

CornellEngineering
Operations Research and
Information Engineering

2023-2024
Handbook for
OR&E Major

<http://www.orie.cornell.edu/orie/programs/undergraduate-program>

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IMPORTANT NOTE:

The primary purpose of the handbook is to provide information specific to the OR&E major. You are responsible for checking College and University documentation for rules and regulations not specific to the OR&E major.

STUDENT RESPONSIBILITIES FOR MEETING DEGREE REQUIREMENTS:

Ultimately, it is your responsibility to understand the degree requirements for the major and to plan your course of study accordingly. You should consult the OR&E undergraduate major office (203 Rhodes) for specific information relating to the fulfillment of degree requirements. Your faculty advisor will assist you in course selection, but it is your responsibility to ensure that the courses you select will fulfill degree requirements.

Updated December 2023

CORNELL ORIE

Introduction

This handbook has been designed to inform you about the School of Operations Research and Information Engineering (ORIE) at Cornell. It will help you gain an understanding of the major program, the courses, the faculty and staff, various procedures, career opportunities, graduate studies, and student activities. This handbook, together with consultations with your faculty advisor, should provide you with the information you need concerning the Operations Research & Engineering major.

The faculty and staff welcome you to the School. We look forward to getting to know you and are confident that you will have a challenging and rewarding educational experience.

What Operations Research Is About

The Operations Research and Engineering (OR&E) undergraduate major will give you a broad understanding of the techniques and modeling concepts needed to analyze and design complex systems. As an operations researcher, you will make many decisions that involve the interplay of people, time, money, technology and materials. Operations research is foremost about general resource allocation problems that naturally can be represented and analyzed mathematically. Specialists in operations research use a variety of mathematical techniques and sophisticated computing tools to develop strategies for getting the most out of valuable resources while still being mindful of desirable restrictions (e.g., maintaining employee satisfaction).

An online retailer, for example, might benefit from careful statistical analysis of massive amounts of sales data, leading to modifications of how its website interacts with users, and perhaps resulting in a redesign of its supply chain so as to reduce inventory holding costs while simultaneously improving on-time deliveries. A manufacturer might be able to save significant recurring costs by identifying and eliminating a few bottlenecks in an assembly line. Operations research methods are integral to our daily lives, providing the underpinnings for apps which quickly result in assignments made to fulfill customer demand, such as those for Lyft and Uber, and for ridesharing.

Employment Opportunities

Historically, the field of operations research was concerned with manufacturing and the delivery of goods and services, and many operations researchers continue to pursue opportunities in these areas. In recent years, the field has expanded briskly, as business and industry have recognized that the methods of operations research are central to profitability. As a result, you'll find OR&E graduates working as investment bankers and in information technology offices, as well as consultants, analysts, industrial engineers and managers in a wide variety of areas. The major provides analytical tools that will allow you to seek flexible career pathways. Indeed, no major exceeds the breadth of opportunities provided by Operations Research and Engineering.

Here are some of the career choices of recent OR&E graduates:

- Accenture, Strategy Analyst
- Amazon, Operations Financial Analyst
- Atlanta Braves, Baseball Analytics Trainee
- Barclays, Rates Trading
- Capital One, Financial Analyst
- Deloitte Consulting, Business Technology Analyst
- ExxonMobil, Industrial Engineer
- Jet.com, Supply Chain Associate
- Johnson & Johnson, Information Technology Leadership Development
- J.P. Morgan Chase & Co., Business Analyst
- Proctor & Gamble, Supply Chain Operations Manager

History of the School

Cornell's educational contributions to our discipline reach back almost to its beginning. In the 1890's, Frederick Taylor introduced ideas for improving the efficiency of labor by breaking down the steps required for a task and designing "the one best method" for all steps and the task they comprise. When Taylor presented a paper, "Shop Management," at the 1903 meeting of the American Society of Mechanical Engineers, Dexter Kimball, then works manager at Stanley Electric Manufacturing Company, later the first Dean of the College of Engineering at Cornell, was in the audience. By 1905 Kimball was teaching about the economics of production at Cornell. In 1913, Kimball wrote in *Principles of Industrial Organization*, "the application of these well-known methods has become known as efficiency engineering, industrial engineering, or scientific management." Since that time, many other terms have been linked to the discipline(s) that grew from this approach, among them: *administrative science*, *administrative engineering*, *systems analysis*, *systems engineering*, *management science*, *engineering management*, *management engineering*, *operations management*, *operations research*. One could debate whether these terms are all variations on a theme, or whether they represent distinct descendants of a common ancestor. Their standard short definitions are very similar – application of *scientific methods* to *systems* in order to design and operate them *efficiently*. They might diverge only when the succinct definitions were expanded to include shades of emphasis and delineations of both methods and application areas.

The designation *operations research* first emerged during World War II in England. Military planners worked with civilians from a variety of disciplines, including mathematics and engineering, to tackle the challenges imposed by the logistical support of massive military operations. Operations Analysis (or, Operational Analysis, in British English) was the name that was initially associated with their systematic approach to planning and with the collection of mathematical tools employed. Over time, it came to be called Operations Research.

Even within Cornell, the name of the academic unit tasked with teaching industrial engineering and its namesakes has changed several times to reflect changes in emphasis within the unit, as well as changes in perspective within the broader professional community: administrative engineering, industrial engineering, operations research and information engineering have all appeared in the name of our unit at various times. It was part of the Sibley School of Mechanical Engineering until the 1960's, when a separate unit was created, which (eventually) became the School of ORIE. For decades, ORIE stood for Operations Research and Industrial Engineering; it now decodes as Operations Research and Information Engineering.

Why the change in 2006 to Operations Research and *Information* Engineering? The ongoing information revolution has dramatically broadened the impact of OR. Information Engineering, the process of transforming data into useful information, has always played a key role in OR, but the rapidly increasing scope and scale of available data challenges us to better understand this process. The role of information is further highlighted by the transformation of the US economy being based primarily on manufacturing to being oriented towards service industries, where information itself is often a key commodity. The names of some courses recently introduced in ORIE – "Urban Analytics", "Statistical Data Mining", "Service System Modeling and Design", "Learning with Big Messy Data" – indicate how the School's mission is expanding in this direction.

The current ORIE faculty has carried forward the strong traditions established by an earlier generation, building more powerful mathematical foundations, designing faster more robust computational methods, and greatly expanding the scope of applications. Operations Research is truly a multidisciplinary field, with great reach in its relevance to business and society.

In teaching, as in research, ORIE at Cornell has put a premium on mathematical rigor, pushing the envelope, not merely presenting what works and what doesn't, but showing why it works or doesn't. Armed with such training, graduates of the OR&E major are typically able to make broader, more fundamental contributions to the practice of OR. They are able to adapt to the ever more rapidly changing workplace, where tools that work today may be based on assumptions that won't hold tomorrow. Cornell's Operations Research and Engineering major is considered premiere in the world of operations research.

PERSONNEL

Faculty

ORIE's faculty members are among the most distinguished academicians in operations research.

<u>Name</u>	<u>Area(s) of Teaching and Research</u>
Siddhartha Banerjee, Assoc. Prof.	Stochastic Modeling, Game Theory, Network Algorithms
Kathryn Caggiano, Prof. of Practice	Supply Chain Management
John R. Callister, Senior Lecturer	Entrepreneurship, Economic Analysis
Damek Davis, Assoc. Prof.	Optimization, Algorithms
Jim Dai, Prof.	Performance Analysis, Stochastic Processing Networks
Brenda Dietrich, Prof. of Practice	Mathematical Optimization, Resource Allocation
Peter Frazier, Assoc. Prof.	Statistical Learning
Eric Gentsch, Lecturer, Interim Dir M.Eng	Manufacturing, Supply Chain Management
David Goldberg, Assoc. Prof., DUS	Inventory Models, Queueing Theory, Prob. & Stoch. Proc.
Oktay Gunluk, Prof. of Practice	Optimization, Algorithms
Shane G. Henderson, Prof.	Applied Prob., Financial Engr., Info. Tech. Modeling
Adrian S. Lewis, Prof.	Optimization, Algorithms
Mark E. Lewis, Prof. and Director	Applied Prob., Financial Engr., Supply Chain Mg.
Andreea Minca, Prof.	Modeling in Mathematical Finance
Pierre Patie, Assoc. Prof.	Probability Theory, Financial & Insurance Mathematics
Jamol Pender, Assoc. Prof, DGS	Queueing Theory, Applied Probability, Markov Processes
James Renegar, Prof.	Optimization, Algorithms
David Ruppert, Prof.	Statistics, Data Science, Financial Engineering
Gennady Samorodnitsky, Prof.,	Applied Probability, Financial Engr., Statistics
Frans Schalekamp, Senior Lecturer	Optimization, Algorithms
Katya Scheinberg, Prof.	Optimization, Algorithms
Ziv Scully, Asst. Prof	Applied Probability, Queueing & Scheduling, Stoch. Control
Soroosh Shafiee, Asst. Prof	Optimization, Machine Learning
David B. Shmoys, Prof.	Optimization, Algorithms, Supply Chain Mgt.
David P. Williamson, Prof.	Optimization, Algorithms, and Data Science
Manxi Wu, Asst. Prof.	Network Optimization, Societal Networks, Game Theory
Christina Lee Yu, Asst. Prof.	Statistics & Machine Learning, Data Science, Algorithms

Support Staff

You may also have occasion to interact with some of the support staff of the School, including:

Max Schoenberger (mss462) Undergraduate Services Coordinator 278 Rhodes Hall

Max Schoenberger is responsible for tracking your progress towards graduation and is available to answer your questions about the administrative aspects of the undergraduate program.

