

INDUSTRIAL ENGINEERING (IE)

IE 505: Linear Programming

3 Credits

An accelerated treatment of the main theorems of linear programming and duality structures plus introduction to numerical and computational aspects of solving large-scale problems.

Prerequisite: I E 405

IE 507: Operations Research: Scheduling Models

3 Credits

Scheduling models with simultaneous job arrival and probabilistic job arrival, network scheduling, and scheduling simulation techniques.

Prerequisite: I E 425

IE 509: Operations Research: Waiting Line Models

3 Credits

Waiting line models including models with infinite queues, finite queues, single and multiple servers under various priorities and disciplines.

Prerequisite: I E 516

IE 510: Integer Programming

3 Credits

Study of advanced topics in mathematical programming; emphasis on large-scale systems involving integer variables.

Prerequisite: I E 405

IE 511: Experimental Design in Engineering

3 Credits

Statistical design and analysis of experiments in engineering; experimental models and experimental designs using the analysis of variance.

Prerequisite: I E 323

IE 512: Graph Theory and Networks in Management

3 Credits

Graph and network theory; application to problems of flows in networks, transportation and assignment problems, pert/CPM, facilities planning.

Prerequisite: I E 405

IE 513: Stochastic Optimization

3 Credits

This course is designed to provide students with the ability to model optimization problems in uncertain settings and develop and analyze the convergence properties of the associated algorithms. It consists of six parts: 1) Review and Overview of models for decision-making under

uncertainty; 2) Stochastic programming (Theory); 3) Decomposition Methods; 4) Monte-Carlo Sampling Methods; 5) Robust optimization; 6) Special topics: Risk-averse optimization, stochastic variational inequality problems; and/or distributed stochastic optimization. Apart from students in Industrial and Manufacturing Engineering, this course would be of interest to students from math, engineering, computer science, statistics, machine learning, economics and operations management. Students are required to have some background in optimization and probability theory.

Prerequisites: IE 505

IE 516: Applied Stochastic Processes

3 Credits

Study of stochastic processes and their applications to engineering and supply chain and information systems. I E (SC&IS) 516 Applied Stochastic Processes (3) This course covers the mathematical fundamentals and tools for analyzing stochastic systems evolving over time, including concepts and techniques related to Poisson Processes, renewal processes, and discrete and continuous time Markov chains. Students will also learn to build probabilistic intuition and insights when thinking about random processes. Additionally, students will learn to apply the essential techniques of stochastic processes to real world problems in the supply chain and information systems area. This is a prescribed research foundation course for Ph.D. students in SC&IS. Student evaluations are based on class participation, individual and group assignments, and exams. This course will be offered during Spring semester to approximately 5-10 students.

Prerequisite: I E 322 or STAT 318

Cross-listed with: SCIS 516

IE 517: Models and Technologies for Financial Services

3 Credits

The objective of this course is to study current and emerging electronic financial services used in enterprise and global supply chain operations. The emphasis will be on technologies used in these services and how they can be used for improving operations. Topics covered include electronic financial services, financial engineering, financial services for enterprise and supply chain operations, modeling cash-flow bullwhip in supply chains, cash-flow forecasting algorithms, and models for sustainable microfinance in supply chains.

Prerequisites: IE 505 or IE 516

IE 519: Dynamic Programming

3 Credits

Theory and application of dynamic programming; Markov decision processes with emphasis on applications in engineering systems, supply chain and information systems. I E (SC&IS) 519 Dynamic Programming (3) This course presents the basic theory and applications of dynamic programming. The focus of the course will be on the theory of Markov decision processes (MDP), which provides an analytical tool to optimally control the behavior of a Markov Chain. The students will learn fundamental MDP models, computational methods and applications in supply chain and information systems, including production and inventory control, quality control, logistics, scheduling, queueing network, and economic problems. Student evaluations are based on class participation, individual and group assignments, and projects. This

course will be offered during Spring semester for approximately 5-10 students.

Prerequisite: I E 516 or SC&IS516 or equivalent
Cross-listed with: SCIS 519

IE 520: Multiple Criteria Optimization

3 Credits

Study of concepts and methods in analysis of systems involving multiple objectives with applications to engineering, economic, and environmental systems.

Prerequisite: I E 405 or INS 427

IE 521: Nonlinear Programming

3 Credits

Fundamental theory of optimization including classical optimization, convex analysis, optimality conditions and duality, algorithmic solution strategies, variational methods in optimization.

