

# Industrial and Systems Engineering

## Mission Statement

*To pursue excellence and national prominence in the areas of manufacturing, operations research, information technology and related fields of industrial and systems engineering through innovative teaching, distinguished research and scholarship, and active professional leadership. Building on its unique strength and national reputation in undergraduate education and industrial research, the department strives for leadership in educational innovation, multidisciplinary research, and industrial partnership. Our ultimate mission is to produce leaders who have learned to think critically and analytically, have the skills and techniques to comprehend and create new knowledge, and are willing to serve and inspire others.*

## Physical Facilities

The industrial and systems engineering department is located in the Harold S. Mohler Laboratory at 200 West Packer Avenue at the northwest corner of the Lehigh University Asa Packer campus. The Mohler Lab building contains the classrooms, laboratories, and faculty offices of the department. Labs in the Mohler Laboratory building include:

*Computational Optimization Research @ Lehigh (COR@L) Lab.* The COR@L lab consists of high performance computer workstations, each equipped with state-of-the-art commercial and noncommercial software for large-scale numerical optimization. COR@L is used for both research and instruction.

*Enterprise Systems Center Laboratories.* The ESC Laboratories contain a variety of computer systems and software in support of agility in Computer Integrated Manufacturing (CIM) and in engineering logistics and distribution problem solving, including: Computer Aided Design (CAD) and Engineering (CAE), discrete event simulation, linear and nonlinear optimization, Finite Element Analysis (FEA), facilities design, process design, process control, and analytics software, such as the SAS software suite.

*Manufacturing Technology Laboratory (MTL).* The MTL contains equipment for instruction and research in manufacturing processes, numerical control (NC), NC part programming, material handling and storage, industrial control systems, and metrology.

*Automation and Robotics Laboratory.* This lab is located in the MTL, it contains a variety of industrial robots and other automated systems to provide students with hands-on experience in the planning and use of this kind of equipment.

*Work Systems Laboratory.* This classroom/laboratory affords the opportunity for undergraduate students to analyze and plan human work activities for individual workstations and worker team situations. A full scale manual assembly line is available for study.

*ISE Computer Laboratories.* Considerable use is made of university computer facilities in ISE coursework. ISE/computing center PC laboratories containing 38 and 16 PCs, respectively, are located in the Mohler Laboratory building.

**Professors.** Theodore K. Ralphs, PHD (Cornell University); Katya Scheinberg, PHD (Columbia University); Lawrence V Snyder, PHD (Northwestern University); Robert H. Storer, PHD (Georgia Institute of Technology); Tamas Terlaky, PHD (Eotvos Lorand University); Luis Nunes Vicente, PHD (Rice University); Emory W. Zimmers, Jr., PHD (Lehigh University)

**Associate Professors.** Frank E. Curtis, PHD (Northwestern University); Alberto Lamadrid, PHD (Cornell University); Eugene Perevalov, PHD (University Texas, Austin); Louis J. Plebani, Jr., PHD (Lehigh University); Gregory L. Tonkay, PHD (The Pennsylvania State University); George R. Wilson, PHD (The Pennsylvania State University); Luis Zuluaga, PHD (Carnegie Mellon University)

**Assistant Professors.** Boris Defourny, PHD (Universite de Liege); Martin Takac, PHD (University of Edinburgh); Xiu Yang

**Professors Of Practice.** Ana Iulia Alexandrescu, MS (Lehigh University); Pasquale (Pat) J. Costa, BS (The Pennsylvania State University); Derya Pamukcu, PHD (Louisiana State University); Janos D. Pinter, PHD (Lomonosov Moscow State University)

**Emeriti.** John W. Adams, PHD (University of North Carolina); Keith M Gardiner, PHD (Manchester College); Mikell P. Groover, PHD (Lehigh University); John C Wiginton, PHD (Carnegie Mellon University); Szu-Yung D. Wu, PHD (The Pennsylvania State University)

## B.S. in Industrial & Systems Engineering

Industrial & Systems Engineering (ISE) is concerned with the analysis, design, and implementation of integrated systems of people, materials, information, and equipment to accomplish useful work.

## Career Opportunities

ISE graduates are sought by nearly all industrial corporations as well as government agencies and other service institutions. Major employers of our graduates include management consulting firms, manufacturing companies, banks, hospitals, railroads, the postal service, and transportation/logistics services. A typical career path of an industrial and systems engineer is to start in an entry level engineering position or as a technical analyst and to progress through various management positions in the firm or institution. Significant numbers of industrial and systems engineers ultimately become chief executive officers, chief operating officers, and chief technology officers in their respective organizations.

### Production Systems Career Opportunities

The discipline of industrial & systems engineering is applicable in nearly all industries, whether the industry involves manufacturing of a product or delivery of a service. Job functions performed by ISEs include: systems analysis, cost estimation, capital equipment selection, engineering economy, facilities planning, production planning and scheduling, inventory control, quality control, project management, operations management, engineering management, as well as methods analysis and work measurement. Manufacturing systems engineering (MSE) is a specialty field associated with industrial and systems engineering that emphasizes functions and technologies such as process planning, plant layout design, manufacturing resource planning, production management, production line design, automation, robotics, flexible manufacturing systems, and computer integrated manufacturing.

### Information Systems Career Opportunities

The Industrial & Systems Engineering program can also produce graduates who understand the complex facets of modern information systems, and the integration of these systems in industrial, service and financial organizations. The ISE student has an opportunity to focus on three important areas that are key to a successful information systems-oriented career. (1) Information Economics, (2) Quantitative Systems Analysis, and (3) Information Technology. These areas are coupled with general engineering and business background courses. Information economics studies the formulation, structure, and operational dynamics of information-centric systems in the context of industrial organizations, service sector economics, and financial institutions. Quantitative systems analysis studies operations research and computational tools for analyzing complex systems and their information components. Information technology and applications studies computer and communication technologies needed to design and implement information system applications. Topic areas include the applications of information technology in manufacturing and business environments, including electronic commerce, supply chain and enterprise information systems, manufacturing information systems, and financial enterprises.