CURRICULUM

See the Cornell Engineering handbook for requirements pertaining to all majors in the College. Below are the requirements, options and recommendations specific to the OR&E major.

First-year students intending to affiliate with OR&E: CS 1110 is recommended rather than CS 1112. The most suitable Introduction to Engineering course for OR&E majors is ENGR1 1101.

Engineering Core Courses, and Allowed Substitutions

OR&E affiliates are required to complete Math 1910, 1920 and 2940. Either Math 2930, Math 3040 or CS 2800 may be used to satisfy the fourth mathematics requirement. Students should discuss with their advisor which of these three courses is most appropriate to their future program of study. Chemistry 2080, Chemistry 2150, Math 2930 (if not used to meet the mathematics requirement), CS 2800 (if not used to meet the mathematics requirement), Math 3040 (if not used to meet the mathematics requirement), Math 3110 or Math 3360 may be taken in place of Physics 2214. Students who do not take Math 2930 may not enroll in Physics 2214 (Math 2930 is a pre-requisite for Physics 2214) and should plan to enroll in one of the alternative courses.

OR&E affiliates must receive at least a C in MATH 2940. Each remaining course in mathematics used to fulfill a core requirement must be passed with a grade of at least C-. If the required grade level is not achieved, the course must be repeated.

Engineering Distribution Courses

ENGRD/CS 2110 is required of all OR&E majors and must be passed with a grade of C- or better before the end of the sixth semester. If this grade level is not achieved, the course must be repeated. ENGRD/CS 2110 may be taken as a distribution course or major approved elective. ENGRD 2700 is a required distribution course and must be passed with a grade of C or better. The Engineering Communications requirement can be fulfilled by ENGRC 3120 or by ORIE 4100 (which simultaneously can be used as a Major Approved Elective or as an ORIE elective).

Major Required Courses

The following courses are required of all OR&E majors:

ORIE 3120, 3150¹, 3300, 3310, 3500, 3510, 4580.

Each ORIE major required course must be passed with a grade of C- or better. If this requirement is not met the first time a course is taken, the course must be repeated within one year and a satisfactory grade attained before the next course in the sequence (ORIE 3310 and ORIE 3510 in particular) may be taken. Failure to achieve at least a C- the second time will generally result in withdrawal from the program. Courses taken a second time in order to meet this requirement do not yield additional credit toward the degree. Transfer credit will not be granted for required major courses except for (1) transfer students who took an equivalent course at another institution prior to enrollment at Cornell, and (2) students formally enrolled in Cornell's "Study Abroad" program.

¹ Students are allowed to replace the requirement for ORIE 3150 (Financial and Managerial Accounting) by earning at least a C- in one of the following courses:

- MATH 3110 (Introduction to Analysis)
- MATH 4130 (Honors Real Analysis)
- MATH 4310 (Linear Algebra)
- MATH 4330 (Honors Linear Algebra)
- Any 6000 level ORIE course

If a course is used to replace the ORIE 3150 requirement, then it cannot also be used as an advisor approved, major approved, or ORIE elective.

ORIE Electives (9 credits)

The allowed courses are all ORIE courses at the 4000 level or higher which are not listed as a Major Required Course, and which are not one of the following: ORIE 4152², 9000, 9100 and 9101. Additionally, ORIE 3800 may be used as an ORIE Elective.

ORIE 4990 (Teaching in ORIE) – at most 3 credits

ORIE 4999 (ORIE Project), CS 4999 (Individual Reading and Research) – at most 3 credits between the two courses.

Major Approved Electives (12 credits for Classes of 2023 and later)

All major-approved electives must be technical courses numbered 2000 or above. “Technical” means that in a significant part of the course (homework, projects), students actively use their skills in mathematics, the sciences, or engineering design.

Major Approved Electives fall into either category A (Engineering, Science, and Mathematics) or category B (Engineering Design, Finance, and Economic Analysis). At least 6 credits must be from category A, and at least 6 credits must be from outside ORIE. Below are lists of popular courses that may be used as Major Approved Electives. Students may petition for other courses to be allowed. Petitions go to the Director for Undergraduate Studies, who, with the Academic Standards Committee, will determine if the course meets the definition of “technical” and whether the course is in category A or B. A petition must be accompanied with a syllabus of the course indicating the textbooks used and the types of assignments that will be given.

Out of the 12 credits required for major approved electives, at most 3 credits (in total) can come from undergraduate research, team project courses, and TAships combined. Depending on the details of the research/project/TAship, this credit may be counted towards either Category A or Category B, as determined by the ORIE Director for Undergraduate Studies and Undergraduate Coordinator. This 3 credit limitation is applicable to those students who affiliated to the ORIE major in Fall 2023 and later. Other students should refer to the ORIE student handbook from their year of affiliation to the major. If you have any questions, please reach out to the ORIE Director for Undergraduate Studies and Undergraduate Coordinator

Category A (Engineering, Science, and Mathematics):

All ORIE courses numbered 3000 or above EXCEPT 4152, 9000, 9100, 9101 and 9110
 All MATH courses numbered 3000 or above EXCEPT 4030, 4080, 4710, 4720 and 4740
 All PHYSICS courses with Physics 2213 or 2214 as a prerequisite
 All ENGRD Courses (except ENGRD 2700 which must be used in the Distribution Category.)
 All CS courses with CS 2110 as a prerequisite
 AEM 4110 (Introduction to Econometrics) (but not with Econ 3140)
 AEP 4210 (Mathematical Physics I)
 ASTRO 3340 (Symbolic and Numerical Computing)
 BEE 2220 (Bioengineering Thermodynamics and Kinetics)
 BEE 4710 (Introduction to Groundwater)
 BEE 4880 (Applied Modeling and Simulation for Renewable Energy)
 BIOMG 3300 (Principles of Biochemistry)
 BIOMG 3310 (Principles of Biochemistry: Proteins and Metabolism)
 BIOMG 3320 (Principles of Biochemistry: Molecular Biology)
 BTRY 4270 (Survival Analysis)
 BTRY 4381 (Biomedical Data Mining and Modeling)
 CEE 4620 (Analysis and Control of Transportation Systems and Networks)
 CEE 4630 (Future Transportation Technologies and Systems)
 CEE 4665 (Modeling and Optimization for Smart Infrastructure Systems)
 CEE 5980 (Intro to Decision Analysis)
 CEE 6230 (Environmental Quality Systems Analysis)
 CHEM 2080 (General Chemistry II)
 CHEM courses with CHEM 2080 or 2160 as a prerequisite
 EAS 3420 (Atmospheric Dynamics)
 EAS 4840 (Inverse Methods in the Natural Sciences)
 ECE 4450 (Computer Networks and Telecommunications)
 ECE 3530 (Introduction to Systems and Synthetic Biology)
 ECON 3140 (Introduction to Econometrics, but not with AEM 4110) ECON 3120 is not approved.

CS 2800 (Discrete Structures)
 CS 3420 (Embedded Systems)
 CS 4450 (Introduction to Computer Networks)
 CS 4780 (Intro to Machine Learning)
 CS 4810 (Intro to Theory of Computing)
 CS 4852 (Networks II) (CS 2850, Networks, is NOT a Major Approved elective).
 CS 5722 (Heuristic Methods for Optimization)
 FDSC 2000 (Introduction to Physiochemical and Biological Aspects of Food)
 INFO 2950 (Introduction to Data Science)
 INFO 3950 (Data Analytics for Information Science)
 MAE 3100 (Intro. to Applied Math)
 MAE 3260 (System Dynamics)
 MAE 4860 (Automotive Engineering)
 MAE 5790 (Nonlinear Dynamics and Chaos)
 PSYCH 4760 (Quantitative Methods 2)
 PAM 3100 (Multiple Regression Analysis)
 PAM 5690 (Regression Analysis and Managerial Forecasting)
 STSCI 3100 (Statistical Sampling)
 STSCI 4030 (Linear Models with Matrices)
 STSCI 4140 (Applied Design)
 STSCI 4520 (Statistical Computing)
 SYSEN 5300 (SysEng and Six Sigma for the Design and Operation of Reliable Systems)

Category B (Engineering Design, Finance, and Economic Analysis):