Prerequisite: I E 505

IE 522: Discrete Event Systems Simulation

3 Credits

Fundamentals of discrete event simulation, including event scheduling, time advance mechanisms, random variate generation, and output analysis.

Prerequisite: I E 425

IE 525: Advanced Linear Optimization

3 Credits

This is a graduate level course on linear optimization (LO) and its extensions emphasizing the underlying mathematical structures, geometrical concepts, and algorithms. The topics covered include: the geometry of linear optimization, duality theory, the simplex method, sensitivity analysis, large scale linear problems, the ellipsoid method as a polynomial time algorithm for LO, and interior point methods.

Prerequisites: IE 405 Recommended Preparation: An undergraduate course in linear algebra

IE 527: Additive Manufacturing Processes

4 Credits

The course will cover the fundamentals of Additive Manufacturing (AM) processes. During the course the students will leverage their background in computer-aided manufacturing to learn the Digital Work Flow steps from Design to Manufactured AM parts. They will learn and gain experience in the various data representation, algorithms and software tools, processes, and techniques that enable advanced/additive manufacturing. Computational algorithms will be researched and evaluated. Detailed research investigations into the fundamental process models of various additive manufacturing (AM) processes using polymers, metals, and other material will provide insight into the operating principles, capabilities, and limitations of AM processes. In addition to theoretical knowledge, the students will gain hands-on experience with AM machines and understand the complete process

steps through design, fabrication, and measurement of example parts. The students will study the range of applications of AM across a spectrum of industries (e.g., aerospace/automotive, medical devices, and consumer products) while developing an understanding of the requirements, constraints, and business case for the applications. After completing this course, students will have a fundamental understanding of the research in AM processes and prepare them for additional depth in follow on courses. Additionally the students will be able to appropriately utilize (e.g., evaluate, select, design) this developing technology in the future of manufacturing and digital transformation of manufacturing.

Cross-listed with: AMD 527

IE 530: Financial Engineering

3 Credits

Financial option pricing and portfolio design relevant to investment decision making. I E 530 Financial Engineering (3) The objective of this course is to provide students with the basic terminology, concepts, and issues relevant to financial engineering. It serves as an introduction to the investment, financial instruments, and valuation of projects via portfolio theory and option pricing and is primarily for students who have had exposure to multi-variable calculus and probability theory. Students will learn the core concepts and advanced techniques for decision making of capital investment and for managing and valuing risky projects. This course also aims to enable students to effectively use tools in finance and mathematics in order to conduct rigorous research on topics involving the analysis of managing and valuing flexibility and uncertainty. A requisite course in applied stochastic processes will provide the necessary background on probability models needed for this course.

Prerequisite: I E 516

IE 532: Reliability Engineering

3 Credits

Mathematical definition of concepts in reliability engineering; methods of system reliability calculation; reliability modeling, estimation, and acceptance testing procedures.

Prerequisite: I E 323 or 3 credits in probability and statistics with a prerequisite of calculus

IE 533: Workforce Engineering

3 Credits

Methods and applications for selecting, assigning, scheduling, and planning for workforce operations in the manufacturing and service industries. I E 533 Workforce Engineering (3) This course studies the field of workforce engineering, and bridges the areas of human factors engineering, production planning, and optimization. The objective of the course is to examine state-of-the-art practices, models, solution techniques, and opportunities for graduate research. The course studies quantitative applications related to determining workforce size, skill sets, and multifunctionality in service and manufacturing systems based on measurable quality and productivity performance. Students will develop the skills necessary to model and solve problems considering the tradeoffs between speed and accuracy.

Prerequisite: I E 405 and I E 425

IE 546: Designing Product Families**3 Credits**

Product families, product platforms, mass customization, product variety, modularity, commonality, robust design, product architectures. I E (M E) 546 Designing Products Families (3) Designing Product Families is a graduate-level course generally offered in the spring. It is designed for students interested in product realization, engineering design, and manufacturing to gain an understanding of mass customization and methods for designing families of products based on modular and scalable product platforms. The transition from craft production to mass production to mass customization will be covered in this course along with methods and tools for designing robust, modular, and scalable product platforms. Platform leveraging strategies and commonality metrics will be investigated through product dissection activities, which will also be integrated with lectures on evaluating manufacturing and assembly. Several industry case studies will also be discussed in the course to examine the implications of producing a variety of products and strategies for effective mass customization and product postponement. Students interested in taking this course should be familiar with product design and manufacturing. Students are evaluated through individual and group homework assignments, in-class participation and activities, and a group project report and presentation.

