating models, and how to build an effective team. There will be skill-building workshops as well as living case studies with startup founders. Each student will be on a team that will tackle a real world business problem for a high growth venture and present their findings to the class. The selection process will run during Fall quarter 2020, and applications will be available at https://stvp.stanford.edu/students.

MS&E 277B. Entrepreneurial Leadership. 3 Units.
This course sequence is part of the Accel Leadership Program which accepts 24 technically-minded students from across Stanford. The program focuses on how to lead entrepreneurial ventures, with a focus on startup strategy, organizational structure, securing resources, operating models, and how to build an effective team. There will be skill-building workshops as well as living case studies with startup founders. Each student will be on a team that will tackle a real world business problem for a high growth venture and present their findings to the class. The selection process will run during Fall quarter 2020, and applications will be available at https://stvp.stanford.edu/students.

MS&E 278. Patent Law and Strategy for Innovators and Entrepreneurs. 2-3 Units.
This course teaches the essentials for a startup to build a valuable patent portfolio and avoid a patent infringement lawsuit. Jeffrey Schox, who is the top recommended patent attorney for Y Combinator, built the patent portfolio for Twilio (IPO), Cruise ($1B acquisition), and 300 startups that have collectively raised over $3B in venture capital. This course is equally applicable to EE, CS, and Bioengineering students. For those students who are interested in a career in Patent Law, please note that this course is a prerequisite for ME238 Patent Prosecution.
Same as: ME 208

MS&E 280. Organizational Behavior: Evidence in Action. 3-4 Units.
Organization theory; concepts and functions of management; behavior of the individual, work group, and organization. Emphasis is on cases and related discussion. Enrollment limited.

MS&E 284. Designing Modern Work Organizations. 3 Units.
This practice-based experiential lab course is geared toward MS&E masters students. Students will master the concepts of organizational design, with an emphasis on applying them to modern challenges (technology, growth, globalization, and the modern workforce). Students will also gain mastery of skills necessary for success in today's workplace (working in teams, communicating verbally, presenting project work). Guest speakers from industry will present real-world challenges related to class concepts. Students will complete a quarter-long project designing and managing an actual online organization.

MS&E 292. Health Policy Modeling. 3 Units.
Primarily for master's students; also open to undergraduates and doctoral students. The application of mathematical, statistical, economic, and systems models to problems in health policy. Areas include: disease screening, prevention, and treatment; assessment of new technologies; bioterrorism response; and drug control policies.

MS&E 293. Technology and National Security: Past, Present, and Future. 3-4 Units.
Explores the relation between technology, war, and national security policy from early history to modern day, focusing on current U.S. national security challenges and the role that technology plays in shaping our understanding and response to these challenges. Topics include the interplay between technology and modes of warfare; dominant and emerging technologies such as nuclear weapons, cyber, sensors, stealth, and biological; security challenges to the U.S.; and the U.S. response and adaptation to new technologies of military significance.
Same as: INTLPOL 256, MS&E 193

MS&E 296. Technology, Innovation and Modern War: Keeping America's Edge in an Era of Great Power Competition. 4 Units.
This course explores how technology advances in areas like Cyber, Space, AI, Machine Learning, and Autonomy will create new types of military systems that will be deployed in modern conflicts, and the new operational concepts, organization and strategies that will emerge from these technologies. The course develops an appreciation that innovation in military systems throughout history has followed a repeatable pattern: technology innovation > new weapons > experimentation with new weapons/operational concepts > pushback from incumbents > first use of new operational concepts. Students will apply course concepts and learning to identify opportunities for the U.S. to maintain its technological edge and compete more effectively in this era of great power rivalry. The course builds on concepts presented in MS&E 193/293: Technology and National Security and provides a strong foundation for MS&E 297: Hacking for Defense.
Same as: INTLPOL 340

MS&E 297. "Hacking for Defense": Solving National Security issues with the Lean Launchpad. 3-4 Units.
In a crisis, national security initiatives move at the speed of a startup yet in peacetime they default to decades-long acquisition and procurement cycles. Startups operate with continual speed and urgency 24/7. Over the last few years they've learned how to be not only fast, but extremely efficient with resources and time using lean startup methodologies. In this class student teams will take actual national security problems and learn how to apply lean startup principles, ("business model canvas," "customer development," and "agile engineering) to discover and validate customer needs and to continually build iterative prototypes to test whether they understood the problem and solution. Teams take a hands-on approach requiring close engagement with actual military, Department of Defense and other government agency end-users. Team applications required in February, see hacking4defense.stanford.edu. Limited enrollment.