AEM 3100 (Business Statistics)
 AEM 3360 (Corporate Financial Reporting I)
 AEM 3390 (Research Methods in International Development)
 AEM 4060 (Risk Simulation and Monte Carlo Methods)
 AEM 4150 (Price Analysis)
 AEM 4160 (Strategic Pricing)
 AEM 4210 (Futures, Options and Financial Derivatives)
 AEM 4230 (Topics in Behavioral Finance)
 AEM 4260 (Fixed Income Securities)
 AEM 4280 (Valuation of Capital Investment)
 AEM 4290 (International Financial Management)
 AEM 4380 (Entrepreneurial Strategy for Technology Ventures)
 AEM 4390 (Technology Strategy)
 AEM 4410 (Marketing Research)
 AEM 4600 (Predictive Analytics for Business Strategy)
 AEM 4610 (Business Processes, Analytics and Enterprise Systems)
 AEM 4660 (Market Dynamics, Computer Simulation and Modeling)
 AEM 4670 (Investments)
 BEE 3299 (Sustainable Development)
 BEE 4010 (Renewable Energy Systems)
 BEE 4890 (Entrepreneurial Management for Engineers)
 ECON 4220 (Financial Economics)
 ECON 4610 (Industrial Organization I)
 ECON 4620 (Industrial Organization II)
 ECON 4903 (Quantitative Analysis of Economic Data)
 CEE 3610 (Introduction to Transportation Engineering)
 CEE 4530 (Research in Environmental Engineering)
 CEE 4640 (Transportation Systems Design)
 CEE 5900 (Project Management)
 CEE 5970 (Risk Analysis and Management)
 CS/INFO 2300 (Intermediate Web Design)
 HADM 3430 (Marketing Research)
 HADM 4410 (Strategic Management)
 INFO 3350 (Text Mining for History and Literature)
 INFO 4120 (Ubiquitous Computing)

MAE 2250 (Mechanical Synthesis)
 NBA 4120 (Equity Investment Research and Analysis)
 NBA 5060 (Financial Statement Analysis)
 NBA 5380 (The Business Idea Factory) 1.5 cr.
 NBA 5061 (Comprehensive Financial Statement Analysis)
 NBA 5111 (Foundations of Financial Modeling)
 NBA 5410 (Project Management)
 NBA 5420 (Investments and Portfolio Analysis)
 NBA 5550 (Fixed Income Securities and Interest Rate Derivatives)
 NBA 6200 (Marketing Research)
 NBA 6730 (Intro. to Derivatives, Part 1)
 NBA 6740 (Intro. to Derivatives, Part 2)
 NBA 6930 (Strategy and Tactics of Pricing)
 NBA 6940 (Equity derivatives and related products)
 ORIE 4152/ENGRG 4610 (Entrepreneurship for Engineers)
 SYSEN 5740 (Design Thinking for Complex Systems)

Advisor Approved Electives (6 credits)

Any course mutually agreed upon by a student and their advisor may be included in this category. For a course to count as an Advisor Approved elective, a student must meet in-person with their advisor to discuss the courses before getting approval. Advisors approve courses in this category if the course is considered to be relevant to the student's educational objectives. For students who matriculate Fall 2023 and later, courses in this category must be approved before or during the semester the student enrolls in the course.

Credits for a Course Can Be Spread

The three categories of the major's electives can be viewed as an ordered list:

ORIE Electives → Major Approved Electives → Advisor Approved Electives

Excess credit is allowed to flow in the direction of the arrows. If, for example, a student takes three courses each allowed as an ORIE Elective, and whose credits are 4, 4 and 3, then 9 of those credits can be used to complete the requirements for ORIE Electives, and the remaining 2 credits can be distributed among Major Approved Electives and Advisor Approved Electives (assuming the student's advisor is agreeable). Likewise, excess Major Approved Electives can count towards Advisor Approved Electives (but not towards ORIE Electives).

Curriculum Checklist

The curriculum for the B.S. degree with a major in Operations Research and Engineering is summarized on the curriculum checklist at the end of this handbook. When all the courses listed are completed successfully, and the student's cumulative GPA is at least 2.0, and the student's Major GPA is at least 2.0, the degree will be awarded. (The Major GPA includes all courses used to fulfill the major's specific requirements as described in the preceding sections under "Curriculum", except that Advisor Approved Electives are not included.)

For each student, an updated copy of the checklist is maintained by Max Schoenberger (Rhodes 278). Each student should also maintain a copy of their checklist, and occasionally meet with Max to compare copies.

Junior and Senior Year Courses

The following is a typical junior year schedule for an Operations Research and Engineering major who has completed ENGRD 2700, CS 2110, Math 2940 and ORIE 3120.

Fall Semester

ORIE 3300 Optimization I
 ORIE 3500 Probability & Statistics II
 ORIE 3150 Accounting (or replacement)
 Approved/Major-approved Elective
 Liberal Elective

Spring Semester

ORIE 3310 Optimization II
 ORIE 3510 Stochastic Processes
 Major-approved elective
 Approved/Major-approved Elective
 Liberal Elective

In the Fall Semester of the senior year, ORIE 4580 must be taken (if not taken before). The rest of the schedule in the senior year will consist of the various types of electives necessary to complete degree requirements.

The minimum course load required to be considered a full-time student is 12 credit hours in each semester, except in the student's final semester. In the final semester, the minimum course load is simply the number of credit hours needed to complete degree requirements.

Honors Program

Eligibility: To be eligible for the OR&E honors program, a student must achieve and sustain a cumulative GPA of at least 3.5, both overall and in the major program.

Timing: A student must apply for and be admitted to the honors program no later than the beginning of their penultimate semester, i.e., the student must be in the program for at least two semesters prior to graduation. Students may apply for and be admitted to the program as early as the first semester of their junior year.

Procedures: If you are interested in ORIE's honors program, you will first find an honors faculty advisor to supervise, and will work with that advisor to formally apply to the honors program. A good first step is to discuss with your already assigned ORIE faculty advisor (who may or may not be the faculty who ultimately supervises your honors program if your application is successful), and to email the Associate Director for Undergraduate Studies David Goldberg at dag369@cornell.edu.

The application to the program shall consist of a letter from the student describing the specific proposed honors program. The letter should include the explicit approval of the proposed honors faculty advisor and be signed by both the student and proposed honors faculty advisor. Each program must be approved by the Associate Director for Undergraduate Studies, and any changes to the student's program must also be approved by the Associate Director for Undergraduate Studies. The letter should be emailed to the Associate Director for Undergraduate Studies at dag369@cornell.edu with the proposed honors faculty advisor CC'd, with email subject heading "ORIE Honors Program Application".

An OR&E honors program shall consist of at least nine credits beyond the minimum required for graduation in OR&E, so that no part of the honors program may also be used to satisfy graduation requirements. The nine credits shall be from one or more of the following with at least four credits in category 1:

1. Select ORIE courses at the 5000-level, and all ORIE courses at the 6000-level and above with the exception of seminars and colloquia.
2. A significant research experience or honors project under the direct supervision of an ORIE faculty member using ORIE 4999 (ORIE Project). A significant written report must be submitted as part of this component.
3. A significant teaching experience under the direct supervision of a faculty member in ORIE 4990 (Teaching in ORIE).

No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

Preparing for Ph.D. Programs

Pursuing a Ph.D. in Operations Research is an exciting, rewarding, and challenging experience. The OR&E major at Cornell can be tailored to prepare students for rigorous Ph.D. programs in Operations Research. Beyond classes, our department offers many opportunities to prepare for a Ph.D. program and to become a more competitive applicant. We encourage students to start by discussing their interest in graduate programs with their advisor and other faculty in the department. Due to the rigor of Ph.D. programs, we also suggest students to take electives that strengthen their mathematical background; several of these are suggested below. Students interested in Ph.D. programs might also discuss on- and off-campus research opportunities with our faculty. Additional advice may also be found on the ORIE website.

Ph.D. programs in Operations Research generally assume mathematical maturity and the ability to read and write sophisticated mathematical arguments (proofs). Taking at least three of following courses is highly recommended as preparation for Ph.D. programs (especially a course in analysis (Math 3110 or Math 4130), and a course in theoretical linear algebra (Math 4310 or Math 4330)).

CS 2800* Discrete Structures
 CS 4820 Introduction to analysis of algorithms
 CS 4850 Mathematical foundations for the information age
 Math 3040* Prove it!
 Math 3110** Introduction to analysis
 Math 3360 Applicable algebra
 Math 4130** Honors introduction to analysis I
 Math 4310** Linear algebra
 Math 4330** Honors linear algebra

* These courses can fulfil the fourth engineering math requirement and/or be substituted for Physics 2214

** Only one of Math 4310 and 4330 can be taken for credit, and only one of Math 3110 and 4130 can be taken for credit

The following electives build on core topics in Operations Research. Taking a few electives in an area you're excited about builds depth and experience.

ORIE 4320 Nonlinear optimization
 ORIE 4330 Discrete models
 ORIE 4520 Introduction to stochastic processes II (stochastics at scale)
 ORIE 4741 Learning with Big Messy Data
 ORIE 6XXX Ph.D. courses
 CS 3220 Introduction to scientific computing
 Math 4410 Introduction to combinatorics I
 Math 4710 Basic Probability
 Math 4720 Statistics

The following course entails working on an independent project in Operations Research, appropriate for delving into research.

ORIE 4999 ORIE Project

More information and advice about how to best use the undergraduate curriculum to prepare for competitive Ph.D. programs can be found on the ORIE website and by speaking with your advisor.

