INDUSTRIAL ENGINEERING AND MANAGEMENT SCIENCES

Degree Types: PhD

The Industrial Engineering and Management Sciences PhD Program (https://www.mccormick.northwestern.edu/industrial/phd-program/) produces researchers who combine strength in core methodologies of operations research (e.g., optimization, stochastic modeling and simulation, statistics, and data analytics) with the ability to apply them to yield practical benefits in solving problems that are important in the real world. The program offers students the opportunity to use skills in computing, mathematical analysis and modeling, and economics to produce research that helps to improve the efficiency, quality, and the potential of organizations to fulfill their missions. The program prepares students for research-based careers in industry, academia, non-profit, and government.

Areas of specialization include Analytics, Stochastic Analysis & Simulation, Optimization, Financial Engineering, Logistics & Operations, Healthcare Engineering, Applied Statistics &Statistical Learning, and Management Science.

Applicants must have a bachelor's or master's degree in a relevant discipline, but need not have a degree in industrial engineering. The program has attracted students of applied mathematics, computer science, economics, finance, mathematics, physics, statistics, and most other engineering disciplines.

Additional resources:

- Department website (https://www.mccormick.northwestern.edu/industrial/)
- Program handbook(s)

Degree Offered

- Industrial Engineering and Management Sciences PhD (https://catalogs.northwestern.edu/tgs/industrial-engineering-management-sciences/industrial-engineering-management-sciences-phd/)

Learning objective(s)/Students should be able to…

- Identify and design a research problem
- Use Operations Research methodologies to analyze problems
- Assess the intellectual and broader impact of research results
- Lead a research project independently
- Teach and communicate their knowledge
- Enact ethical research methodologies and practice

Industrial Engineering and Management Sciences Courses

IEMS 303-0 Statistics (1 Unit)
Introduction to the foundations of statistics and statistical computing for data analysis and their applications. Descriptive statistics and statistical inference for estimation, testing, and prediction. May not receive credit for both IEMS 303-0 and any of IEMS 201-0, BMD_ENG 220-0, or CHEM_ENG 312-0. May not be taken for credit with or after STAT 320-1.
Prerequisites: IEMS 302-0 or equivalent; COMP_SCI 150-0 or equivalent.

IEMS 304-0 Statistical Learning for Data Analysis (1 Unit)
Predictive modeling of data using modern regression and classification methods. Multiple linear regression; logistic regression; pitfalls and diagnostics; nonparametric and nonlinear regression and classification such as trees, nearest neighbors, neural networks, and ensemble methods.
Prerequisites: IEMS 303-0 and COMP_SCI 150-0 or equivalents.

IEMS 307-0 Quality Improvement by Experimental Design (1 Unit)
Methods for designing and analyzing industrial experiments. Blocking; randomization; multiple regression; factorial and fractional factorial experiments; response surface methodology; Taguchi's robust design; split plot experimentation. Homework, labs, and project.
Prerequisite: IEMS 201-0, IEMS 303-0, or equivalent.

IEMS 308-0 Data Science and Analytics (1 Unit)
Focuses on select problems in data science, in particular clustering, association rules, web analytics, text mining, and dimensionality reduction. Lectures will be completed with exercises and projects in open source framework R. Prior knowledge of classification techniques and R is required.
Prerequisites: IEMS 304-0; COMP_SCI 217-0.

IEMS 310-0 Operations Research (1 Unit)
Survey of operations research techniques. Linear programming, decision theory, stochastic processes, game theory. May not be taken for credit with or after IEMS 313-0.
Prerequisites: IEMS 201-0 or IEMS 302-0; GEN_ENG 205-1 or MATH 240-0.

IEMS 313-0 Foundations of Optimization (1 Unit)
Formulation and solution of applicable optimization models, including linear, integer, nonlinear, and network problems. Efficient algorithmic methods and use of computer modeling languages and systems. Homework, exams, and project.
Prerequisites: GEN_ENG 205-1; MATH 228-1; COMP_SCI 110-0 or COMP_SCI 111-0 or COMP_SCI 150-0; sophomore standing.