MS&E 301. Dissertation Research. 1-10 Unit.
Prerequisite: doctoral candidacy.

MS&E 302. Fundamental Concepts in Management Science and Engineering. 1 Unit.
Each course session will be devoted to a specific MS&E PhD research area. Advanced students will make presentations designed for first-year doctoral students regardless of area. The presentations will be devoted to: illuminating how people in the area being explored that day think about and approach problems, and illustrating what can and cannot be done when addressing problems by deploying the knowledge, perspectives, and skills acquired by those who specialize in the area in question. Area faculty will attend and participate. During the last two weeks of the quarter groups of first year students will make presentations on how they would approach a problem drawing on two or more of the perspectives to which they have been exposed earlier in the class. Attendance is mandatory and performance will be assessed on the basis of the quality of the students¿ presentations and class participation. Restricted to first year MS&E PhD students.

MS&E 310. Linear Programming. 3 Units.
Formulation of standard linear programming models. Theory of polyhedral convex sets, linear inequalities, alternative theorems, and duality. Variants of the simplex method and the state of art interior-point algorithms. Sensitivity analyses, economic interpretations, and primal-dual methods. Relaxations of harder optimization problems and recent convex conic linear programs. Applications include game equilibrium facility location. Prerequisite: MATH 113 or consent of instructor.

MS&E 311. Optimization. 3 Units.
Applications, theories, and algorithms for finite-dimensional linear and nonlinear optimization problems with continuous variables. Elements of convex analysis, first- and second-order optimality conditions, sensitivity and duality. Algorithms for unconstrained optimization, and linearly and nonlinearly constrained problems. Modern applications in communication, game theory, auction, and economics. Prerequisites: MATH 113, 115, or equivalent.
Same as: CME 307

MS&E 313. Almost Linear Time Graph Algorithms. 3 Units.
Over the past decade there has been an explosion in activity in designing new provably efficient fast graph algorithms. Leveraging techniques from disparate areas of computer science and optimization researchers have made great strides on improving upon the best known running times for fundamental optimization problems on graphs, in many cases breaking long-standing barriers to efficient algorithm design. In this course we will survey these results and cover the key algorithmic tools they leverage to achieve these breakthroughs. Possible topics include but are not limited to, spectral graph theory, sparsification, oblivious routing, local partitioning, Laplacian system solving, and maximum flow. Prerequisites: calculus and linear algebra.
Same as: CS 269G

MS&E 315. Advanced Optimization Theory. 3 Units.
Advanced optimization methods, algorithmic techniques, and proof strategies for obtaining provably efficient methods for minimizing high dimensional continuous functions. Focus on solving broad canonical optimization and obtaining start-of-the-art running times for both general oracle-based optimization problems as well as structured problems. Topics vary year to year based on interest. Possible topics include (but are not limited to) critical point computation of non-convex functions, linear system solving, eigenvector computation, finite sum optimization, linear system solving, principle component analysis, interior point methods, linear programming, semi-definite programming, and cutting-plane methods. Prerequisite: MS&E 213 or equivalent.

MS&E 316. Discrete Mathematics and Algorithms. 3 Units.
Topics: Basic Algebraic Graph Theory, Matroids and Minimum Spanning Trees, Submodularity and Maximum Flow, NP-Hardness, Approximation Algorithms, Randomized Algorithms, The Probabilistic Method, and Spectral Sparsification using Effective Resistances. Topics will be illustrated with applications from Distributed Computing, Machine Learning, and large-scale Optimization. Prerequisites: CS 261 is highly recommended, although not required.
Same as: CME 305

MS&E 319. Approximation Algorithms. 3 Units.
The theory of matching with its roots in the work of mathematical giants like Euler and Kirchhoff has played a central and catalytic role in combinatorial optimization for decades. More recently, the growth of online marketplaces for allocating advertisements, rides, or other goods and services has led to new interest and progress in this area. The course starts with classic results characterizing matchings in bipartite and general graphs and explores connections with algebraic graph theory, permanent, Pfaffian and counting and sampling matchings. Those results are complemented with models and algorithms developed for modern applications in market design, online advertising, and ride sharing. May be repeated for credit. Prerequisite: 212, CS 261, or equivalent.