## ISE Curriculum

The ISE curriculum is designed to provide graduates with the skills and knowledge that employers expect of young industrial and systems engineers beginning their professional careers, and to instill the ability for lifetime learning. It includes the basic mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design that are specific to industrial

and systems engineering. These principles and methods include probability and statistics, engineering economy, cost accounting, operations research, computer simulation, work methods and measurement, manufacturing processes, production and inventory control, and information technology.

In the junior year, an ISE student may elect to specialize more in production systems by choosing a course in modern manufacturing methods. Alternatively, a student may elect to specialize more in information systems by choosing a course in computer algorithm design. An ISE student must choose at least one of these courses, but may elect to choose both for a broader preparation for a career.

Specialized ISE electives in the senior year include: advanced optimization models, stochastic models, operations research, operations management, organization planning and control, statistical quality control, database design, web technologies, and data communications technologies. Electives related to manufacturing systems engineering include: industrial robotics, facilities planning and material handling, logistics and supply chain, and production engineering.

### Program Educational Objectives

The set of key, over-arching objectives of the Industrial and Systems Engineering program are to prepare our students, within the first several years of the beginning of their careers, to

1. meet the expectations of employers of industrial and systems engineers,
2. pursue advanced study, if desired,
3. be active leaders in their profession and/or community.

Specifically, these general objectives can be met by graduates that

1. recognize and analyze problems, design innovative solutions, and lead their implementation,
2. excel as industrial and systems engineering professionals who are able to operate effectively in a global, culturally diverse society,
3. communicate effectively using written, oral, and electronic media,
4. pursue life-long learning and professional growth as ethical and responsible members of society,
5. form, lead, and participate on multi-disciplinary teams that solve problems in engineering and business.

In each course in the Industrial & Systems Engineering program, a subset of the student outcomes, listed below, are pursued to prepare students to achieve the Industrial and Systems Engineering program's stated objectives. This list of student outcomes articulated by the Engineering Accreditation Commission of ABET, <http://www.abet.org>, have been adopted by the program and are as follows:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

### ISE Major Requirements

The ISE degree requires a minimum of 130 credit hours.

See freshman year requirements on the First Year Courses for Engineering Degrees under the heading of the P.C. Rossin College of Engineering and Applied Science (<http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience>) An HSS course is assumed to be taken in the freshman year in the following semester course plans.

Sophomore					
Fall	Credits	Spring	Credits		
ISE 111	3	ISE 121	3		
ISE 112	1	ISE 131	3		
MATH 023	4	ISE 132	1		
PHY 021	4	MATH 205	3		
PHY 022	1	MAT 033 or CSE 017	3		
Engineering Elective <sup>3</sup>	3	ECO 001 or HSS 3-4 Elective <sup>1</sup>	1		
CSE 002	2				
	18		16-17		
Junior					
Fall	Credits	Spring	Credits	Summer	Credits
ISE 230	3	ISE 240	3	ISE 100	0
HSS Electives <sup>1</sup>	6-8	ISE 224	3		
Select one of the following:	4	Engineering Elective <sup>3</sup>	3		
ISE 172		ISE 305	3		
ISE 215 & ISE 216		ISE 226	3		
Engineering Elective <sup>3</sup>	3	HSS Elective <sup>1</sup>	3-4		
	16-18		18-19		0
Senior					
Fall	Credits	Spring	Credits		
ISE 251	3	ISE Technical Electives <sup>2</sup>	6		
ISE Technical Electives <sup>2</sup>	6	Free Electives	6		
ACCT 108	3	ISE 254 <sup>4</sup>	3		
Free Elective	3				
HSS Elective <sup>1</sup>	3-4				
	18-19		15		

Total Credits: 101-106

### Notes:

<sup>1</sup> HSS elective credit totals must satisfy the college HSS program requirements.

<sup>2</sup> **ISE Technical Electives** include all ISE 300-level courses (except ISE 305, which is required), ISE 275, the CSE 2XX (except CSE 241 and CSE 252) and 3XX courses, the BIS 3XX courses, and MATH 230. In addition, ISE 215 can be used as a technical elective, if ISE 172 is selected as a core course. Conversely, if ISE 215 and ISE 216 are selected as core courses, ISE 172 can be used as a technical elective. ISE 256 can be used as a technical elective. Of the 4 ISE technical electives that must be taken, at least 2 must be ISE courses.

<sup>3</sup> **Engineering Elective Course Candidates:** Courses of 3 or more credits with course prefixes of BIOE, CHE, CEE, CSE, ECE, MAT, ME, or MECH for which the prerequisites are met. The courses with these prefixes that are excluded from consideration are listed on the following ISE Dept. web page: <https://ise.lehigh.edu/content/courses>. The list of excluded courses for an individual ISE major is governed by the catalog in force when admitted to Lehigh. A provisional course offered with one of these prefixes requires departmental approval. Any course meeting these stipulations is denoted "Engineering Elective Requirement" in the ISE program description. A course counts toward meeting only one course requirements category for the ISE program.

<sup>4</sup> The senior project course, ISE 254, requires senior standing and can be taken in either the fall or spring semester of the senior year.

### Special Opportunities for ISE students

The following special opportunities are available to majors in industrial and systems engineering:

**Nontechnical Minor.** Students may choose to pursue a nontechnical minor in an area of the humanities, social sciences, business, or entrepreneurship. Students in the business minor can satisfy the ACCT 108 requirement by completing BUS 127.