IEMS 315-0 Stochastic Models (1 Unit)
Fundamental concepts of probability theory; modeling and analysis of systems having random dynamics, particularly queueing systems.
Prerequisites: IEMS 302-0; COMP_SCI 150-0; GEN_ENG 205-1; and prior completion of or concurrent enrollment in IEMS 303-0.

IEMS 317-0 Discrete Event Systems Simulation (1 Unit)
Computer simulation of discrete-change systems subject to uncertainty. Choice of input distributions; development of models; design and analysis of simulation experiments. Mini-projects, exams, and computer labs.
Prerequisites: IEMS 303-0; IEMS 310-0 or IEMS 315-0.

IEMS 325-0 Engineering Entrepreneurship (1 Unit)
Overview of the entrepreneurial process from an engineering perspective. Idea generation, planning, financing, marketing, protecting, staffing, leading, growing, and harvesting. Business models for startups. Lectures, guest speakers, and case studies. Taught with IEMS 325-0; may not receive credit for both courses.
Prerequisite: 1 course in accounting or finance such as CIV_ENV 205-0 or ENTREP 330-1.

IEMS 341-0 Social Networks Analysis (1 Unit)
The use of social network analysis to understand the growing connectivity and complexity in the world around us on different scales, ranging from small groups to the World Wide Web. How we create social, economic, and technological networks, and how they enable and constrain attitudes and behaviors.

IEMS 342-0 Organizational Behavior (1 Unit)

Manager's view of tools available to recruit, develop, appraise, compensate, organize, and lead a team going through change. Application of psychological principles relating to human dynamics, motivation, teams, power, and organizational culture. Lectures, guest speakers, and exams. Work experience recommended.

IEMS 343-0 Project Management for Engineers (1 Unit)
A case study-based exploration of the body of project management knowledge. Key topics include project scheduling, risk management, project leadership, small-group dynamics, project methodologies, lifecycle concepts, and project controls. A Socratic approach is taken to exploring various case studies in the context of established and leading-edge project management concepts.
Prerequisites: CIV_ENV 205-0 and IEMS 303-0.

IEMS 344-0 Whole-Brain Leadership (1 Unit)
This course examines whole-brain thinking and leading. Students will draw upon previous work and leadership experience to identify their own thinking and leading preferences and those of team member, and will examine contrasting thinking and leading styles in an effort to appreciate and combine these to produce optimal outcomes. A number of leadership theories and ways of leading will be examined including creative and agile leadership. Analytical thinkers/leaders will be challenged to spend more time with innovation and creativity, while creative thinkers/leaders will be presented with opportunities to engage in analytical problem-solving. Work experience recommended.
Prerequisite: Junior standing.

IEMS 345-0 Negotiations and Conflict Resolution for Engineers (1 Unit)
In this highly interactive class, students participate in negotiation and dispute resolution simulations that range in complexity from single-party/single-issue to multiparty/ multi-issue cases. In addition students explore the role of agents and third parties in the managing conflict. Throughout all of the simulations integrative and distributive strategies are emphasized that can be applied across a variety of contexts.
Prerequisite: Junior standing.

IEMS 351-0 Optimization Methods in Data Science (1 Unit)
Introduction to nonlinear mathematical optimization with applications in data science. The theoretical foundation and the fundamental algorithms for nonlinear optimization are studied and applied to supervised learning models, including nonlinear regression, logistic regression, and deep neural networks. Students write their own implementation of the algorithms in the Python programming language and explore their performance on realistic data sets.
Prerequisites: COMP_SCI 111-0 and IEMS 303-0 and IEMS 313-0, or equivalent.