MS&E 321. Stochastic Systems. 3 Units.
Topics in stochastic processes, emphasizing applications. Markov chains in discrete and continuous time; Markov processes in general state space; Lyapunov functions; regenerative process theory; renewal theory; martingales, Brownian motion, and diffusion processes. Application to queueing theory, storage theory, reliability, and finance. Prerequisites: 221 or STATS 217; MATH 113, 115.

MS&E 322. Stochastic Calculus and Control. 3 Units.
Ito integral, existence and uniqueness of solutions of stochastic differential equations (SDEs), diffusion approximations, numerical solutions of SDEs, controlled diffusions and the Hamilton-Jacobi-Bellman equation, and statistical inference of SDEs. Applications to finance and queueing theory. Prerequisites: 221 or STATS 217: MATH 113, 115.

MS&E 323. Stochastic Simulation. 3 Units.
Emphasis is on the theoretical foundations of simulation methodology. Generation of uniform and non-uniform random variables. Discrete-event simulation and generalized semi-Markov processes. Output analysis (autoregressive, regenerative, spectral, and stationary times series methods). Variance reduction techniques (antithetic variables, common random numbers, control variables, discrete-time, conversion, importance sampling). Stochastic optimization (likelihood ratio method, perturbation analysis, stochastic approximation). Simulation in a parallel environment. Prerequisite: MS&E 221 or equivalent.

MS&E 324. Stochastic Methods in Engineering. 3 Units.
The basic limit theorems of probability theory and their application to maximum likelihood estimation. Basic Monte Carlo methods and importance sampling. Markov chains and processes, random walks, basic ergodic theory and its application to parameter estimation. Discrete time stochastic control and Bayesian filtering. Diffusion approximations, Brownian motion and an introduction to stochastic differential equations. Examples and problems from various applied areas. Prerequisites: exposure to probability and background in analysis.
Same as: CME 308, MATH 228

MS&E 325. Optimal Transport in Operations Research, Statistics, and Economics. 3 Units.
Current stochastic models, motivated by a wide range of applications in engineering, business, and science, as well as the design and analysis of associated computational methods for performance analysis and control of such stochastic systems.

MS&E 326. Advanced Topics in Game Theory with Engineering Applications. 3 Units.
Advanced Topics in Game Theory with Engineering Applications.

MS&E 327. Topics in Causal Inference. 3 Units.
This course introduces the fundamental ideas and methods in causal inference, and surveys a broad range of problems and applications. Emphasis will be on framing causal problems and identifying causal effects in both randomized experiments and observational studies. Topics will include: the potential outcomes framework; randomization-based inference and covariate adjustment; matching, and IPW; instrumental variables, regression discontinuity and synthetic ncontrols. Examples and applications will be taken from the fields of education, political science, economics, public health and digital marketing.
Same as: STATS 209A

MS&E 330. Law, Order, & Algorithms. 3 Units.
Human decision making is increasingly being displaced by predictive algorithms. Judges sentence defendants based on statistical risk scores; regulators take enforcement actions based on predicted violations; advertisers target materials based on demographic attributes; and employers evaluate applicants and employees based on machine-learned models. One concern with the rise of such algorithmic decision making is that it may replicate or exacerbate human bias. Course surveys the legal and ethical principles for assessing the equity of algorithms, describes statistical techniques for designing fairer systems, and considers how anti-discrimination law and the design of algorithms may need to evolve to account for machine bias. Concepts will be developed in part through guided in-class coding exercises. Admission by consent of instructor and limited to 20 students. To enroll complete course application by March 15 at: https://5harad.com/mse330/. Grading based on: response papers, class participation, and a final project.
Same as: CS 209, CSRE 230, SOC 279

MS&E 332. Security and Risk in Computer Networks. 3 Units.
Risk management of large scale computing and networking systems with respect to security, data integrity, performance collapse, and service disruption. Qualitative and analytical basis for assessment, modeling, control, and mitigation of network risks. Stochastic risk models. Contact process. Random fields on networks. Virus and worm propagation dynamics and containment. Denial of service attacks. Intruder detection technologies. Distributed network attacks and countermeasures. Disaster recovery networks. Network protection services and resource placement. Autonomic self-defending networks. Economics of risk management. Emphasis is on analytics and quantitative methods.