Preparing for Ph.D. Programs: Sample Courses

Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 4
CHEM 2090	PHYS 1112	PHYS 2213	CS 2800	ORIE 3300	ORIE 3310	MATH 4330	ORIE 4330
MATH 1910	MATH 1920	MATH 2940	MATH 3040	ORIE 3500	ORIE 3510	ORIE 4999	ORIE 4320
ENGR 1101	CS 111x	ENGRD 2700	ORIE 3120	ORIE 3150	Behavioral Science	ORIE 4580	MATH 4410
First-Year Writing Seminar	First-Year Writing Seminar	ENGRD 2110		MATH 4130		CS 4820	ORIE 4741
PE	PE	Liberal Studies	Liberal Studies	Liberal Studies	Liberal Studies	Liberal Studies	Liberal Studies

POLICIES AND PROCEDURES

To maintain fair and uniform academic standards, the School has adopted the following policies and procedures to govern course registration and academic credit. The Associate Director of Undergraduate Studies, Prof. David Goldberg, and the Major Coordinator Max Schoenberger are responsible for most administrative aspects of the undergraduate curriculum.

Requirements for Affiliation

Students apply for affiliation at the end of the first semester of their sophomore year by visiting the Undergraduate Office in 203 Rhodes Hall. Requirements for OR&E affiliation are: at least C in each of MATH 2940 and ENGRD 2700; GPA \geq 2.2 in required math, science, and engineering courses (both overall and in the term immediately before affiliation); at least C- in all ORIE courses completed thus far. Good academic standing in the College of Engineering.

Advising

Advisors are assigned when a student is affiliated with the major. Students normally continue with this advisor through graduation.

Your advisor serves as a source of information on academic matters. These include, checking requirements, choosing elective courses, and advising on career planning and graduate schools. The approval of your assigned advisor is required on advisor approved elective forms and all petition forms.

You are encouraged to consult with other members of the faculty as well. One reason for getting acquainted with the faculty is that they can act as references for jobs and graduate schools.

Good Standing Status

Scholastic requirements are:

1. A cumulative grade point average of at least 2.0.
2. A cumulative grade point average of at least 2.0 in required ORIE courses.
3. At least C- in all Operations Research courses, and by the end of the sixth semester, a grade of at least C- in ENGRD 2110/CS 2110.
4. Satisfactory progress - a minimum of 12 credit hours per semester.
5. No failures or incompletes.

Students who fail to achieve good standing status may be warned, suspended for one or more terms, or denied permission to re-register in the major. The specific action in each case will be based upon the pertinent circumstances as well as the student's previous record.

Decisions regarding academic matters are made by the Academic Standards Committee of the School of OR&IE. Each student's record is reviewed at the end of each semester upon receipt by the School of semester grades. In cases for which some form of academic action is necessary, students may request the opportunity to appear personally before the committee.

Requirements for Graduating with Distinction

For students with a degree conferral date earlier than December 2026, Cum Laude requires a GPA ≥ 3.50 either overall or for each of the last four semesters. Magna Cum Laude requires a GPA ≥ 3.75 based on all credits taken at Cornell. Summa Cum Laude requires a GPA ≥ 4.00 based on all credits taken at Cornell. See "Courses of Study" for detailed information. Dean's List and Distinction are determined by the Engineering Registrar's Office in 158 Olin Hall.

For students with a degree conferral date of December 2026 or later, the College of Engineering will confer Latin honors based solely on final cumulative undergraduate GPA at the time of degree conferral, as follows: *Summa cum laude* – top 5%, *Magna cum laude* – next 10%, and *Cum laude* – next 15%.

Transfers

Applications to transfer from other majors in the College of Engineering are considered by the Academic Standards Committee on a case-by-case basis. In no event will a student be considered unless:

- 1 the student has completed ENGRD 2700 and MATH 2940 with a grade of "C" or better
AND
- 2 the student has a combined GPA of 2.2 or higher in required mathematics, science and engineering courses, and at least a C- in Operations Research and Information Engineering courses (including ENGRD 2110) taken so far.

A student contemplating transfer into OR&E should make an appointment with the Associate Director as early as possible. The student will need to complete a Change of Major form available in the Engineering Advising Office in 167 Olin Hall. Applications to transfer from outside the College of Engineering and Cornell University are handled by the Office of Undergraduate Admissions, Hollister Hall.

Course Load

The minimum course load for a full-time student in the College of Engineering is twelve credit hours **except in the student's final semester**.

Exceptions to Curriculum Requirements

Occasionally a student may perceive a need for an exception to one or more of the curriculum requirements, either a College or School requirement. Such exceptions are considered on a case-by-case basis by the appropriate College or School committee. See the *General Petition Form* at the end of this handbook.

S/U Option

No more than 15 S/U option credits will count toward a student's degree requirements (but S/U credits in Spring 2020 do not count towards the 15-credit limit). A student may take more than one S/U course in any one semester. If a course is offered S/U only, it will not count toward the 15-credit limit. Only courses in the humanities, social sciences, and advisor approved electives may be taken as S/U courses (except in Spring 2020 for which all courses are allowed to be S/U).

Approval for Courses Taken at Other Colleges and Universities

To receive credit for a course taken elsewhere, the student must obtain the approval of the department representative in charge of the course, or the Associate Director and the student's faculty advisor, PRIOR to taking the course. The request should be accompanied by written documentation including the name of the college, a course description, the number of credit hours, and the duration of the course (one quarter, one semester, etc.). Only in exceptional circumstances will approval be granted for technical courses; these must be offered by an accredited school of engineering. Forms can be found at <http://www.engineering.cornell.edu/resources/registrar/forms.cfm> or in Rhodes 203.

It is important to note that transfer credit will NOT be granted for ORIE Major Required Courses except for (1) transfer students who took an equivalent course at another institution prior to enrollment at Cornell, and (2) students formally enrolled in Cornell's Study Abroad program.

College Policy on Extramural Study, Withdrawal, Leaves of Absence

Residence Requirements: A candidate for an undergraduate degree in engineering shall be required to spend a minimum of four semesters, or the equivalent, in residence (full-time study) at this University, and a minimum of three semesters in residence as a student in a major field of engineering, or in the Independent Major.

Credit Earned Through Extramural Study: No more than 11 credits earned through study in the Extramural Division may be used to satisfy the requirements for the bachelor's degree in engineering.

Study in Absentia: Candidates for the degree may study away from the campus, with the permission of the appropriate faculty authority. Such students must register for Study in Absentia and pay an appropriate fee. For example, students going on Coop assignments are required to register in Absentia for the term that they are away from campus.

Leave of Absence: Students may temporarily suspend study for a period of time by taking a Leave of Absence. A formal petition for Leave of Absence must be filed and written approval must be granted for such a leave to be in effect. Leaves of Absence are normally granted for no more than two years. Credit earned while on Leave of Absence is subject to the limitation placed on extramural credit.

Withdrawal: A student who voluntarily withdraws from the degree program severs all connection with the College and University and may be re-admitted only on formal application for re-admission.

Students who fail either to register within the first three weeks of a semester, or to receive permission for Study in Absentia or Leave of Absence, may be involuntarily withdrawn by action of the faculty.

Student Responsibilities

Each undergraduate enrolled in the School of Operations Research and Information Engineering is responsible for timely selection, registration (including any changes which may be necessary), and completion of appropriate courses in each of several categories needed to fulfill the curriculum requirements of this School and the College of Engineering. Failure to discharge these responsibilities in a timely manner is likely to result in a delay in graduation and/or incorrect entries on the student's transcript. Each student is encouraged to examine their CHECKLIST as frequently as necessary. A student may obtain a copy of their checklist from the OR&IE Undergraduate Office in 278 Rhodes Hall.

ACADEMIC INTEGRITY

The School of Operations Research and Information Engineering adheres to the policies and procedures of the University on academic integrity, as stated in the *Policy Notebook for Students, Faculty, and Staff* (February 2000). The definition of academic integrity, as it appears in the *Policy Notebook* is as follows:

a. General Responsibilities

1. A student assumes responsibility for the content and integrity of the academic work they submit, such as papers, examinations, or reports.
2. A student shall be guilty of violating the Code and subject to proceedings under it if they:
 - a. Knowingly represents the work of others as their own.
 - b. Uses or obtains unauthorized assistance in any academic work.
 - c. Gives fraudulent assistance to another student.
 - d. Fabricates data in support of laboratory or field work.

b. Specific Guidelines

The following are the specific rules and regulations in regard to the general responsibilities listed under "a":

1. Examinations. During in-class examinations no student may use, give, or receive any assistance or information not given in the examination or by the proctor. No student may take an examination for another student. Between the time a take-home examination is distributed and the time it is submitted for grading by the student, the student may not consult with any persons other than the course professor and teaching assistants regarding the examination. The student is responsible for understanding the conditions under which the examination will be taken.
2. Course Assignments. Students are permitted to consult with others and receive advice and assistance. The copying of another student's work, computation, diagrams, analyses, laboratory reports, or commentaries is prohibited. It is plagiarism and a violation of this Code for anyone to represent another's published work as his own. If materials are taken from published sources, the student must clearly and completely cite the source of such materials. Work submitted by a student and used by a faculty member in the determination of grade in a course may not be submitted by that student in a different course.
3. The crucial underpinning of all specific guidelines regarding academic integrity remains that the student's submitted work, examinations, laboratory reports and term project, must be their own work and no one else's.

c. Variations

A faculty member may, at their discretion, make additions to or revisions of those guidelines in a particular course. It is their responsibility to make clear to their students and teaching assistants specific regulations concerning academic integrity that apply to work in their course.

In the School of Operations Research and Information Engineering, students are expected to exercise reasonable care to prevent their work from being copied or used by others. Students who knowingly facilitate the use of their work by others will be considered guilty of a violation of academic integrity.