**Technical Minor.** Technical minors such as engineering leadership, materials science, environmental engineering, and computer science are available through departments in the P. C. Rossin College of Engineering and Applied Science. Consult the specific department for more details.

**Graduate Courses.** Seniors in industrial and systems engineering can petition to take up to two graduate ISE courses (400-level) to satisfy two of their four 300-level elective ISE course requirements. The petitioning senior must have a good scholastic record (generally above a 3.0 GPA).

**Senior Thesis Option.** Students interested in continuing on to graduate school or performing research are encouraged to take the senior thesis option. In this option a student takes ISE 255 as a free elective to develop the thesis proposal. ISE 255 serves as a prerequisite to ISE 256 in which the thesis is written. ISE 256 may be used as an ISE technical elective.

### Technical Minor in Engineering Leadership

The minor in engineering leadership provides students with the background and practice to become more effective leaders. The minor consists of 5 courses that explore different aspects of leadership. Additional details can be found on the Engineering Leadership Minor website (<http://lehigh.edu/~inleader/>).

### Technical Minor in Manufacturing Systems Engineering

The minor in manufacturing systems engineering provides a concentration of courses in the manufacturing and production areas. This minor is not available to students majoring in industrial and systems engineering. It requires 16 credits.

### Graduate Programs

Several programs leading to master's and doctoral degrees are offered by the Department of Industrial and Systems Engineering. Each program has core requirements. Core requirements can be satisfied by previous coursework upon petition of the ISE curriculum committee. All core course prerequisites must also be satisfied. Prerequisites may be satisfied by (1) previous course work, (2) completing the prerequisite course without graduate credit, or (3) passing the final examination of the prerequisite course with a grade of B or better.

A Ph.D. student is required to complete core requirements with grades of B or better before being formally admitted to Ph.D. candidacy.

Further information about graduate programs is contained in an ISE graduate brochure available from the department. In addition, documents are available from the department that describe the requirements of each graduate program, both at the ISE departmental office and on its web page.

### M.S. in Industrial and Systems Engineering

The minimum program for the master of science degree in Industrial and Systems Engineering consists of 24 credit hours of approved coursework and completion of a satisfactory thesis. Courses in other

departments for which the student has the prerequisites may be integrated into this program. Subject to advisor approval, up to nine credit hours of 300 and 400-level courses from other departments may be included in the Industrial and Systems Engineering masters program. The other department courses usually include other engineering disciplines, mathematics, computer science, and business and economics.

### M.Eng. in Industrial and Systems Engineering

This program of study is for those students whose interests are toward engineering design rather than research. The program provides opportunity to gain greater breadth of field through 30 credit hours of coursework (which can include a 3-credit-hour project).

### M.S. in Management Science and Engineering

See separate catalog listing under Management Science and Engineering (<http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/managementscienceandengineering>).

### M.Eng. in Management Science and Engineering

See separate catalog listing under Management Science and Engineering (<http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/managementscienceandengineering>).

### M.Eng. in Healthcare Systems Engineering

This concentrated degree program is designed to prepare graduate students for engineering and management careers in firms engaged in delivering healthcare and health related products and services. See separate catalog listing under Healthcare Systems Engineering (<http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/healthcaresystemsengineering>).

### M.S. in Analytical Finance

The Masters in Analytical Finance program combines key concepts in financial theory, mathematical finance and engineering decision making to produce professionals instrumental in creating innovative solutions to real financial issues. See separate catalog listing under Interdisciplinary Graduate Study and Research (<http://catalog.lehigh.edu/coursesprogramsandcurricula/interdisciplinarygraduatestudyandresearch/analyticalfinance>).

### Ph.D. in Industrial and Systems Engineering

The graduate program leading to the doctor of philosophy (Ph.D.) degree is organized to meet the individual goals and interests of graduate students whose professional plans include teaching, consulting, or research in an educational, governmental, or industrial environment. Each doctoral candidate is required to demonstrate: (1) a high level of proficiency in one or more fields of industrial and systems engineering, and (2) a capacity for independent research through the preparation of a dissertation related to his/her field of specialization.

This is to be facilitated as follows. During the first year of study, all Ph.D. students must complete the following core courses (or a substitute approved by the Ph.D. program coordinator): ISE 401, ISE 402, ISE 406, ISE 429, ISE 417, and ISE 418. During the second year all PhD students must pass ISE 407. At the end of the first year, each student must declare one of the following three methodological fields of study:

- Optimization, or
- Applied Probability and Statistics
- Applied Operations Research

In addition to the core courses, two courses in each of the three fields of study are required. Following the first year, an initial review, consisting of faculty evaluation, classroom performance, and a qualifier exam, must be passed. A review by the student's dissertation committee must be passed in each subsequent year, along with the required dissertation proposal and general exam.

**Courses****ISE 100 Industrial Employment 0 Credits**

Usually following the junior year, students in the industrial engineering curriculum are required to do a minimum of eight weeks of practical work, preferably in the field they plan to follow after graduation. A report is required. Must have sophomore standing.

**ISE 111 Engineering Probability 3 Credits**

Random variables, probability models and distributions. Poisson processes. Expected values and variance. Joint distributions, covariance and correlation.

**Prerequisites:** MATH 022 or MATH 096 or MATH 032 or MATH 052

**ISE 112 Computer Graphics 1 Credit**

Introduction to interactive graphics and construction of multiview representations in two and three dimensional space. Applications in industrial engineering. Must have sophomore standing in industrial engineering.

**ISE 121 Applied Engineering Statistics 3 Credits**

The application of statistical techniques to solve industrial problems. Regression and correlation, analysis of variance, quality control, and reliability.