IEMS 373-0 Intro to Financial Engineering (1 Unit)
Financial markets, derivative securities, risk management, mathematical models in finance. Foreign exchange, debt, equity, commodity markets. Investing, trading, hedging, arbitrage. Forwards, futures, options, swaps, exotic derivatives. Models of price dynamics, binomial model, introduction to Black-Scholes theory and Monte Carlo simulation. Homework, projects, and guest speakers.
Prerequisites: CIV_ENV 205-0, IEMS 302-0, IEMS 303-0 or equivalents, or consent of instructor.

IEMS 381-0 Supply Chain Modeling and Analysis (1 Unit)
Application and development of mathematical modeling tools for the analysis of strategic, tactical, and operational supply-chain problems, including facility location, customer assignment, vehicle routing, and inventory management. Related topics including the role of information and decision support systems in supply chains. Homework, exams, and project.
Prerequisite: IEMS 313-0.

IEMS 382-0 Operations Engineering and Management (1 Unit)
Applications of operations research methods in managing and control of operations processes in manufacturing and service systems: including operations strategy; process-flow analysis; forecasting; capacity management; variability analysis; flow time and inventory management; flexible operations; lean operations; and production and workforce scheduling in manufacturing and service systems. Case studies, homework, and exams.
Prerequisites: IEMS 302-0; IEMS 310-0 or IEMS 313-0.

IEMS 383-0 Service Engineering and Management (1 Unit)
Exploration of service industries: cost-reduction and service-enhancement models, location planning, workforce scheduling, yield management, queuing analysis, and call-center management.
Prerequisites: IEMS 313-0, IEMS 315-0.

IEMS 385-0 Introduction to Health Systems Management (1 Unit)
Health systems, lean concepts, patient-flow analysis, inference, and data-driven knowledge generation, decisions, and change. Forecasting, operations, and optimization of health resources.
Prerequisites: IEMS 303-0, IEMS 313-0.

IEMS 395-0 Special Topics in Industrial Engineering (1 Unit)
Topics suggested by students or faculty members and approved by the department.

IEMS 401-0 Applied Mathematical Statistics (1 Unit)
An applied perspective on mathmatical statistics. Topics include estimation, statistical decision theory, sufficency and likelihood principle, unbaised estimation, convergence concepts, maximum likelihood estimation, Bayesian estimation, confidence intervals, hypothesis tests, non-parameteric estimation and confidence intervals.
Prerequisite: IEMS 303-0 or equivalent.

IEMS 402-0 Statistical Learning (1 Unit)
The amount of data in our world has been exploding and analyzing large data sets is a central societal challenge. The course introduces statistical principles and computational tools for analyzing big data. Topics include statistical modeling and inference, model selection and regularization, scalable computational algorithms, and more.
Prerequisites: IEMS 401-0 or equivalent (i.e. graduate-level statistics and probability).

IEMS 404-1 Predictive Analytics I (1 Unit)
Parametric regression and classification models for analyzing medium to large data sets.

IEMS 404-2 Predictive Analytics II (1 Unit)
This course covers nonparametric modeling of complex, nonlinear predictive relationships between variables. Covered supervised learning methods include neural networks, trees, nearest neighbors, local kernel weighting, boosted trees, random forests, support vector machines, and naive Bayes. Emphasis is on practical implementation of predictive modeling, as well as theoretical concepts for building a deeper understanding of the methods.

IEMS 405-0 Mathematical Foundations of Statistical Learning (1 Unit)
Basics of information theory. Concentration, information, stability, and generalization; minimax lower bounds. Nonparametric regression; exponential family and maximum entropy; and online learning and bandits.
Prerequisites: IEMS 401-0 or equivalent (i.e., graduate-level statistics and probability).

IEMS 407-0 Uncertainty Quantification (1 Unit)

"Computational techniques for modern uncertainty quantification which includes uncertainty representation, uncertainty propagation, surrogate inference, calibration, approximate inference and evaluation. Covers computational tools including Monte Carlo, sensitivity analysis, quasi-Monte Carlo, Markov chain Monte Carlo, variational inference, experimental design, divergences, and scoring rules. Prerequisites: Prerequisites: An understanding of graduate level statistics and probability and being comfortable with a scripting language like python, R, or matlab will prove helpful.".