Prerequisite: M E 414 or M E 415 or I E 466

Cross-listed with: ME 546

IE 547: Designing for Human Variability**3 Credits**

Statistics, optimization, and robust design methodologies to design products and environments that are robust to variability in users.

Cross-Listed

IE 548: Interaction Design**3 Credits**

Strategies in user-centered design, ergonomic product analysis, statistical data analysis, low and high fidelity prototyping, and innovative design techniques. EDSGN 548 Interaction Design (3) Interaction Design provides an integrative perspective on the types of human-centered design techniques that can be used to analyze existing consumer products and develop innovative solutions. In this class, students will learn qualitative (e.g., observations and surveys) and quantitative methods (e.g., emg sensing and eye tracking) to measure user interactions. This knowledge will be used develop design recommendations for future products. The material will be presented through a variety of hands-on activities including a semester long interaction design project which requires students to evaluate an existing product using human-centered design techniques, develop solutions based on interaction design principles, prototype solutions, and evaluate their designs in a formal user study. Upon completion of this course, students will be able to identify appropriate research methods (quantitative and qualitative) for guiding interaction design decisions, conduct a user study, and develop design recommendations based on interaction design principles.

Prerequisite: EDSGN 547 or I E 479 or IST 501 or equivalent

Cross-listed with: EDSGN 548

IE 549: Design Decision Making**3 Credits**

Complexity of design-making; state-of-the-art methods and tools. EDSGN (IE) 549 Design Decision Making (3) Students in this course will internalize the importance of information and decision-making in design; understand the complexities due to uncertain information, multi-person decision making, technology obsolescence, competitive priorities; become familiar with state-of-the-art methods and tools for design decision-making; and, demonstrate the application of this knowledge in the context of a collaborative design project. Learning in this course will be facilitated in an "apply what you have learned" fashion with ample opportunities for students to demonstrate their learning through in-class participation, discussion of solved problems, hands-on design projects. Strategies, methods, and means of the design process will be discussed and practiced to include such things as understanding client needs, generating design concepts, and evaluating design ideas.

Cross-listed with: EDSGN 549

IE 550: Manufacturing Systems**3 Credits**

Fundamental theory for analyzing manufacturing systems including structural analysis, optimization and economics of manufacturing systems, automated and computer-aided manufacturing.

IE 551: Computer Control of Manufacturing Systems**3 Credits**

Analysis of microprocessor-controlled servo loops, adaptive control, stochastic methods in control; analysis of NC machines, robots, and their controllers.

IE 552: Mechanics of the Musculoskeletal System**3 Credits**

Structure and biomechanics of bone, cartilage, and skeletal muscle; dynamics and control of musculoskeletal system models. BIOE 552 BIOE (I E) 552 Mechanics of the Musculoskeletal System (3) The course focuses on the upper limbs and its musculoskeletal components, including mechanical properties and models; work-related musculoskeletal injuries, techniques, models, and instruments to measure and quantify the risks for developing such injuries. Specific topics covered in the first third of the course include an introduction to basic biomechanical principles, the anatomical structure of the musculoskeletal system including soft tissue, neuromuscular physiology, and motor control including muscle receptors. The second third covers various muscle models starting from basic mass/spring/dashpot viscoelastic models as in Hill's 3-element model and continuing on to Hatze's multi-element model, frequency analysis, control theory approaches. More complex models include static and dynamic aspects of tendon-pulley models and multiple muscle-tendon systems. The final third covers basic epidemiology as applied to musculoskeletal disorders and risk factors including instrumentation to measure them and various analysis tools (e.g., the PSU CTD Risk Index) to assess the not only the overall risk for injury but the reliability and validity of such assessments. Time permitting applications to hand tools and office environment with computer work stations are examined. Two exams and a modeling project are given. The course is typically offered Spring Semester.

Prerequisite: Consent of program. Prerequisite or concurrent: BIOL 472
Cross-listed with: BIOE 552

IE 553: Engineering of Human Work

3 Credits

Physics and physiology of humans at work; models of muscle strength, dynamic movements; neural control; physical work capacity; rest allocation.