**Prerequisites:** ISE 111 or MATH 231 or IE 111

**ISE 131 Work Systems and Operations Management 3 Credits**

Workermachine systems, work flow, assembly lines, logistics and service operations, and project management. Operations analysis, methods engineering, work measurement, lean production, and six sigma. Workplace ergonomics, plant layout design, and work management.

**Prerequisites:** ISE 111 or MATH 231 or IE 111

**Can be taken Concurrently:** ISE 111, MATH 231, IE 111

**ISE 132 Work Systems Laboratory 1 Credit**

Laboratory exercises, case studies, and projects in operations analysis, methods engineering, work measurement, and plant layout design.

**Prerequisites:** ISE 131 or IE 131

**Can be taken Concurrently:** ISE 131, IE 131

**ISE 168 (EMC 168) Production Analysis 3 Credits**

A course for students not majoring in industrial engineering. Engineering economy; application of quantitative methods to facilities analysis and planning, operations planning and control, work measurement, and scheduling.

**Prerequisites:** MATH 021 or MATH 031 or MATH 051 or MATH 075 or MATH 076

**ISE 172 Algorithms in Systems Engineering 4 Credits**

Use of computers to solve problems arising in systems engineering. Design and implementation of algorithms for systems modeling, systems design, systems analysis, and systems optimization. Computer systems, basic data structures, the design and implementation of efficient algorithms, and application of algorithms to the design and optimization of complex systems such as those arising in transportation, telecommunications, and manufacturing. Weekly laboratory with exercises and projects.

**Prerequisites:** CSE 017 or CSE 018

**ISE 215 Fundamentals of Modern Manufacturing 3 Credits**

Manufacturing processes and systems. Metal machining and forming, polymer shape processes, powder metallurgy, assembly and electronics manufacturing. Introduction to automation, numerical control, and industrial robots.

**Prerequisites:** MAT 033

**ISE 216 Manufacturing Laboratory 1 Credit**

Laboratory exercises and experiments in manufacturing processes and systems.

**Prerequisites:** ISE 215 or IE 215

**Can be taken Concurrently:** ISE 215, IE 215

**ISE 224 Information Systems Analysis and Design 3 Credits**

An introduction to the technological as well as methodological aspects of computer information systems. Content of the course stresses basic knowledge in database systems. Database design and evaluation, query languages and software implementation. Students that take CSE 241 cannot receive credit for this course.

**ISE 226 Engineering Economy and Decision Analysis 3 Credits**

Economic analysis of engineering projects; interest rate factors, methods of evaluation, depreciation, replacement, breakeven analysis, aftertax analysis. decision-making under certainty and risk.

**Prerequisites:** ISE 111 or MATH 231 or IE 111

**Can be taken Concurrently:** ISE 111, MATH 231, IE 111

**ISE 230 Introduction to Stochastic Models in Operations****Research 3 Credits**

Formulating, analyzing, and solving mathematical models of real-world problems in systems exhibiting stochastic (random) behavior. Discrete and continuous Markov chains, queueing theory, inventory control, Markov decision process. Applications typically include traffic flow, call centers, communication networks, service systems, and supply chains.

**Prerequisites:** ISE 111 or IE 111 or MATH 231

**ISE 240 Introduction to Deterministic Optimization Models in Operations Research 3 Credits**

Formulating, analyzing, and solving mathematical models of real-world problems in systems design and operations. A focus on deterministic optimization models having parameters that are known and fixed. Algorithmic approaches for linear, integer, and nonlinear problems. Solving optimization problems utilizing specialized software.

**Prerequisites:** MATH 205

**ISE 251 Production and Inventory Control 3 Credits**

Techniques used in the planning and control of production and inventory systems. Forecasting, inventory models, operations planning, and scheduling.

**Prerequisites:** ISE 121 and ISE 230 and ISE 240

**Can be taken Concurrently:** ISE 230, ISE 240

**ISE 254 Senior Project 3 Credits**

The use of industrial and systems engineering techniques to solve a major problem in either a manufacturing or service environment. Problems are sufficiently broad to require the design of a system. Human factors are considered in system design. Laboratory.

**ISE 255 Senior Thesis I 3 Credits**

In-depth study of a research topic in industrial and systems engineering supervised by an Industrial and Systems Engineering department faculty member. Requires completion of a formal research proposal and a public presentation of the proposal at the end of the semester.

**ISE 256 Senior Thesis II 3 Credits**

Continued in-depth study of a research topic in industrial and systems engineering supervised by an Industrial and Systems Engineering department faculty member. Requires a formal thesis and public presentation of the results.

**Prerequisites:** ISE 255

**ISE 275 Fundamentals of Web Applications 3 Credits**

Introduction to web technologies required to support the development of client side and server side components of Internet based applications. Students will be exposed to the problems of design, implementation, and management by way of assigned readings, class discussion, and project implementation. Term project.

**Prerequisites:** ISE 224 or IE 224 or CSE 241

**Can be taken Concurrently:** ISE 224, IE 224, CSE 241

**ISE 281 Leadership Project 1-3 Credits**

Application of leadership principles through team projects with industry. Written report required.

**Repeat Status:** Course may be repeated.

**Prerequisites:** ISE 382 or IE 382

**ISE 300 Apprentice Teaching 1-4 Credits****ISE 305 Simulation 3 Credits**

Applications of discrete and continuous simulation techniques in modeling industrial systems. Simulation using a highlevel simulation language. Design of simulation experiments.

**Prerequisites:** ISE 121 or IE 121

**ISE 316 Optimization Models and Applications 3 Credits**

Modeling and analysis of operations research problems using techniques from mathematical programming. Linear programming, integer programming, multicriteria optimization, stochastic programming, and nonlinear programming using an algebraic modeling language.