The general procedures to be followed in cases of violation of academic integrity are as follows (details are found in the *Policy Notebook*):

1. The faculty member may summon the student to an interview, called a Primary Hearing, but this is not mandatory; the student is entitled to one week notice of the Primary Hearing. At the primary hearing there must be a third party, appointed by the School, present to witness the proceedings. If the faculty member finds the charge supported, he may impose a penalty of a failing grade in all or part of the course. A finding of guilt is to be reported to the student's college.

In the School of Operations Research and Information Engineering, the penalty for violations of academic integrity is automatic failure of the course involved, unless the faculty member determines that there are mitigating circumstances and chooses to impose a lesser penalty. Courses failed because of such violations may not be dropped.

Violations of academic integrity will be reported to the student's college, which will maintain a record, and may recommend a review by the Dean in cases of repeated violations by a student.

2. The case may be heard by the Academic Integrity Hearing Board of the College of Engineering if:

- a. The student wishes to appeal the findings of the primary hearing on one of three grounds: lack of due process, excessively harsh penalty, or contested judgment of the faculty member;
- or
- b. The faculty member wishes to impose a harsher penalty than failure of the course;
- or
- c. The faculty member wishes to omit the primary hearing;
- or
- d. The Dean summons the student because of repeated violations.

The Hearing Board may clear the student, affirm the penalty imposed by the faculty member, or impose a harsher penalty, including recording the violation on the student's transcript, suspension, or expulsion.

SPECIAL PROGRAMS

Minor: Operations Research and Management Science

Operations Research and Management Science (OR&MS) aims to support decision-making through modeling and analysis of complex systems. This understanding is used to predict system behavior and improve system performance. This minor gives the student opportunity to obtain a wide exposure to the core methodological tools for OR&MS, including mathematical programming, stochastic and statistical models, and simulation. All undergraduate students are eligible to complete the OR&MS minor except those majoring in ORIE or ISST. A list of OR&MS minor requirements can be found on page 30 of this handbook.

Engineering Co-Op Program

The Co-Op program is an excellent way to obtain practical experience, and therefore the School encourages participation in it. See the College of Engineering website for information (under "special programs").

Cornell University's Study Abroad Program

Opportunities are available for OR&E undergraduates to spend a semester studying abroad. Such opportunities present many advantages, cultural as well as curricular, and are encouraged by ORIE. In recent years, for example, OR&E students have taken advantage of full-semester programs at the University of New South Wales (Australia), the London School of Economics, University College London, City University London, Hong Kong University of Science & Technology, CEA Prague (Czech Republic), the University of Sydney (Australia), and other universities. It is important to note that at each of these universities the students took courses used to fulfill certain (technical) OR&E degree requirements; thus the study abroad experience was completed within the students' normal program of study lasting four years. See the College of Engineering website for more information (under "special programs").

Master of Engineering (ORIE)

As a two- or three-semester professional degree program, the ORIE Master of Engineering (MEng) has become highly valued in the marketplace and continues to be an attractive option for well prepared undergraduates in operations research, industrial engineering, mathematics, finance, and many other quantitative disciplines.

The main objectives of the MEng program at Cornell are to advance the breadth and depth of our students' technical knowledge and to provide students with opportunities to synthesize and apply this knowledge in a real-world environment. In ORIE, the technical tools of primary importance are mathematical modeling and the application of quantitative techniques instilled within the fields of optimization, probability, stochastic processes, statistics, and simulation. The areas of application for these tools are virtually limitless, although our MEng students most often choose to apply their knowledge to the design, operation, and improvement of business systems.

The capstone component of the ORIE MEng program is a team-based engineering design project, sponsored by company or organization, and completed with the guidance of a Cornell faculty advisor. The MEng project is fundamentally and purposefully different from traditional coursework and/or the completion of an individual Masters' thesis. The project is intended to prepare students for the professional arena by engaging them in client-sponsored project work with real data, deadlines, and deliverables. Students are expected to play major roles in all aspects of their projects, including formulating and analyzing the problem, managing the client relationship, monitoring the project timeline and milestones, and delivering the final results.

Early program planning is very important for students contemplating the MEng program. See ORIE's website for additional information, including the handbook. If you are seriously interested, you are encouraged to meet with the program's interim director, Prof. Eric Gentsch (elg46), to discuss the program.

M.S. and Ph.D. Programs

In operations research Ph.D. and M.S. programs, the problem areas and techniques are approached from a highly analytical viewpoint. Theories and techniques from mathematical programming, combinatorics, the theory of games, statistics, stochastic processes (queuing and inventory), scheduling, simulation, and the data sciences, are developed and used extensively. Consideration is given to the construction of appropriate mathematical models to represent various real-life operational systems and to the development of techniques for analyzing the performance of these models. Each student pursues a course of study and research emphasizing the use of the mathematical, probabilistic, statistical, and computational sciences. The ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying such techniques to problems in diverse fields. Those students contemplating M.S./Ph.D. study in operations research, either at Cornell, or elsewhere, should use their electives to obtain a strong mathematical background. See the earlier section, "Preparing for Ph.D. Programs".

Six-Year Joint Master of Engineering/MBA Program

The joint Master of Engineering/MBA program allows undergraduates in the College of Engineering to receive a Bachelor's degree and two professional Master's degrees in six years: the M.Eng. (ORIE) degree after the fifth year, and the MBA degree after the sixth year. This program is attractive for several reasons. First, the solid engineering background combined with a business background makes graduates of this program some of the most highly recruited students in the Johnson Graduate School of Management. Second, each year, eight students in this program are chosen as Knight Scholars and receive an award to support each of their two years of graduate study. These awards are named for Mr. Lester B. Knight (ME '29), who has generously provided funding for them. Third, since the MBA is normally a two-year program by itself, the combined program shortens the time needed to complete both degrees by one year.

Planning for this program takes place during the first weeks of the Spring term of the junior year and students must submit a formal application to the Johnson School. For additional information, google "johnson meng/mba", and meet with the interim director of ORIE's MEng program, Prof Eric Gentsch (elg46)

Five-Year Program

This program allows a student to obtain a baccalaureate degree after four years and a professional graduate management degree (MBA, MPA, or MPS) after a fifth year of study with the Johnson Graduate School of Management.

Careful planning is required for a successful integration of the work toward the two degrees. Students accepted for the 5-year program will need to have fulfilled almost all of their undergraduate degree requirements by the end of the junior year. A small number of Cornell undergraduates, from all colleges in the University, are accepted for the 5-year program each year. The competition for these places is, therefore, extremely keen.

For information, google "johnson 5-year bachelors/mba".

MISCELLANEOUS

Career Services Office

The Career Services Office (Carpenter Hall) has an extensive recruiting program. Hundreds of interviewing companies come to campus each year. Seniors should be in touch with the office no later than the first week of classes. Seniors will need to make recruiting preparations early since interview sign-ups usually begin during the first few weeks of the semester. Visit this office often and take advantage of the extensive opportunities it offers. The University Placement Office has a series of special lectures on how to approach the job market, preparation of resumes, how to take interviews, etc.

Cornell Student Chapter of the Institute for Operations Research and the Management Sciences (INFORMS)

The Student Chapter of INFORMS serves the purpose of introducing students to the professional aspects of the field, career opportunities, and a variety of social activities. Members may benefit by the opportunity to interact with other students and professors, and to learn about the latest developments and opportunities in ORIE and operations research generally.

As a service to the students and the School, INFORMS presents awards for Outstanding Professor and Teaching Assistant. The peer advisory program gives students the opportunity to consult with seniors and graduate students concerning course selections and career planning.

The Society of Women Engineers

The Society of Women Engineers is a professional, non-profit, educational service organization of graduate engineers and men and women with equivalent engineering experience. The objective of the Society is to encourage, assist, and inform young women, parents and counselors of the opportunities open to women in engineering. Hosting the Northeast Regional Conference and conducting a conference for high school students are a few of the major activities undertaken by the very active Cornell Chapter of SWE.

Seminars

In addition to the speakers sponsored by INFORMS, two regular seminar programs are organized by the School. There is a weekly seminar held on Tuesdays from 4:15-5:30 on research topics, and a seminar held on Wednesday from 4:30-5:30 on recent applications. Although the seminars are intended for faculty and graduate students, but undergraduates are welcome.

NOTE: ORIE 9000, 9100, 9101 or 9110 MAY NOT be used to fill the ORIE Elective requirement.

Awards for Outstanding Seniors

Several prizes have been established to recognize outstanding academic accomplishment in the Operations Research Engineering program, with certain awards designated specifically for students who intend to pursue the Master of Engineering degree. These prizes are named in honor of Cornell graduates who have made significant contributions in the field of Operations Research and Information Engineering.

Lynn E. Bussey dedicated his career to the teaching of engineering economics. His well-known text, "The Economic Analysis of Industrial Projects", is valued as a particularly thorough treatment of this topic at the graduate level. The Lynn Bussey Prize is awarded annually at commencement to an outstanding student in OR&E who is continuing in the ORIE Master of Engineering Program.

Allan H. Mogensen was one of the pioneers in the field of industrial engineering. He developed the concept of work simplification in the 1920's and led the movement for quality work and employee involvement from 1929 until his retirement in 1985. The Allan H. Mogensen award is also designated for an outstanding student in OR&E who is continuing in the ORIE Master of Engineering Program.