MS&E 334. Topics in Social Data. 3 Units.
This course provides a in-depth survey of methods research for the analysis of large-scale social and behavioral data. There will be a particular focus on recent developments in discrete choice theory and preference learning. Connections will be made to graph-theoretic investigations common in the study of social networks. Topics will include random utility models, item-response theory, rank aggregation, centrality and ranking on graphs, and random graphs. The course is intended for Ph.D. students, but masters students interested in research topics are welcome. Recommended: 221, 226, CS161, or equivalents.

MS&E 335. Queueing and Scheduling in Processing Networks. 3 Units.
Advanced stochastic modeling and control of systems involving queueing and scheduling operations. Stability analysis of queueing systems. Key results on single queues and queueing networks. Controlled queueing systems. Dynamic routing and scheduling in processing networks. Applications to modeling, analysis and performance engineering of computing systems, communication networks, flexible manufacturing, and service systems. Prerequisite: 221 or equivalent.

MS&E 336. Computational Social Choice. 3 Units.
An in-depth treatment of algorithmic and game-theoretic issues in social choice. Topics include common voting rules and impossibility results; ordinal vs cardinal voting; market approaches to large scale decision making; voting in complex elections, including multi-winner elections and participatory budgeting; protocols for large scale negotiation and deliberation; fairness in societal decision making;nalgorithmic approaches to governance of modern distributed systems such as blockchains and community-mediated social networks; opinion dynamics and polarization. Prerequisites: algorithms at the level of 212 or CS 161, probability at the level of 221, and basic game theory, or consent of instructor.
Same as: CS 366

MS&E 337. Network Structure and Epidemics. 3 Units.
Explores the underlying network structure of social, economic, and technological world using techniques from graph theory and economics, as well as machine learning and data analysis. Prerequisite: 226, CME 195, or equivalents. Recommended: 212.
Same as: MS&E 235

MS&E 338. Reinforcement Learning: Frontiers. 3 Units.
This class covers subjects of contemporary research contributing to the design of reinforcement learning agents that can operate effectively across a broad range of environments. Topics include exploration, generalization, credit assignment, and state and temporal abstraction. An important component of the class is a research project aimed at understanding a focused issue in reinforcement learning. Can be repeated for credit. Prerequisites: 226, CS 234, or EE 277, and experience with mathematical proofs.

MS&E 346. Reinforcement Learning for Stochastic Control Problems in Finance. 3 Units.
This course will explore a few problems in Mathematical Finance through the lens of Stochastic Control, such as Portfolio Management, Derivatives Pricing/Hedging and Order Execution. For each of these problems, we formulate a suitable Markov Decision Process (MDP), develop Dynamic Programming (DP) solutions, and explore Reinforcement Learning (RL) algorithms. The course emphasizes the theory of DP/RL as well as modeling the practical nuances of these finance problems, and strengthening the understanding through plenty of coding exercises of the methods. No pre-requisite coursework expected, but a foundation in undergraduate Probability, basic familiarity with Finance, and Python coding skills are required. Dynamic Programming or Reinforcement Learning background not required.
Same as: CME 241

MS&E 347. Credit Risk: Modeling and Management. 3 Units.
Credit risk modeling, valuation, and hedging emphasizing underlying economic, probabilistic, and statistical concepts. Point processes and their compensators. Structural, incomplete information and reduced form approaches. Single name products: corporate bonds, equity, equity options, credit and equity default swaps, forwards and swaptions. Multiname modeling: index and tranche swaps and options, collateralized debt obligations. Implementation, calibration and testing of models. Industry and market practice. Data and implementation driven group projects that focus on problems in the financial industry.

MS&E 348. Optimization of Uncertainty and Applications in Finance. 3 Units.
How to make optimal decisions in the presence of uncertainty, solution techniques for large-scale systems resulting from decision problems under uncertainty, and applications in finance. Decision trees, utility, two-stage and multi-stage decision problems, approaches to stochastic programming, model formulation; large-scale systems, Benders and Dantzig-Wolfe decomposition, Monte Carlo sampling and variance reduction techniques, risk management, portfolio optimization, asset-liability management, mortgage finance. Projects involving the practical application of optimization under uncertainty to financial planning.

MS&E 349. Financial Statistics. 3 Units.
Topics in financial statistics with focus on current research: Time-series modeling, volatility modeling, high-frequency statistics, large-dimensional factor modeling and estimation of continuous-time processes. Prerequisites: 220, 226 or STATS 200, 221 or STATS 217, 245A, or equivalents.