**Prerequisites:** ISE 220 or IE 220 or ISE 240 or IE 240 or ISE 221 or IE 221 or ISE 222 or IE 222

**ISE 319 Facilities Planning and Material Handling 3 Credits**

Facilities planning including plant layout design and facility location. Material handling analysis including transport systems, storage systems, and automatic identification and data capture.

**Prerequisites:** ISE 131 or IE 131

**ISE 320 Service Systems Engineering 3 Credits**

Models and algorithms for reducing costs and improving customer service in service industries such as transportation, health care, retail, hospitality, education, and emergency services. Topics include facility location, resource allocation, inventory management, workforce planning, queuing analysis, call center management, and vehicle routing, with an emphasis on their applications in service industries. This course is an undergraduate version of ISE 420. Credit will not be given for both ISE 320 and ISE 420.

**Prerequisites:** ISE 230 and ISE 240

**Can be taken Concurrently:** ISE 230

**ISE 321 Independent Study in Industrial & Systems Engineering 1-3 Credits**

Experimental projects in selected fields of industrial engineering, approved by the instructor. A written report is required. Department permission required.

**Repeat Status:** Course may be repeated.

**ISE 324 Industrial Automation and Robotics 3 Credits**

Introduction to robotics technology and applications. Robot anatomy, controls, sensors, programming, work cell design, part handling, welding, and assembly. Laboratory exercises.

**Prerequisites:** (MECH 003 or MECH 002) and MATH 205

**ISE 328 Engineering Statistics 3 Credits**

Random variables, probability functions, expected values, statistical inference, hypothesis testing, regression and correlation, analysis of variance, introduction to design of experiments, and fundamentals of quality control. This course cannot be taken by IE undergraduates.

**Prerequisites:** MATH 023 or MATH 096

**ISE 332 Product Quality 3 Credits**

Introduction to engineering methods for monitoring, control, and improvement of quality. Statistical models of quality measurements, statistical process control, acceptance sampling, and quality management principles. Some laboratory exercises.

**Prerequisites:** ISE 121 or IE 121

**ISE 334 Organizational Planning and Control 3 Credits**

Design of organization and procedures for managing functions of industrial engineering. Analysis and design of resources planning and control, including introduction of change in man-machine systems; manpower management and wage administration. Must have junior standing.

**ISE 339 Stochastic Models and Applications 3 Credits**

Introduction to stochastic process modeling and analysis techniques and applications. Generalizations of the Poisson process; renewal theory and applications to inventory theory, queuing, and reliability; Brownian motion and stationary processes.

**Prerequisites:** ISE 220 or IE 220 or ISE 230 or IE 220

**ISE 340 Production Engineering 3 Credits**

Development of process plans for manufacturing of discrete parts. Emphasis on machining processes planning and design manufacturing interface. Economic analysis of process design alternatives. Concurrent engineering topics. Introduction to mechanization, automation, and flexible manufacturing systems. Fundamentals of group technology and cellular manufacturing Term project. Laboratory.

**Prerequisites:** ISE 215 or IE 215

**ISE 341 Data Communication Systems Analysis and Design 3 Credits**

An introduction to the hardware as well as performance evaluation of data communication networks. Emphasis on data transmission, encoding, data link control, communication networking techniques, and queuing/simulation analysis of network performance.

**Prerequisites:** (ISE 230 or IE 230) and (ISE 240 or IE 240)

**ISE 347 Financial Optimization 3 Credits**

Making optimal financial decisions under uncertainty. Financial topics include asset/liability management, option pricing and hedging, risk management and portfolio optimization. Optimization techniques covered include linear and nonlinear optimization, discrete optimization, dynamic programming and stochastic optimization. Emphasis on use of modeling languages and solvers in financial applications. Requires basic knowledge of linear optimization and probability. Credit will not be given for both ISE 347 and ISE 447.

**Prerequisites:** ISE 316

**ISE 355 Optimization Algorithms and Software 3 Credits**

Basic concepts of large families of optimization algorithms for both continuous and discrete optimization problems. Pros and cons of the various algorithms when applied to specific types of problems; information needed; whether local or global optimality can be expected. Participants practice with corresponding software tools to gain hands-on experience. Credit will not be given for both IE 355 and IE 455.

**Prerequisites:** ISE 220 or IE 220 or ISE 240 or IE 240

**ISE 356 Introduction to Systems Engineering and Decision Analysis 3 Credits**

Systems Engineering modeling techniques. Architectures for large scale systems design. Includes physical, functional, and operational architectures. Requirements engineering, interface and integration issues, graphical modeling techniques. Additional topics may include: decision analysis techniques for systems, uncertainty analysis, utility functions, multiattribute utility functions and analysis, influence diagrams, risk preference, Analytical Hierarchy and Node Processes in decision making.

**Prerequisites:** (ISE 220 or IE 220) or ((ISE 230 or IE 230) and (ISE 240 or IE 240), )

**ISE 357 Introduction to Industrial Engineering Mathematics 3 Credits**

A review of linear algebra and an introduction to quantitative analysis, manipulation of matrices, core concepts associated with systems of linear equations and linear optimization, algebraic and geometric models. The credits for this course cannot be applied to any undergraduate degree offered by the Industrial & Systems Engineering Department. Consent of department required.

**ISE 358 Game Theory 3 Credits**

A mathematical analysis of how people interact in strategic situations. Applications include strategic pricing, negotiations, voting, contracts and economic incentives, and environmental issues.

**Prerequisites:** MATH 021 or MATH 031 or MATH 051 or MATH 076

**ISE 362 (MSE 362) Logistics and Supply Chain Management 3 Credits**

Modeling and analysis of supply chain design, operations, and management. Analytical framework for logistics and supply chains, demand and supply planning, inventory control and warehouse management, transportation, logistics network design, supply chain coordination, and financial factors. Students complete case studies and a comprehensive final project.