The Byron W. Saunders Award is named in honor of a former faculty member of the School of OR&IE who also served as Dean of the University Faculty. Professor Saunders devoted his energy for many years to the encouragement of excellence in academic performance by OR&E undergraduates. The Saunders prize is awarded each spring to the senior(s) who have achieved the best academic record in the School of OR&IE.

In 2008, Samuel M. Dell III ('65, MEng '66), a leader and manager at Exxon Mobil for 35 years, established the Geraldine and Sam Dell Master of Engineering Fellowship. This award recognizes exceptional students who were undergraduates at Cornell University and are pursuing a MEng in ORIE. The recipient(s) must demonstrate strong ethical grounding, leadership, teamwork, and have a fundamental understanding of the application of theory to practical business problems.

In recent years, Professor Muckstadt and his wife Linda endowed the *Jack and Linda Muckstadt Graduate Award for ORIE Master of Engineering Excellence*, a generous tuition award for a Cornell undergraduate to pursue the ORIE Master of Engineering degree. Recipients of the Muckstadt Fellowship are selected for their outstanding professional character, their leadership, and their passion for applying OR methods to practical business problems.

Suggestions Requested

This handbook was written to provide information to students who are currently enrolled in, or who are planning to enroll in the School of Operations Research and Information Engineering. Your suggestions would be appreciated. Please leave your comments in the School Office.

Appendix I: Courses Offered in ORIE

Not all courses are offered every academic year. See the Cornell Course Roster for a list of the courses that will be offered in a given semester.

ENGRI 1101 Engineering Applications of Operations Research

Fall, Spring. 3 credits. Enrollment not open to OR&E upper-class majors.

An introduction to the problems and methods of Operations Research and Industrial Engineering focusing on problem areas (including inventory, network design, and resource allocation), the situations in which these problems arise, and several standard solution techniques. In the computational laboratory, students encounter problem simulations and use some standard commercial software packages.

ENGRD 2700 Basic Engineering Probability and Statistics

Fall, Spring, Summer. 4 credits. Pre- or corequisite: MATH 2940.

This course gives students a working knowledge of basic probability and statistics and their application to engineering. Computer analysis of data and simulation are included. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

ORIE 1380 Data Science for All

Spring. 4 credits. Enrollment not open to OR&E upper-class majors.

This course provides an introduction to data science. Given data from economics, medicine, biology, or physics, collected from internet denizens, survey respondents, or wireless sensors, how can one understand the phenomenon generating the data, make predictions, and improve decisions? We focus on building skills in inferential thinking and computational thinking, guided by the practical questions we seek to answer. The course teaches critical concepts and skills in computer programming and statistical inference, in conjunction with hands-on analysis of real-world datasets including economic data, document collections, geographical data, and social networks. We will also consider social issues in data analysis such as privacy and design.

ORIE 3120 Practical Tools for Operations Research, Machine Learning, and Data Science

Spring. 4 credits. Prerequisite: ENGRD 2700.

The practical use of software tools and mathematical methods from operations research, machine learning, statistics and data science. Software tools include structured query language (SQL), geographical information systems (GIS), Excel and Visual Basic programming (VBA), and programming in a scripting language (either R or Python). Operations research methods include inventory management, discrete event simulation, and an introduction to the analysis of queuing systems. Machine learning and statistical methods include multiple linear regression, classification, logistic regression, clustering, time-series forecasting, and the design and analysis of A/B tests. These topics will be presented in the context of business applications from transportation, manufacturing, retail, and e-commerce.

ORIE 3150 Financial and Managerial Accounting

Fall. 4 credits.

Course covers: principles of accounting, financial reports, financial-transactions analysis, financial-statement analysis, budgeting, job-order and process-cost systems, standard costing and variance analysis, and economic analysis of short-term decisions.

ORIE 3300 Optimization I

Fall. 4 credits. Prerequisite: grade of C- or better in MATH 2210 or 2940.

Formulation of linear programming problems and solutions by the simplex method. Related topics such as sensitivity analysis, duality, and network programming. Applications include such models as resource allocation and production planning. Introduction to interior-point methods for linear programming.

ORIE 3310 Optimization II

Spring. 4 credits. Prerequisite: grade of C- or better in ORIE 3300 or permission of instructor.

A variety of optimization methods stressing extensions of linear programming and its applications but also including topics drawn from integer programming, dynamic programming, and network optimization. Formulation and modeling are stressed as well as numerous applications.

ORIE 3500 Engineering Probability and Statistics II

Fall. 4 credits. Prerequisite: grade of C- or better in ENGRD 2700 or equivalent.

This second course in probability and statistics provides a rigorous foundation in theory combined with the methods for modeling, analyzing, and controlling randomness in engineering problems. Probabilistic ideas are used to construct models for engineering problems, and statistical methods are used to test and estimate parameters for these models. Specific topics include: random variables, probability distributions, density functions, expectation and variance, multidimensional random variables, and important distributions including normal, Poisson, exponential, hypothesis testing, confidence intervals, and point estimation using maximum likelihood and the method of moments.

ORIE 3510 Introductory Engineering Stochastic Processes I

Spring. 4 credits. Prerequisite: grade of C- or better in ORIE 3500 or equivalent.

Basic concepts and techniques of random processes are used to construct models for a variety of problems of practical interest. Topics include the Poisson process, Markov chains, renewal theory, models for queuing, and reliability.

ORIE 4100 Design of Manufacturing Systems

4 credits. Senior OR&E students only. Others by permission of instructor only.

Can simultaneously satisfy Engineering Communications requirement and Major-Approved Elective.

This project-based course puts students in the roles of analysts and advisors to an industrial firm facing broad challenges in customer service, product quality, market share, and profitability. Students, working in teams, design a manufacturing logistics system and conduct capacity, material flow, and cost analyses of their design. By taking a view that integrates marketing, distribution, manufacturing, and engineering, students help the company transform into a world-class competitor.

ORIE 4120 Inventory, Operations, and Supply Chain Management: Models & Optimization

2 credits.

This course will provide a rigorous coverage of the (stochastic and deterministic) models commonly used in the study of inventory, operations, and supply chain management. This includes the multi-period newsvendor model and its many variants, as well as more sophisticated models which arise in supply chain management, logistics, and the study of operations more broadly. We will study tools for analyzing and optimizing such systems, as well as operational insights which can be extracted from such models. The course will in general have a fairly mathematical orientation, focusing on using tools from stochastic modeling, optimization, and dynamic programming/algorithms to formulate and analyze these models.

ORIE 4126 Principles of Supply Chain Management

4 Credits

Supply chain management focuses on the flow of products, information, and money through organizations that constitute the supply chain. The course provides an overview of the key principles on which an effective supply chain should be constructed. These principles are presented and illustrated through a collection of cases. These cases are taught using an experiential learning model. Additionally, applications of analytic and simulation tools to the design and operation of supply chains are given.

ORIE 4130 Service System Modeling and Design

3 credits. Prerequisites: ORIE 3310 or 5311; ability to program simple algorithms in some appropriate environment (e.g., VisualBasic or MATLAB).

Today's economy is dominated by service industries. These systems differ from manufacturing industries in many ways, but primarily in the level of interaction with the customer. Examples of service systems include contact centers (aka call centers), airlines, and hospitals. This course covers various techniques that are useful in the analysis and design of such systems. The class is structured around a number of cases that drive the need for the theory. The emphasis is on modeling and solving the models. Both operational and strategic decisions are covered through appropriate examples.

ORIE 4150 Economic Analysis of Engineering Systems

4 credits. Prerequisites: ORIE 3300 and ORIE 3150.

Course topics include: financial planning, including cash-flow analysis and inventory flow models; engineering economic analysis, including discounted cash flows and taxation effects; application of optimization techniques, as in equipment replacement or capacity expansion models, and issues in designing manufacturing systems. Includes a student group project.

ORIE 4152 Entrepreneurship for Engineers

3 credits. Enrollment open to upper class engineers; others with permission of instructor.

This course develops skills necessary to identify, evaluate, and begin new business ventures. Topics include intellectual property, competition, strategy, business plans, technology forecasting, finance and accounting, and sources of capital. A rigorous, quantitative approach is stressed throughout, and students create financial documents and plans, analyze human resource models, and work with sophisticated valuation methods, complicated equity structures, and legal and business documents. As such, this course represents the "red meat" of entrepreneurship, and the soft skills are left for other courses. Coursework consists of discussions, assignments, and the preparation and presentation of a complete business plan.

ORIE 4154 Revenue Optimization and Marketplace Design

3 credits, Prerequisites: ORIE 3300 and 3500, or permission of instructor

Application of modeling and optimization techniques in designing a company's interface with the market. We will cover a variety of topics (product pricing and capacity control; designing product assortments and customer segmentation; the use of customer data in modeling and optimization; the design of online platforms and markets), with examples from transportation, retail, hospitality and the sharing economy.

ORIE 4160 Topics in Data Science and OR

3 credits Prerequisite: ORIE 3120, ORIE 3300, ORIE 3310, ORIE 3500, ORIE 3510

Each year, the course will cover a different advanced topic at the intersection of data science and operations research, with the specific topic to be chosen by the instructor that year. The class will entail advanced reading, homework, and course project. Example semester-long topics include: Multi-arm bandit models in ML and OR, Statistical recovery in data science and OR, Graphical models in data science and OR, Causal inference in data science and OR, and Reinforcement learning in data science and OR.