Prerequisite: BIOL 141 or BIOL 472
Cross-listed with: BIOE 553

IE 555: Industrial Engineering Capstone

3 Credits

This course constitutes a culminating experience in the MS in Industrial Engineering (IE). The course culminates in a semester proposal that demonstrates an IE student's ability to apply knowledge and skills related to applying IE principles in a way that makes a substantial contribution to research in IE. Students in this class work individually to design, implement, and report on a proposed solution for a significant problem in one of the subareas of IE based on the application of knowledge and skillsets gained through the IE curriculum. Students will also collaborate with each other to iteratively develop and refine project topics, methods, and solutions. Students are oriented at the beginning of the course with modules reviewing research methods, public presentation strategies, and scholarly communication skills. IE faculty will present research problems in each of the IE subareas including: Human Factors (HF), Manufacturing, Operations Research (OR), and Operations, Services, and Analytics (OSA). Students will meet weekly milestones through the balance of the semester, engaging in peer review to refine their work in addition to receiving guidance from their instructor.

Recommended Preparation: All degree and option requirements must be met prior to taking this course or be met concurrently in the same semester this course is taken.

IE 556: Robotic Concepts

3 Credits

Analysis of robotic systems; end effectors, vision systems, sensors, stability and control, off-line programming, simulation of robotic systems.

Prerequisite: I E 456 or M E 456

IE 557: Human-in-the-Loop Simulation

3 Credits

Design and programming of simulations that facilitate human control, real-time discrete-event simulation, supervisory control of dynamic system. I E 557 Human-in-the-Loop Simulation (3) This course is designed to provide graduate students with the capability to develop an interactive, real-life simulation and to create interfaces for an interactive simulation. The course will cover key phases in the life cycle of interactive systems development including design, implementation, and evaluation. Course topics will be explored through application in supervisory control of complex, dynamic systems. Java will be the programming language used for software development in this course. Students will understand the fundamental concepts in interactive simulation; learn how to implement random variant generation and event handling in a simulation; understand the uses of human-in-the-loop simulation to investigate

human performance within the simulated system; and demonstrate the application of knowledge gained in the course in a project. Human-in-the-Loop Simulation is designed for students interested in human interaction with simulations of dynamic, supervisory control systems. The design and implementation of real-time interactive simulations will be covered. The construction of simulations from basic object-oriented programming concepts will be discussed. The role of the human within a dynamic, supervisory control system and methods of evaluating human performance within the simulated system will be examined. Students will be evaluated via laboratory assignments, two mid-semester examinations, and a semester project.

Prerequisite: I E 418 and I E 453

IE 558: Engineering of Cognitive Work

3 Credits

Information processing and decision making models of the human in the modern workplace, emphasizing visual inspection and other industrial applications.

Prerequisite: I E 323 and I E 408

IE 560: Manufacturing Processes and Materials

3 Credits

Materials processing and manufacturing methods for engineering materials; manufacturing process modeling and control; manufacturability of engineering materials. I E 560 Manufacturing Processes and Materials (3) The course provides a broad exploration of the manufacturability of engineering materials. In particular it investigates the fundamentals of material performance during processing, manufacturability requirements for primary material processing methods, and the processing limitations of widely used material systems. It considers formability, machinability, castability, weldability and, particulate consolidation of metallic systems with emphasis on widely used ferrous and non-ferrous alloys and widely used polymer, composite and ceramic systems. Building upon these insights, students will develop an integrated understanding of material processing science and control, and microstructure/property/processing relationships. They will be able to select appropriate material and manufacturing processes for engineering components and identify critical material and manufacturability issues that limit manufacturing success. Students will be able to apply these principles to develop an understanding of manufacturability constraints for newly developed engineering materials and processing methods. The course is an elective course for all Industrial Engineering MS, MENG and PhD degrees and is part of the required core of courses for the MS and MENG Manufacturing Option.