**Prerequisites:** ((ISE 220 or IE 220) and (ISE 251 or IE 251), ) or ((ISE 230 or IE 230) and (ISE 240 or IE 240), )

**ISE 364 Introduction to Machine Learning 3 Credits**

Techniques of applied machine learning rather than deep theory behind the algorithms and methods. Programming solutions for machine learning problems using a high-level programming language and associated machine learning libraries. Regression, clustering, principal component analysis, Bayesian methods, decision trees, random forests, support vector machines, and neural networks.

**Prerequisites:** CSE 002

**ISE 365 Applied Data Mining 3 Credits**

Introduction to the data mining process including business problem understanding, data understanding and preparation, modeling and evaluation, and model deployment. Emphasis on hands-on data preparation and modeling using techniques from statistics, artificial intelligence, such as regression, decision trees, neural networks, and clustering. A number of application areas are explored. This course is an undergraduate version of IE 465. Credit will not be given for both IE 365 and IE 465.

**Prerequisites:** ISE 121 or IE 121 or ISE 328 or IE 328

**ISE 367 Mining of Large Datasets 3 Credits**

Explores how large datasets are extracted and analyzed. Discusses suitable algorithms for high dimensional data, graphs, and machine learning. Introduces the use of modern distributed programming models for large-scale data processing. An undergraduate version of ISE 467, with assignments better geared towards undergraduate students. Credit will not be given for both ISE 367 and ISE 467.

**Prerequisites:** ISE 111 and CSE 002

**ISE 372 Systems Engineering Design 3 Credits**

Analysis, design, and implementation of solutions to problems in manufacturing and service sectors using information technology. Emphasis on problem identification and the evaluation of proposed solutions and implementations. Term Project.

**Prerequisites:** ((ISE 220 or IE 220) or ((ISE 230 or IE 230) and (ISE 240 or IE 240)), ) and (ISE 275 or IE 275)

**ISE 382 Leadership Development 3 Credits**

Exploration and critical analysis of theories, principles, and processes of effective leadership. Managing diverse teams, communication, and ethics associated with leadership. Application of knowledge to personal and professional life through projects and team assignments.

**ISE 401 Convex Analysis 3 Credits**

Theory and applications of convex analysis, particularly as it relates to convex optimization and duality theory. Content of the course emphasizes rigorous mathematical analysis as well as geometric and visually intuitive viewpoints of convex objects and optimization problems.

**ISE 402 Applied Models in Operations Research 3 Credits**

Applied models in operations research, including applications in supply chain, energy, health care, and other fields. Seminal models, theorems, algorithms, and experience in translating practical problems into mathematical ones.

**Prerequisites:** ISE 406 and ISE 429

**Can be taken Concurrently:** ISE 429

**ISE 404 Simulation 3 Credits**

Applications of discrete and continuous simulation techniques in modeling industrial systems. Simulation using a highlevel simulation language. Design of simulation experiments. This course is a version of IE 305 for graduate students, with research projects and advanced assignments.

**Prerequisites:** ISE 121 or IE 121 or ISE 328 or IE 121

**ISE 405 Special Topics in Industrial & Systems Engineering 3 Credits**

An intensive study of some field of industrial & systems engineering.

**ISE 406 Introduction to Mathematical Optimization 3 Credits**

Algorithms and techniques for the solution and analysis of deterministic linear optimization models used in operations research. Linear and integer linear optimization problems. Modeling techniques and fundamental algorithms and their complexity properties. Available open source and commercial solvers discussed.

**ISE 407 Computational Methods in Optimization 3 Credits**

Introduction to a wide range of topics related to computational methods encountered in the implementation of optimization algorithms. Lectures focus primarily on theoretical aspects of computation, but with the goal of understanding computation in practice. Assigned exercises focus on employing computational methods in real-world applications. Topical coverage will include data structures, design and analysis of algorithms (sequential and parallel), programming paradigms and languages, development tools and environments, numerical analysis, and matrix computations.

**ISE 409 Time Series Analysis 3 Credits**

Theory and applications of an approach to process modeling, analysis, prediction, and control based on an ordered sequence of observed data. Single or multiple time series are used to obtain scalar or vector difference/ differential equations describing a variety of physical and economic systems.

**ISE 410 Design of Experiments 3 Credits**

Experimental procedures for sorting out important causal variables, finding optimum conditions, continuously improving processes, and trouble shooting. Applications to laboratory, pilot plant and factory. Must have some statistical background and experimentation in prospect.

**Prerequisites:** ISE 121 or IE 121 or ISE 328 or IE 328

**ISE 411 Networks and Graphs 3 Credits**

This course examines the theory and applications of networks and graphs. Content of the courses stresses on the modeling, analysis and computational issues of network and graph algorithms. Complexity theory, trees and arborescences, path algorithms, network flows, matching and assignment, primaldual algorithms, Eulerian and Hamiltonian walks and various applications of network models.

**Prerequisites:** ISE 406 or IE 406

**ISE 412 Quantitative Models of Supply Chain Management 3 Credits**

Analytical models for logistics and supply chain coordination. Modeling, analysis, and computational issues of production, transportation, and other planning and decision models. Logistics network configuration, risk pooling, stochastic decision-making, information propagation, supply chain contracting, and electronic commerce implication.

**Prerequisites:** ISE 316 or ISE 426

**ISE 413 Asset Valuation 3 Credits**

Valuation of projects and companies by discounted cash flow models. Mechanics of present value calculations. Understanding financial statements. The determinants of equity risk, expected return, earnings, reinvestment needs and growth. Role of debt and taxation. Valuing start-up companies, distressed companies, cyclical companies, firms with exclusive rights.