ORIE 4330 Discrete Models

4 credits. Prerequisites: ORIE 3300 and CS 2110, or permission of instructor.

Course covers basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific optimization models studied include flows in networks, the traveling salesman problem, and network design.

ORIE 4340 Introduction to Game Theory

4 credits. Prerequisites: ORIE 3300, ORIE 3500

This course will cover the use of optimization models in several industries. Covered industries will include manufacturing, process, distribution, retail, and transportation. We will not cover models used exclusively in the financial industry. In each covered industry we will start with simple text-book models to reflect the realities of the industry, the existing business decisions processes and the available data. We expect to have lectures from experts in some of these industries, each of whom will also discuss Operations Research roles and careers.

ORIE 4350 Introduction to Game Theory

4 credits. Prerequisites: ORIE 3300

A broad survey of the mathematical theory of games, including such topics as: two-person matrix and bimatrix games; cooperative and noncooperative n-person games; and games in extensive, normal, and characteristic function form. Economic market games. Applications to weighted voting and cost allocation.

ORIE 4390 Optimization Models for Logistics, Markets, and Networks

1.5 Credits Prerequisite: ORIE 3300 and ORIE 3310, or permission of instructor. Hands-on experience with integer linear programming and dynamic programming: creating ILPs and DPs, implementing them, critiquing them, understanding solver output, and improving ILPs using better variables, constraints, symmetry breaking, etc. Examples of problems that we will study in this course are logistical problems like sequencing in production, scheduling problems with conflicts (vertex coloring), matching problems for markets and clustering problems in networks, but are not limited to these domains. In addition, a variety of general linear programming techniques such as Fourier-Motzkin elimination, Dantzig-Wolfe decomposition, Benders decomposition and extended formulations may be covered, as well as rounding techniques of LP solutions.

ORIE 4520 Introductory Engineering Stochastic Processes II

4 credits. Prerequisite: ORIE 3510 or equivalent.

Course topics include: stationary processes, martingales, random walks, and gambler's ruin problems, processes with stationary independent increments, Brownian motion and other cases, branching processes, renewal and Markov-renewal processes, reliability theory, Markov decision processes, optimal stopping, statistical inference from stochastic models, and stochastic comparison methods for probability models. Applications to population growth, spread of epidemics, and other models.

ORIE 4580 Simulation Modeling and Analysis

4 credits. Prerequisite: ORIE 3500 (may be taken concurrently) and CS/ENGRD 2110.

Introduction to Monte Carlo and discrete-event simulation. Emphasis on tools and techniques needed in practice. Random variate generation, input and output analysis, modeling using a discrete-event simulation package.

ORIE 4600 Introduction to Financial Engineering

3 credits. Prerequisites: ORIE 3500 and 3510.

This is an introduction to the most important notions and ideas in modern financial engineering, such as arbitrage, pricing, derivatives, options, interest rate models, risk measures, equivalent martingale measures, complete and incomplete markets, etc. Most of the time the course deals with discrete time models. This course can serve as a preparation for a course on continuous time financial models such as OR&IE 568.

ORIE 4630 Operations Research Tools for Financial Engineering.

3 credits. Prerequisites: engineering math through MATH 2940 and ORIE 2700 and 3500.

This course is an introduction to the applications of OR techniques, e.g., probability, statistics, and optimization, to finance and financial engineering. No previous knowledge of finance is required. The course first reviews probability and statistics and then surveys assets returns, ARIMA time series models, portfolio selection, regression, CAPM, option pricing, GARCH models, fixed-income securities, resampling techniques, and behavioral finance. The use of MATLAB, MINITAB, and SAS for computation is also covered.

ORIE 4740 Statistical Data Mining

4 credits. Prerequisites: ORIE 3500 and MATH 2940 or equivalent; programming experience. Exposure to multiple linear regression and logistic regression strongly recommended.

This course examines the statistical aspects of data mining, the effective analysis of large data sets. The first half of the course covers the process of building and interpreting statistical models in a variety of settings including multiple regression and logistic regression. The second half connects these ideas to techniques being developed to handle the large data sets that are now routinely encountered in scientific and business applications. Assignments are done using one or more statistical computing packages.

ORIE 4741 Learning with Big Messy Data

4 Credits. Prerequisite: linear algebra and matrix notation, a modern scripting language (Python, Matlab, Julia, R), and basic complexity on $O(n)$ notations.

Modern data sets, whether collected by scientists, engineers, medical researchers, government, financial firms, social networks, or software companies, are often big, messy, and extremely useful. This course addresses scalable robust methods for learning from big messy data. We'll cover techniques for learning with

data that is messy — consisting of real numbers, integers, booleans, categoricals, ordinals, graphs, text, sets, and more, with missing entries and with outliers — and that is big — which means we can only use algorithms whose complexity scales linearly in the size of the data. We will cover techniques for cleaning data, supervised and unsupervised learning, finding similar items, model validation, and feature engineering. The course will culminate in a final project in which students extract useful information from a big messy data set.

ORIE 4742 Information Theory, Probabilistic Modeling, & Deep Learning with Scientific & Financial Applications

3 credits. Prerequisite: ORIE 3500 and MATH 2940. Programming experience. Exposure to statistical machine learning at the level of ORIE 4740 or ORIE 4741.

This course is about building and understanding machine learning models for scientific and financial applications. It will cover foundational aspects of information theory and probabilistic inference as they relate to model construction and deep learning. Topics include hamming codes, repetition codes, entropy, mutual information, Shannon information, channel capacity, likelihood functions, Bayesian inference, graphical models, and deep neural networks. The section on deep neural networks will consider fully connected, convolutional, recurrent, and LSTM networks, generative adversarial training, and variational autoencoders.

ORIE 4820 Spreadsheet-Based Modeling and Data Analysis

3 credits. Prerequisites: ORIE 3300, ENGRD 2700, or equivalent.

Students develop and implement practical spreadsheet models to analyze data and evaluate decision problems in a hands-on learning environment. Microsoft Excel is heavily used. A wide variety of application areas are covered that incorporate concepts from probability, statistics, and constrained optimization.

ORIE 5126 Principles of Supply Chain Management

4 credits. Prerequisites ORIE 3310, 3510, or MBA courses in operations management.

Supply chain management focuses on the flow of products, information, and money through organizations that constitute the supply chain. The course provides an overview of the key principles on which an effective supply chain should be constructed. These principles are presented and illustrated through a collection of cases. These cases are taught using an experiential learning model. Additionally, applications of analytic and simulation tools to the design and operation of supply chains are given.

ORIE 5140 Model Based Systems Engineering

4 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.

Fundamental ideas of systems engineering, and their application to design and development of various types of engineered systems. Defining system requirements, creating effective project teams, mathematical tools for system analysis and control, testing and evaluation, economic considerations, and the system life cycle.

ORIE 5142 Systems Analysis Architecture, Behavior, and Optimization

3 credits. Prerequisite: ORIE 5140.

An advanced course in the application of the systems engineering process to the design and operation of complex systems. It focuses on the descriptive and analytical tools of systems engineering including optimization, discrete event simulation, dynamic systems, statistics for design and control, and decision analysis. Case studies are presented in the application of these techniques to space transportation, power, manufacturing, transportation, nuclear power licensing, and military systems.

ORIE 5370 Optimization Modeling in Finance

3 credits. Prerequisites: ORIE 3300/5300 and basic knowledge of statistics, probability and finance.

Explores optimization in the context of finance, including methodologies beyond linear programming, such as second-order cone programming and semidefinite programming. Topics include Markowitz portfolio theory and modeling, factor models for portfolio selection and risk control; the Black-Litterman model (and related Bayesian topics); utility functions; coherent risk measures; stochastic programming; and optimal execution of portfolio transactions. Emphasis is on concepts that are directly implementable. Homework and project require considerable coding in MATLAB.

ORIE 5550 Applied Time-Series Analysis

4 credits. Prerequisites: ORIE 3510, or permission of instructor.

The first part of this course treats regression methods to model seasonal and nonseasonal data. After that, Box-Jenkins models, which are versatile, widely used, and applicable to nonstationary and seasonal time

series, are covered in detail. The various stages of model identification, estimation, diagnostic checking, and forecasting are treated. Analysis of real data is carried out. Assignments require computer work with a time-series package.

ORIE 5582 Monte Carlo Methods in Financial Engineering

2 credits. Weeks 8-14. Prerequisite: ORIE 4580

An overview of Monte Carlo methods as they apply in financial engineering. Generating sample paths. Variance reduction (including quasi random number), discretization, and sensitivities. Application to derivative pricing and risk management.

ORIE 5600 Financial Engineering with Stochastic Calculus I

4 credits. Prerequisite: knowledge of probability at the level of ORIE 3500.

This course is an introduction to continuous-time models of financial engineering and the mathematical tools required to use them, starting with the Black-Scholes model. Driven by the problem of derivative security pricing and hedging in this model, the course develops a practical knowledge of stochastic calculus from an elementary standpoint, covering topics including Brownian motion, martingales, the Ito formula, the Feynman-Kac formula, and Girsanov transformations.