IEMS 408-0 Decision Making in Dynamic Learning Environments (1 Unit)
Decision making in stochastic and dynamic environments plays an essential role in many areas, including finance, robotics, game theory, revenue management and social networks. This course aims to gain a theoretical understanding for some popular tools used to solve these problems. Topics include: theoretic foundations of reinforcement learning/dynamic programming, multi-armed bandit problems and its solutions, random graph models for social and economic networks which can be used to explain small world phenomena, wealth concentration and disease/information spreading.
Prerequisites: probability theory, real analysis or equivalent for mathematical maturity.

IEMS 411-0 Field Research in Organizations (1 Unit)
Methods for testing and evaluating proposed improvements or changes in the management of technical projects or organizations. Topics include problem identification and design and pilot test of data-gathering protocols (interviews, questionnaires, observation and records) for a real-world problem chosen by the student.

IEMS 434-0 Systems Methodology (1 Unit)
Introduction to the concept of a system and unstructured, multidisciplinary problems. Fundamental systems models and concepts, modeling, and selected decision-making approaches.

IEMS 435-0 Stochastic Simulation (1 Unit)
Introduction to stochastic discrete-event simulation for graduate students, covering simulation modeling and programming; probability foundations of stochastic simulation; proper design and analysis of the simulation experiment; and simulation for research.
Prerequisites: IEMS 202-0 and IEMS 303-0 or equivalent; previous programming experience in some language.

IEMS 441-0 Social Network Analysis (1 Unit)
This seminar is intended to overview theoretical, computational, and analytic issues associated with network perspectives on communicating and organizing. The course will review scholarship on the science of networks in communication, computer science, engineering, organizational science, and social sciences in order to take an in-depth look at theories, methods, and tools to examine the structure and dynamics of networks.

IEMS 443-0 Health Policy Modeling (1 Unit)
PhD level course on the application of mathematical, satistical, economic, and systems models to problems in health policy.

IEMS 444-1 Healthcare Management Science (1 Unit)
The course focuses on models and methods for health resource allocation and utilization, planning, operations, polcies, logistics, and treatments. A particular focus will be on predictive modeling techniques, multi-objective and stochastic decision making. Contemporary topics will be included as appropriate.

IEMS 445-0 Decision and Risk Analysis (1 Unit)
Theory and practice of decision making under uncertainty. Decision trees, influence diagrams, the value of information; Bayesian approaches, including conjugate and predictive distributions; utility theory foundations, risk preference, multi-attribute utility.
Prerequisite: IEMS 202-0 or equivalent.

IEMS 446-0 Game Theory and Networked Systems (1 Unit)
The strategic interactions among multiple agents is a fundamental feature of many networked systems. Examples include peering agreements among Internet Service Providers, licensing agreements for wireless spectrum, designing the right incentives for crowdsourcing platforms, competition among producers of electricity, engaging robotic groups to cooperate. Game theory is a basic tool for understanding such interactions. This course gives an interdisciplinary introduction to the fundamentals of game theory and it applications to such networked systems. Linear Algebra (e.g. Math 240 or GenEng 205-1), Probability (e.g. ELEC_ENG 302, IEMS 302), basic optimization and mathematical maturity.

IEMS 450-1 Mathematical Optimization I (1 Unit)
Linear programming formulation, simplex algorithm, optimality conditions, duality, sensitivity analysis, robust optimization, network flow, discrete optimization, Lagrangian method.
Prerequisites: Linear algebra and calculus.

IEMS 450-2 Mathematical Optimization II (1 Unit)
Constrained and unconstrained nonlinear optimization: Optimality conditions; linesearch and trust-region methods; Newton and quasi-Newton methods; active-set methods; augmented Lagrangian, sequential quadratic programming and interior point methods; convergence theory for numerical algorithm.
Prerequisites: Linear algebra and calculus.