**ISE 416 Dynamic Programming 3 Credits**

This course is concerned with the dynamic programming approach to sequential decision making under uncertainty, exact solution algorithms, and approximate methods adapted to large-scale problems. Value iteration, policy iteration and lambda-policy iteration are introduced and analyzed using fixed-point theory. The linear optimization approach to dynamic programming is introduced. Special policy structures are studied. Algorithms based on sampling and on the use of linear approximation architectures are covered.

**Prerequisites:** ISE 316 or IE 316

**ISE 417 Nonlinear Optimization 3 Credits**

Advanced topics in mathematical optimization with emphasis on modeling and analysis of nonlinear problems. Convex analysis, unconstrained and constrained optimization, duality theory, Lagrangian relaxation, and methods for solving nonlinear optimization problems, including descent methods, Newton methods, conjugate gradient methods, and penalty and barrier methods.

**Prerequisites:** ISE 406 or IE 406

**ISE 418 Discrete Optimization 3 Credits**

Advanced topics in mathematical optimization with emphasis on modeling and analysis of optimization problems with integer variables. Polyhedral theory, theory of valid inequalities, duality and relaxation, computational complexity, and methods for solving discrete optimization problems, such as branch and bound.

**ISE 419 Planning and Scheduling in Manufacturing and Services 3 Credits**

Models for the planning and scheduling of systems that produce goods or services. Resource allocation techniques utilizing static and dynamic scheduling methods and algorithms. Application areas include manufacturing and assembly systems, transportation system timetabling, project management, supply chains, and workforce scheduling.

**ISE 420 Service Systems Engineering 3 Credits**

Models and algorithms for reducing costs and improving customer service in service industries such as transportation, health care, retail, hospitality, education, and emergency services. Topics include facility location, resource allocation, inventory management, workforce planning, queuing analysis, call center management, and vehicle routing, with an emphasis on their applications in service industries. This course is a graduate version of ISE 320 featuring some advanced assignments. Credit will not be given for both ISE 320 and ISE 420.

**Prerequisites:** ISE 339 or ISE 429 or MATH 310 or STAT 410

**ISE 424 Robotic Systems and Applications 3 Credits**

Detailed analysis for robotic systems in manufacturing and service industries. Task planning and decomposition, motion trajectory analysis, conveyor tracking, error detection and recovery, end effector design, and systems integration.

**ISE 425 Advanced Inventory Theory 3 Credits**

Advanced analytical, algorithmic, and heuristic methods for optimizing and managing inventory systems. Economic order quantity model and extensions; power-of-two policies; base-stock and other policies for stochastic systems; the Clark-Scarf model; assembly and distribution systems; proofs of policy optimality.

**ISE 426 Optimization Models and Applications 3 Credits**

Modeling and analysis of operations research problems using techniques from mathematical programming. Linear programming, integer programming, multicriteria optimization, stochastic programming and nonlinear programming using an algebraic modeling language. This course is a version of IE 316 for graduate students, with research projects and advanced assignments. Closed to students who have taken IE 316.

**Prerequisites:** ISE 240 or IE 240

**ISE 429 Stochastic Models and Applications 3 Credits**

Introduction to stochastic process modeling and analysis techniques and applications. Generalization of the Poisson process; renewal theory, queueing, and reliability; Brownian motion and stationary processes. This course is a version of IE 39 for graduate students, with research projects and advanced assignments. Closed to students who have taken IE 339.

**Prerequisites:** ISE 220 or IE 220 or ISE 230 or IE 230

**ISE 430 Management Science Project 3 Credits**

Analysis of a management problem and design of its solution incorporating management science techniques. An individual written report is required. Recommended to be taken in the last semester of the program.

**ISE 431 Operations Research Special Topics 3 Credits**

Extensive study of selected topics in techniques and models of operations research.

**ISE 433 Manufacturing Engineering Special Topics 3 Credits**

Extensive study of selected topics in the research and development of manufacturing engineering techniques.

**ISE 437 Advanced Database Analysis and Design 3 Credits**

Intensive treatment of design and application of modern database technology, including information modeling and logical design of databases. Emphasis on applications to the manufacturing environment.

**Prerequisites:** ISE 224 or IE 224

**ISE 438 Advanced Data Communication Systems Analysis and Design 3 Credits**

Study of technological development, operational algorithms and performance analysis in data networks. Emphasis on recent developments in communication technologies, modeling and simulation of largescale networks, routing models and algorithms, and flow control issues.

**ISE 439 Queueing Systems 3 Credits**

Queueing theory and analysis of manufacturing, distribution, telecommunications, and other systems subject to congestion. Design and analysis of queueing networks; approximation methods such as mean value analysis, uniformization, fluid and diffusion interpretations; numerical solution approaches.

**ISE 441 Financial Engineering Projects 3 Credits**

Analysis, design and implementation of solutions to problems in financial services using information technology, mathematical modeling, and other financial engineering techniques. Emphasis on realworld problem solving, problem definition, implementation and solution evaluation.

**ISE 442 Manufacturing Management 3 Credits**

Study of factors affecting the development of a manufacturing management philosophy; decision-making process in areas of organization, planning, and control of manufacturing. The principles and techniques of TQM, Deming and others; metrics, costs, benchmarking, quality circles, and continuous improvement. Influence of the social, technical, and economic environment upon manufacturing management decisions. Case studies.

**ISE 443 (MSE 443) Automation and Production Systems 3 Credits**

Principles and analysis of manual and automated production systems for discrete parts and products. Cellular manufacturing, flexible manufacturing systems, transfer lines, manual and automated assembly systems, and quality control systems.

**Prerequisites:** ISE 215 or IE 215

**ISE 444 Optimization Methods in Machine Learning 3 Credits**

Machine learning models and advanced optimization tools that are used to apply these models in practice. Machine learning paradigm, machine learning models, convex optimization models, basic and advanced methods for modern convex optimization.