ORIE 5610 Financial Engineering with Stochastic Calculus II

4 credits. Prerequisite: ORIE 5600.

Building on the foundation established in ORIE 5600, this course presents no-arbitrage theories of complete markets, including models for equities, foreign exchange, and fixed income securities, in relation to the main problems of financial engineering: pricing and hedging of derivative securities, portfolio optimization, and risk management. Other topics include model calibration and incomplete markets.

ORIE 5620 Credit Risk: Modeling, Valuation and Management

3 credits. Prerequisite: ORIE 5600.

Credit risk refers to losses due to changes in the credit quality of a counter party in a financial contract. This course is an introduction to the modeling and valuation of credit risks. Emphasis is on credit derivative instruments used for hedging credit risks, including credit swaps, spread options, and collateralized debt obligations.

ORIE 5640 Statistics for Financial Engineering

4 credits. Pre- or corequisite ORIE 3500 and at least one of OIRE 4600, 4630 or 5600.

Time series, GARCH, and stochastic volatility models. Calibration of financial engineering models. Estimation of diffusion models. Data mining in financial engineering. Estimation of risk measures. Bayesian statistics. This course is intended for M.Eng. student in financial engineering and assumes some familiarity with finance and financial engineering. Students not in the M.Eng. program are welcome if they have a suitable background. Students with no background in finance should consider taking ORIE 4600.

ORIE 5650 Quantitative Methods of Financial Risk Management

3 credits. Prerequisites: ORIE 3500

Market Risk. We start with a historical perspective of market risk measurement including the Markowitz, CAPM and APT models. We will then give a closer description of the value-at-risk approach and give an overview of VaR variants and extensions such as delta-VaR, CVaR etc. This section will require a survey of extreme value methods for determining VaR. We will also survey rapidly other methods for evaluating risk and consider multivariate methods for evaluating portfolios requiring copula tools which have become popular. Time permitting, we will survey topics in credit risk: methods for determining default probabilities and company ratings based on financial ratios (logit, probit and discriminant analysis, decision trees etc.), and introduce the main approaches to measuring credit risk which can be roughly divided into structural models and reduced-form models.

**School of Operations Research & Information Engineering
Approved Elective Form**

Name

Expected Degree Date

Email Address

CU ID Number

Advisor's Name

Course to be applied towards the Approved Elective Requirement (6 credits total):

Course #

Course Title

Term Taken

Advisor's Signature

Date

(Please submit form to ORIE Undergraduate Office in 278 Rhodes.)

School of Operations Research & Information Engineering General Petition Form

Last Name First Name

Today's Date

Expected graduation date Advisor's Name

Email Address

I request permission to:

Signature Date

Advisor Statement:

Signature Date

Departmental Approval:

_____ **Request Approved**

_____ **Request Denied**

Comments:

Associate Director, ORE Date

Classes of 2023,2024,2025 Checklist for the OR&E Major
See CoE and OR&E Handbooks for Details

Any course can be used only once, with exceptions for the technical communication requirement.

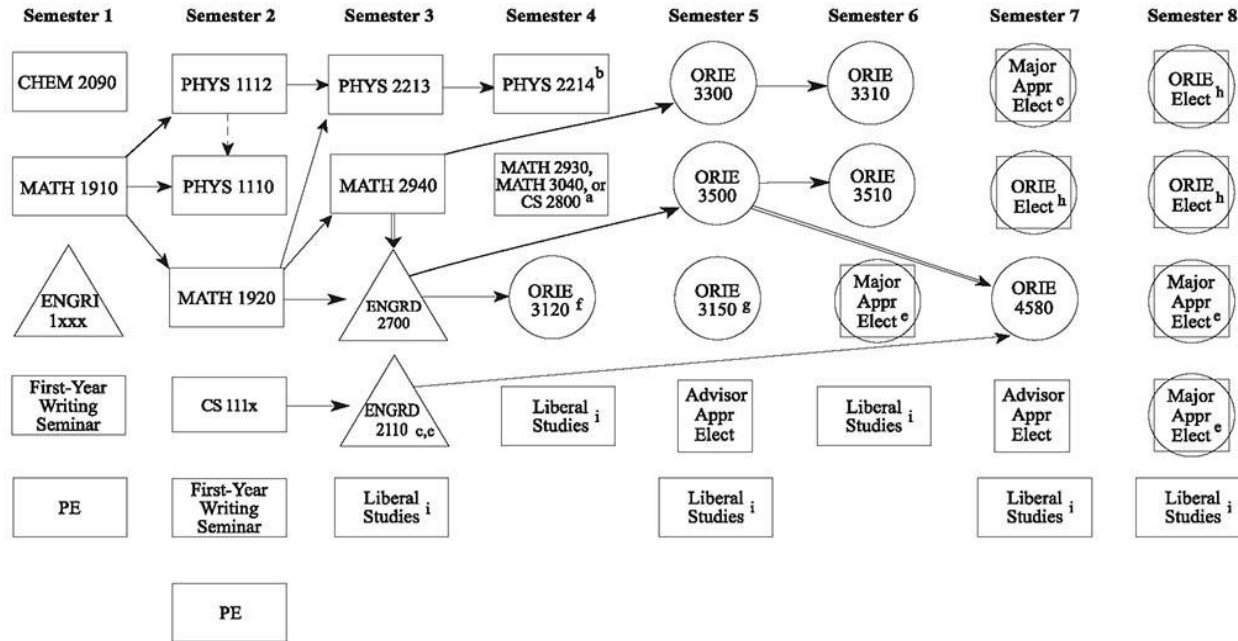
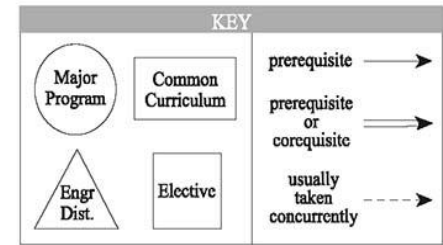
course	credits	term	grade	
College Requirements				
Engineering Courses (at least C-, at least C in noted courses)				
Core Courses				
CHEM 2090	4			
CS 1110 or 1112	4			1110 recommended
MATH 1910	4			
MATH 1920	4			
MATH 2940	4			At least C required
PHYS 1112	4			
PHYS 2213	4			
Choose One Course From Each Set				
CS 2800; MATH 2930, 3040				
CHEM 2080, 2150; CS 2800; MATH 3040, 3110, 3360				
Distribution Courses (2 courses)				
ENGRD 2700				At least C required
ENGRD				
ENGRD 2110 is required, used here or as major-approved elective, cat A				
Introductory Course (1 course)				
ENGR1				1101 recommended
Other				
First-Year Writing Seminars (2 courses)				
Liberal Studies (6 courses, 18 credits) category (CA, HA, etc.)				
Physical Education (2 courses + swim test)				
Technical Communication				
				ORIE 4100 allowed

course	credits	term	grade	
Major Requirements				
Required Courses				
ORIE 3120				
ORIE 3300				
ORIE 3310				
ORIE 3500				
ORIE 3510				
ORIE 4580				
Choose one course				
ORIE 3150, 6XXX; MATH 3110, 4130, 4310, 4330				
ORIE Electives (9 credits)				
(Not ORIE 4152, 9000, 9100, 9101 or 9110.)				
Major-Approved Electives (12 credits)				
At least 6 credits in category A, at least 6 outside ORIE				
(see handbook for lists of courses) A or B				
Advisor Approved Electives (6 credits)				
Optional: ORE Honors Program (9 credits)				
Unused Courses				

Operations Research and Engineering Major (ORE)

Requirements for Major Affiliation: Operations Research and Engineering

At least C in ENGRD 2700 and MATH 2940. GPA ≥ 2.2 in all required math, science, engineering, and CS courses (both overall and in the term immediately before affiliation).
At least C- in all completed ORIE courses. Good academic standing in the college.



Note: The Engineering Communications Requirement must be met and may be taken as a liberal studies, Advisor-Approved Elective, or Major course.⁴

Minor: Operations Research and Management Science

Eligibility

All undergraduates except those majoring in ORIE or ISST. A student may receive credit for at most one minor offered by ORIE.

Educational Objectives

Operations Research and Management Science (OR&MS) aims to support decisionmaking through modeling and analysis of complex systems. This understanding is used to predict system behavior and improve system performance. This minor gives the student the opportunity to obtain a wide exposure to the core methodological tools for OR&MS, including mathematical programming, stochastic and statistical models, and simulation. The intent of this minor is to provide a broad knowledge of the fundamentals, rather than training the student in a particular application domain. With this preparation, students can adjust their advanced courses and pursue either methodological or application-oriented areas most relevant to their educational goals.

Requirements

At least six (6) courses (≥ 18 credits), chosen as follows:

Choose three courses from the following list:

ENGRD 2700: Basic Engineering Probability and Statistics

ORIE 3300: Optimization I

ORIE 3310: Optimization II

ORIE 3500: Engineering Probability and Statistics II

ORIE 3510: Introduction Engineering Stochastic Processes I

ORIE 4580: Simulation Modeling and Analysis

Any ORIE courses at the 3000 level or higher (including those above). At most, three of these credits can be satisfied by undergraduate research in ORIE, team project courses in ORIE, and TAship in ORIE combined.

Academic Standards

At least C- in each course in the minor and a GPA ≥ 2.0 in all courses in the minor.