MS&E 350. Fundamental and Current Topics in Engineering Risk Analysis. 3 Units.
Limited to doctoral students and advanced master students. Literature in the fields of engineering risk assessment and management. New methods and topics, emphasizing probabilistic methods and decision analysis. Applications to risk management problems involving the technical, economic, and organizational aspects of engineering system safety. Possible topics: treatment of uncertainties, learning from near misses, and use of expert opinions.

MS&E 351. Dynamic Programming and Stochastic Control. 3 Units.
Markov population decision chains in discrete and continuous time. Risk posture. Present value and Cesaro overtaking optimality. Optimal stopping. Successive approximation, policy improvement, and linear programming methods. Team decisions and stochastic programs; quadratic costs and certainty equivalents. Maximum principle. Controlled diffusions. Examples from inventory, overbooking, options, investment, queues, reliability, quality, capacity, transportation. MATLAB. Prerequisites: MATH 113, 115; Markov chains; linear programming.

MS&E 352. Decision Analysis II: Professional Decision Analysis. 3-4 Units.
How to organize the decision conversation, the role of the decision analysis cycle and the model sequence, assessing the quality of decisions, framing decisions, the decision hierarchy, strategy tables for alternative development, creating spare and effective decision diagrams, biases in assessment, knowledge maps, uncertainty about probability. Sensitivity analysis, approximations, value of revelation, joint information, options, flexibility, bidding, assessing and using corporate risk attitude, risk sharing and scaling, and decisions involving health and safety. See 353 for continuation. Prerequisite: 252.

MS&E 353. Decision Analysis III: Frontiers of Decision Analysis. 3 Units.
The concept of decision composite; probabilistic insurance and other challenges to the normative approach; the relationship of decision analysis to classical inference and data analysis procedures; the likelihood and exchangeability principles; inference, decision, and experimentation using conjugate distributions; developing a risk attitude based on general properties; alternative decision aiding practices such as analytic hierarchy and fuzzy approaches. Student presentations on current research. Goal is to prepare doctoral students for research. Prerequisite: 352.

MS&E 355. Influence Diagrams and Probabilistics Networks. 3 Units.
Network representations for reasoning under uncertainty: influence diagrams, belief networks, and Markov networks. Structuring and assessment of decision problems under uncertainty. Learning from evidence. Conditional independence and requisite information. Node reductions. Belief propagation and revision. Simulation. Linear-quadratic-Gaussian decision models and Kalman filters. Dynamic processes. Bayesian meta-analysis. Prerequisites: 220, 252, or equivalents, or consent of instructor.

MS&E 365. Mechanism and Market Design. 3 Units.
Primarily for doctoral students. Focus on quantitative models dealing with sustainability and related to operations management. Prerequisite: consent of instructor. May be repeated for credit.
Same as: ECON 287

MS&E 366. Market Design and Resource Allocation in Non-Profit Settings. 3 Units.
Survey of recent research on market design and resource allocation with a focus on under-explored domains in non-profit settings. Will start with classic results in allocation, matching and social choice, and discuss them in the context of relevant objectives such as social welfare and equity. Will then draw on techniques from operations research and economics to explore the design of resource allocation platforms in emerging applications including housing, humanitarian logistics, volunteer coordination, food allocation, conservation and sustainability, and informal markets in the developing world. Prerequisite: consent of instructor; background material will be covered throughout the course as necessary. May be repeated for credit.

MS&E 370. Current Topics in Strategy, Innovation and Entrepreneurship. 1 Unit.
This course will cover focused exploration of contemporary readings and classics as relevant in strategy, innovation and entrepreneurship such as platforms, ecosystems, institutional logics, and strategic "games" in nascent markets. The course will include both content and methods discussions, including theory-building from multiple cases. PhD students only. Prerequisite: Consent of instructor.

MS&E 371. Innovation and Strategic Change. 1-3 Unit.
Doctoral research seminar, limited to Ph.D. students. Current research on innovation strategy. Topics: scientific discovery, innovation search, organizational learning, evolutionary approaches, and incremental and radical change. Topics change yearly. Recommended: course in statistics or research methods.

MS&E 372. Entrepreneurship Doctoral Research Seminar. 1-3 Unit.
Classic and current research on entrepreneurship. In this class, we will focus on questions of how entrepreneurship may exacerbate or alleviate inequalities in society across race/ethnicity, gender and class. How do institutional environments shape who engages in entrepreneurship and how successful they become? We will read literature from economics, sociology and strategy/management that has theoretically and empirically examined the phenomenon of entrepreneurship. Limited enrollment, restricted to PhD students. Prerequisites: SOC 363 or equivalent, and permission of instructor.