**Prerequisites:** ISE 406 or IE 406

**ISE 445 Assembly Processes and Systems 3 Credits**

Joining processes including welding, brazing, soldering, and adhesive bonding. Mechanical assembly methods. Manual assembly lines and line balancing. Automated assembly. Product design considerations including Design for Assembly.

**ISE 447 Financial Optimization 3 Credits**

Making optimal financial decisions under uncertainty. Financial topics include asset/liability management, option pricing and hedging, risk management, and portfolio optimization. Optimization techniques covered include linear and nonlinear programming, integer programming, dynamic programming, and stochastic programming. Emphasis on use of modeling languages and solvers in financial applications. Requires basic knowledge of linear programming and probability. This course is a version of IE 347 for graduate students and requires advanced assignments. Credit will not be given for both IE 347 and IE 447.

**Prerequisites:** ISE 426 or IE 426 or ISE 316 or IE 316

**ISE 455 Optimization Algorithms and Software 3 Credits**

Basic concepts of large families of optimization algorithms for both continuous and discrete optimization problems. Pros and cons of the various algorithms when applied to specific types of problems; information needed; whether local or global optimality can be expected. Participants practice with corresponding software tools to gain hands-on experience. This course is a version of IE 355 for graduate students and requires advanced assignments. Credit will not be given for both IE 355 and IE 455.

**Prerequisites:** ISE 220 or IE 220 or ISE 240 or IE 240

**ISE 456 Conic Optimization 3 Credits**

A Conic Optimization (CO) problem is an optimization problem where the objective and constraints are linear, and the decision variables are required to belong to a closed convex cone. CO has an elegant theory, and allows us to formulate a very rich class of optimization problems that arise both in theory and practice. The aim of this course is to discuss both theoretical aspects of CO, as well as key practical applications.

**Prerequisites:** ISE 406 or ISE 426

**ISE 458 Topics in Game Theory 3 Credits**

A mathematical analysis of how people interact in strategic situations. Topics include normalform and extensiveform representations of games, various types of equilibrium requirements, the existence and characterization of equilibria, and mechanism design. The analysis is applied to microeconomic problems including industrial organization, international trade, and finance. Must have two semesters of calculus.

**Prerequisites:** ECO 412 and ECO 413

**ISE 460 Engineering Project 1-3 Credits**

Intensive study of an area of industrial engineering with emphasis upon design and application. A written report is required.

**ISE 461 Readings 1-3 Credits**

Intensive study of some area of industrial engineering that is not covered in general courses.

**ISE 465 Applied Data Mining 3 Credits**

Introduction to the data mining process including business problem understanding, data understanding and preparation, modeling and evaluation, and model deployment. Emphasis on hands-on data preparation and modeling using techniques from statistics, artificial intelligence, such as regression, decision trees, neural networks, and clustering. A number of application areas are explored. This course is a graduate version of IE 365 possessing some advanced assignments. Credit will not be given for both IE 365 and IE 465.

**Prerequisites:** ISE 121 or IE 121 or ISE 328 or IE 328

**ISE 467 Mining of Large Datasets 3 Credits**

Explores how large datasets are extracted and analyzed. Discusses suitable algorithms for high dimensional data, graphs, and machine learning. Introduces the use of modern distributed programming models for large-scale data processing. A graduate version of ISE 367 that will require graduate students to do more rigorous assignments. Credit will not be given for both ISE 367 and ISE 467. Students are expected to have basic knowledge of programming and probability.

**ISE 470 Introduction to Healthcare Systems 3 Credits**

The state of Healthcare from economic, systems, quality, and historical perspectives. Components of the Healthcare system including, facilities, delivery and treatment systems, and personnel. System costs, reimbursement methods and financial aspects in Healthcare. Healthcare policy, laws and ethics. System performance measures including access, cost effectiveness and quality of care.

**ISE 471 Quality and Process Improvement in Healthcare 3 Credits**

The dimensions of Healthcare quality and their definitions, quality metrics, accreditation and other benchmarking and evaluation methods. Change management, project planning and team management. Continuous improvement tools including "lean", "six-sigma", and "TQM".

**ISE 472 Financial Management in Healthcare 3 Credits**

Engineering economics in Healthcare; value metrics (net present value, return on investment, etc.), cost-benefit analysis, capital projects and improvements. Accounting methods in Healthcare systems. Reimbursement methods, organizations, and alternatives. Financial strategy, planning, pricing and capital formation in "for", and "not for" profit settings.

**ISE 473 Information Technology in Healthcare 3 Credits**

Introduction to information systems in Healthcare. Components of the system; electronic medical records, patient monitoring and data collection (clinical information systems), ancillaries (lab, pharmacy, radiology), imaging and digital technology, financial, inventory and management information systems. Enterprise systems in Healthcare, IT driven cost, efficiency and treatment quality metrics. Data warehousing, sharing, mining, protection and privacy issues.

**ISE 474 Healthcare Systems Engineering Capstone Project 3 Credits**

A three credit hour "capstone" project to be completed in collaboration with industry partners and under the supervision of faculty. Students will work in small groups on projects in the Healthcare industry. The Professor of Practice is the general advisor for the capstone project course.

**ISE 475 Healthcare Systems Project 1-3 Credits**

Intensive study of an area of healthcare systems engineering with emphasis upon design and application. Written report is required.

**ISE 482 Leadership Development 3 Credits**

Exploration and critical analysis of theories, principles, and processes of effective leadership. Managing diverse teams, communication, and ethics associated with leadership. Application of knowledge to personal and professional life through projects and team assignments. Credit will not be given to a student for both ISE 382 and ISE 482.

**ISE 490 Thesis 1-6 Credits****ISE 499 Dissertation 1-15 Credits**