IEMS 451-0 Stochastic Optimization (1 Unit)
Optimization under uncertainty, including modeling and applications; exact optimization methods; deterministic approximation and bounding techniques; and Monte Carlo sampling-based approximations.
Prerequisites: IEMS 450-1 and IEMS 401-0.

IEMS 452-0 Combinatorial Optimization (1 Unit)
Efficient methods and min-max results for combinatorial optimization problems including minimum spanning trees, shortest paths, maximum flows, minimum cost flows, matching; polyhedral combinatorics; complexity theory.
Prerequisite: IEMS 450-1 or equivalent.

IEMS 453-0 Robust Optimization (1 Unit)
Optimization with uncertain variables or parameters to find solutions that are both optimal and immune to uncertainties. Covers computational tools and applications including supply chains, revenue management, energy, portfolio theory, options pricing, risk management, healthcare, statistics and engineering design.
Prerequisite: IEMS 450-1 or equivalent.

IEMS 454-0 Large Scale Optimization (1 Unit)
Algorithms for large-scale optimization. Ellipsoid method and complexity of linear programming; equivalence of separation and optimization; path-following interior point methods, including self-dual methods; decomposition algorithms, including column generation and row generation for linear, nonlinear, and integer programming; selected applications.
Prerequisite: IEMS 450-1.

IEMS 455-0 Machine Learning (1 Unit)
A survey of large-scale machine learning with emphasis on neural networks and kernel methods, including model formulation, large-scale applications and training (optimization). Case studies include text classification, image and speech recognition, and recommender systems. Construction of deep neural networks for large data sets.

Prerequisites: IEMS 202-0, IEMS 303-0 and IEMS 313-0 (or equivalent) and computer programming.

IEMS 456-0 Distributed Optimization (1 Unit)
Large-scale networks and datasets, coming from applications such as Internet, wireless sensor networks, robotic networks and large-scale machine learning problems, are an integral part of modern technology. One main characteristic of these systems is the lack of centralized access to information due to either communication overhead or the large scale of the network. Therefore, control and optimization algorithms deployed in such networks should be completely distributed, relying only on local information and processing. This course studies various models and algorithms in the distributed and parallel settings. Topics include graph theory, algorithms for solving linear equations, iterative methods for convex problems, synchronous and asynchronous setups, consensus algorithms and rate analysis.
Prerequisites: One course in optimization (including primal, dual problems, Lagrangian functions), linear algebra, calculus, familiar with real analysis or permission of instructor.

IEMS 457-0 Integer Programming (1 Unit)
Methods for NP-hard discrete optimization problems including general methods like branch and bound and cutting planes, as well as special purpose branch-and-cut methods and heuristics.
Prerequisite: IEMS 450-1 or equivalent.

IEMS 459-0 Convex Optimization (1 Unit)
The course develops expert knowledge in the theory and algorithms for convex optimization. Emphasis is on understanding fundamental properties of convex sets and functions, and on the role of duality. Covers practical algorithms.
Prerequisites: IEMS 202-0, IEMS 303-0 (or equivalent), and IEMS 450-1 or IEMS 450-2 (or equivalent).

IEMS 460-1 Stochastic Processes I (1 Unit)
Review of probability theory, Poisson processes, discrete-time Markov chains, continuous-time Markov chain, introduction to queuing theory. Theory and applications.
Prerequisite: Permission of instructor.

IEMS 460-2 Stochastic Processes II (1 Unit)
Bernoulli processes, Poisson processes, Markov chains, Markov processes, renewal theory, regenerative process, and queuing models. Theory and applications.
Prerequisite: Permission of instructor.

IEMS 463-0 Statistical Analysis (1 Unit)
Principles of experimental design and their application to the analysis of standard designs including one-way layout, block designs, factorial/fractional factorial experiments, random/mixed effect models, nested/split-plot designs.