MS&E 376. Strategy Doctoral Research Seminar. 1-3 Unit.
Classic and current research on business and corporate strategy. Limited enrollment, restricted to PhD students. Course may be repeated for credit.

MS&E 379. Social Data Analysis. 3 Units.
Applied introduction to good empirical research and causal inference for social scientists and others analyzing social data. Designed to provide an introduction to some of the most commonly used quantitative techniques for causal inference in social data including: survey design and inference, regression and propensity score matching, instrumental variables, differences-in-differences, regression discontinuity designs, standard errors, and the analysis of big data. Applications: organizations, entrepreneurship, public policy, innovation, economics, online education, visual representations, communication, critique and design of figures, graphs. Does not explicitly cover social network structure or machine learning as these topics are well-covered elsewhere. Students work in groups and individually to design and carry out a small research project based on the use of analytics, large data sets, or other digital innovations related to business or other organizations. Students become acquainted with a variety of approaches to research design, and are helped to develop their own research projects. Course prioritizes a thorough substantively grounded understanding of assumptions over mathematical proofs and derivations. Aimed at PhD students, but open by permission to Master's students and to students in other Stanford programs with relevant coursework or experience in analytics and statistics.

MS&E 380. Doctoral Research Seminar in Organizations. 3 Units.
Limited to Ph.D. students. Topics from current published literature and working papers. Content varies. Prerequisite: consent of instructor.

MS&E 384. Groups and Teams. 3 Units.
Research on groups and teams in organizations from the perspective of organizational behavior and social psychology. Topics include group effectiveness, norms, group composition, diversity, conflict, group dynamics, temporal issues in groups, geographically distributed teams, and intergroup relations.

MS&E 387. Design of Field Research Methods. 3 Units.
Field research involves collecting original data (qualitative and/or quantitative) in field sites. This course combines informal lecture and discussion with practical exercises to build specific skills for conducting field research in organizations. Readings include books and papers about research methodology and articles that provide exemplars of field research. Specific topics covered include: the role of theory in field research, variance versus process models, collecting and analyzing different kinds of data (observation, interview, survey), levels of analysis, construct development and validity, blending qualitative and quantitative data (in a paper, a study, or a career), and writing up field research for publication. Students will develop intuition about the contingent relationship between the nature of the research question and the field research methods used to answer it as a foundation for conducting original field research.

MS&E 388. Contemporary Themes in Work and Organization Studies. 3 Units.
Doctoral research seminar, limited to Ph.D. students. Current meso-level field research on organizational behavior, especially work and coordination. Topics: work design, job design, roles, teams, organizational change and learning, knowledge management, performance. Focus on understanding theory development and research design in contemporary field research. Topics change yearly. Recommended: course in statistics or research methods.

MS&E 389. Seminar on Organizational Theory. 5 Units.
The social science literature on organizations assessed through consideration of the major theoretical traditions and lines of research predominant in the field. For PhD students only.
Same as: EDUC 375A, SOC 363A

MS&E 390. Doctoral Research Seminar in Health Systems Modeling. 1-3 Unit.
Restricted to PhD students, or by consent of instructor. Doctoral research seminar covering current topics in health policy, health systems modeling, and health innovation. May be repeated for credit.

MS&E 391. Doctoral Research Seminar in Energy-Environmental Systems Modeling and Analysis. 1-3 Unit.
Restricted to PhD students, or by consent of instructor. Doctoral research seminar covering current topics in energy and environmental modeling and analysis. Current emphasis on approaches to incorporation of uncertainty and technology dynamics into complex systems models. May be repeated for credit.

MS&E 394. Advanced Methods in Modeling for Climate and Energy Policy. 3 Units.
Design and application of computational models and techniques for assessing climate and energy policy, and for predicting the impacts of climate change. Topics include 1) best practices in research design, model design and selection; 2) types of models available, taxonomy, core concepts, and limitations; 3) interpreting and presenting model results; and 4) advanced topics and recent literature, e.g. representing uncertainty, technological change, distributional change, and cross-sectoral climate impacts. Prerequisites: MS&E 241, MS&E 211, or equivalents.

MS&E 408. Directed Reading and Research. 1-15 Unit.
Directed reading and research on a subject of mutual interest to student and faculty member. Available to undergraduate, master, and doctoral students. Student must clarify deliverables, units, and grading basis with faculty member before applicable deadlines. Prerequisite: consent of instructor.

MS&E 441. Policy and Economics Research Roundtable. 1 Unit.
Research in progress or contemplated in policy and economics areas. Emphasis depends on research interests of participants, but is likely to include energy, environment, transportation, or technology policy and analysis. May be repeated for credit.
Same as: PERR

MS&E 448. Big Financial Data and Algorithmic Trading. 3 Units.
Project course emphasizing the connection between data, models, and reality. Vast amounts of high volume, high frequency observations of financial quotes, orders and transactions are now available, and poses a unique set of challenges. This type of data will be used as the empirical basis for modeling and testing various ideas within the umbrella of algorithmic trading and quantitative modeling related to the dynamics and micro-structure of financial markets. Due to the fact that it is near impossible to perform experiments in finance, there is a need for empirical inference and intuition, any model should also be justified in terms of plausibility that goes beyond pure econometric and data mining approaches. Introductory lectures, followed by real-world type projects to get a hands-on experience with realistic challenges and hone skills needed in the work place. Work in groups on selected projects that will entail obtaining and cleaning the raw data and becoming familiar with techniques and challenges in handling big data sets. Develop a framework for modeling and testing (in computer languages such as Python, C++ , Matlab and R) and prepare presentations to present to the class. Example projects include optimal order execution, developing a market making algorithm, design of an intra-day trading strategy, and modeling the dynamics of the bid and ask. Prerequisites: MS&E 211, 245A, 245B, or equivalents, some exposure to statistics and programming. Enrollment limited. Admission by application; details at first class.

MS&E 449. Buy-Side Investing. 1-2 Unit.
In-class lectures and guest speakers who work in the Buy-Side to explore the synergies amongst the various players¿ roles, risk appetites, and investment time and return horizons. We aim to see the forest and the different species of trees growing in the forest known as the Buy-Side, so as to develop a perspective as financial engineers for how the ecosystem functions, what risks it digests, how it generates capital at what rate and amount for the Sell-Side, and how impacts in the real economy are reflected - or should be reflected - in the culture and risk models adopted by the Buy-Side participants.

MS&E 454. Decision Analysis Seminar. 1 Unit.
Current research and related topics presented by doctoral students and invited speakers. May be repeated for credit. Prerequisite: 252.

MS&E 463. Healthcare Systems Design. 3-4 Units.
Students work on projects to analyze and design various aspects of healthcare delivery including hospital patient flow, clinical risk prediction, physician networks, clinical outcomes, reimbursement incentives, and community health. Students work in small teams under the supervision of the course instructor and partners at the Lucille Packard Children's Hospital, the Stanford Hospital, and other regional healthcare providers. Prerequisite: 263 and a mandatory meeting during the preceding Winter quarter to choose projects.
Same as: PEDS 463

MS&E 472. Entrepreneurial Thought Leaders' Seminar. 1 Unit.
Learn about entrepreneurship, innovation, culture, startups and strategy from a diverse lineup of accomplished leaders and entrepreneurs in venture capital, technology, education, philanthropy and more. Open to all Stanford students. Required weekly assignment. May be repeated for credit.

MS&E 489. d.Leadership: Leading Disruptive Innovation. 3-4 Units.
d.Leadership is a course that teaches the coaching and leadership skills needed to drive good design process in groups. d.leaders will work on real projects driving design projects within organizations and gain real world skills as they experiment with their leadership style. Take this course if you are inspired by past design classes and want skills to lead design projects beyond Stanford. Preference given to students who have taken other Design Group or d.school classes. Admission by application. See dschool.stanford.edu/classes for more information.
Same as: ME 368

MS&E 494. The Energy Seminar. 1 Unit.
Interdisciplinary exploration of current energy challenges and opportunities, with talks by faculty, visitors, and students. May be repeated for credit.
Same as: CEE 301, ENERGY 301

MS&E 495. Sustainable Energy Interdisciplinary Graduate Seminar. 1 Unit.
Graduate students will present their ongoing research to an audience of faculty and graduate students with a diversity of disciplinary perspectives regarding sustainable energy.
Same as: CEE 372, ENERGY 309

MS&E 802. TGR Dissertation. 0 Units.
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