IEMS 464-0 Advanced Queueing Theory (1 Unit)
Queueing networks, the single-server queue, heavy-traffic approximations for the G/G/1 queue. Advanced level.
Prerequisite: IEMS 460-1 or equivalent.

IEMS 465-0 Simulation Experiment Design & Analysis (1 Unit)
Selected current topics in modern stochastic simulation research, including variance reduction, simulation optimization, model risk, and simulation analytics.
Prerequisites: IEMS 435-0, IEMS 401-0 and IEMS 460-1, or equivalent.

IEMS 468-0 Stochastic Control (1 Unit)
Optimal control of Markov chains, dynamic programming, finite horizon and discounted models, and applications in operations research.
Prerequisite: IEMS 460-1.

IEMS 469-0 Dynamic Programming (1 Unit)
Theoretical and computational aspects of solving stochastic sequential decision problems. Material supported by many real-world applications.

IEMS 473-1 Financial Engineering I (1 Unit)
Advanced derivative securities. Fixed income markets and derivatives. Risk management. Mathematical models and computational tools of financial engineering.

IEMS 481-0 Logistics (1 Unit)
This course will provide an introduction to modeling and solution methods for facility location, transportation and inventory management decisions. By the end of the quarter, you should learn to model and formulate a variety of logistics problems; to develop and assess solution methods for these problems; and to use these tools to analyze strategic, tactical, and operational supply-chain decisions. Co-requisites: IEMS 450-1. Students should be familiar with some high-level programming language.

IEMS 482-0 Operations (1 Unit)
First Quarter: Introduction to production/logistics including: multi-objective, stochastic and dynamic facility location problems, multi-echelon and multi-item inventory models and heuristic, approximate and exact vehicle routing algorithms. Second Quarter: Introduction to production/distribution facility design and control, capacity management, push and pull production systems: MRP, JIT, ConWIP; introduction to deterministic and stochastic production scheduling: job shop, flow shop.
Prerequisites: IEMS 450-1 and at least concurrent enrollment in IEMS 460-1.

IEMS 484-0 Inventory and Distribution Systems (1 Unit)
Multistage inventory and production models, multiproduct systems, distribution systems, and random yield models.
Prerequisites: IEMS 481-0 and IEMS 482-0.

IEMS 486-0 Introduction to Smart Grid Systems (1 Unit)
The new generation electricity power network, a.k.a., smart grid, is a complex socio-technical system involving nonlinear physical constraints, large scale computations and intricate economic/environmental impacts. This course gives an interdisciplinary perspective of the grid: the fundamental physics of the grid; the related modeling and computation challenges; basic game theoretic tools and analysis of the dynamic market interactions.
Prerequisites: Multi-variable calculus, linear algebra, basic optimization and game theory, or consent of the instructor.

IEMS 488-0 Economics and Decision Analysis (1 Unit)
This course is a collection of decision models with applications in operations management, economics, supply chains, and revenue management. It is designed to complement the operations research methodologies taught in core graduate courses in IEMS department. The goal of the course it to familiarize students with different operations research modeling and solution methodologies that can be used to solve research problems.

IEMS 490-0 Selected Topics in IE (1 Unit)

IEMS 496-0 Graduate Topics in Industrial Engineering (0-1 Unit)
Topics suggested by faculty and approved by the department. Credit dependent on topic and length of course.

IEMS 499-0 Projects (1-3 Units)
SEE DEPT FOR SECTION AND PERMISSION NUMBERS - Special projects under faculty direction. Permission of instructor and department required. May be repeated for credit.

IEMS 519-0 Responsible Conduct of Research Training (0 Unit)

IEMS 590-0 Research (1-3 Units)

Independent investigation of selected problems pertaining to thesis or dissertation. May be repeated for credit. SEE DEPT FOR SECTION AND PERMISSION NUMBERS.