Prerequisite: E SC 414M , MATSC424 , or I E 470

IE 561: Data Mining Driven Design

3 Credits

The study and application of data mining/machine learning (DM/ML) techniques in multidisciplinary design. CSE 561 / EDSGN 561 / IE 561 / IST 561 Data Mining Driven Design (3) This course examines how theoretical data mining/machine learning (DM/ML) algorithms can be employed to solve large-scale, complex design problems. Knowledge Discovery in Databases (KDD) is the umbrella term used to describe the sequential steps involved in capturing and discovering hidden,

previously unknown knowledge in large databases. The course begins with foundational information regarding engineering design and provides an overview of KDD and the emergence of the digital age. Students will investigate data acquisition and storage techniques where they will learn the difference between stated and revealed data as related to design. Students will construct their own databases and learn essential techniques in data base queries (SQL) and management. Data transformation techniques, such as binning and dimensionality reduction, will be examined in the data transformation section of the course. This course has a design-driven focus, which will enable students to solve real-life design challenges spanning diverse domains. Students will work on project-based exercises aimed at proposing novel data mining algorithms, or employing existing algorithms to solve design problems in fields relating to engineering, healthcare, financial markets, military systems, to name a few. Data visualization techniques will also be studied to help communicate complex data mining models in a timely and efficient manner.

Cross-listed with: CSE 561, EDSGN 561, IST 561

IE 562: Computational Foundations of Smart Systems

3 Credits/Maximum of 999

Methodological aspects of expert systems design and review of some existing systems with emphasis on manufacturing and industrial engineering.

IE 563: Computer-Aided Design for Manufacturing

3 Credits

Study of CAD systems and concepts including 3D wireframe and solid modeling systems, emphasizing manufacturing applications.

Prerequisite: I E 463

IE 566: Quality Control

3 Credits

Advanced quality assurance and control topics, including multivariate methods, economic design for control and acceptance, dimensioning, tolerancing, and error analysis.

IE 567: Distributed Systems and Control

3 Credits

Advances in distributed control and decision-making in enterprises and supply chains with emphasis on computing, algorithms, and dynamics. IE 567 Distributed Systems and Control (3) Recently several new open architecture standards have emerged for control and information systems in industrial enterprises. These standards have been largely driven by industry to reduce the cost of integrating and configuring manufacturing systems, allowing a new breed of distributed enterprises to be engineered. This course deals with the multidisciplinary aspects of controls, computing, and communication in this rapidly evolving area. The objective of this course is to study current research and engineering challenges in distributed systems and control in the context of manufacturing and service enterprises, and supply chains. Emphasis will be placed on understanding the dynamics and computational aspects of decision making and control algorithms in integrated enterprises. Assignments and projects in this course will include designing, programming, and integrating distributed control systems. Evaluation will be based on programming and lab assignments, literature review

and class presentation, a semester project, and class participation. This course will be offered every third semester with a maximum enrollment of 18.

IE 568: Healthcare Systems Engineering

3 Credits

Quantitative methods to analyze and improve healthcare systems.

Prerequisite: I E 405 , I E 425 , and I E 433

IE 569: Human Factors in Transportation Engineering

3 Credits

Human Factors in Transportation Engineering is composed of a systematic introduction of major concepts, theories, and methods of human factors research in transportation safety. This course will cover the methods appropriate for studying humans, vehicles, and their interaction. It is designed to prepare graduate students with the knowledge of key topics in driving research, including driver cognition and behavior, vehicle technology, driving impairment, individual difference, driver performance modeling, and other road users.

Prerequisite: IE 408 Recommended Preparation: IE 511 Experimental Design in Engineering or equivalent course that introduces basic concepts in the analysis of experiments.

IE 570: Supply Chain Engineering

3 Credits

Use of operations research models and methods for solving problems in supply chain systems. IE 570 / SCIS 570 Supply Chain Engineering (3) The course provides state-of-the-art mathematical models, concepts and solution methods important in the design, control, operation and management of global supply chains. It provides an understanding of how companies plan, source, make and deliver their products to create/or maintain a global competitive advantage. It emphasizes the application of operations research models and methods to optimize the various components of an integrated supply chain. The course is appropriate for graduate students interested in working in the supply chain area in industry as well as those planning to pursue research in supply chain optimization.

Prerequisite: I E 405 , I E 425 , or SC&IS510

Cross-listed with: SCIS 570

IE 571: Product Design, Manufacturing Specifications, and Measurements

3 Credits/Maximum of 999

Elements of Product Design, Manufacturing Specifications, and Measurements with applications in the design, manufacture, and metrology of discrete parts. Elements of design and manufacturing engineering with an emphasis on the tools, standards, and methods used for product and part representation, specifications, and measurements. Students will learn to identify product dimensional design requirements and develop deterministic and probabilistic solution methods to sets of dependent and independent design requirements. They will then be exposed to industrial interchangeability models and their solutions. This will be followed by an in-depth exposure to the standardization of design and manufacturing, information embodied in the ASME Y14.5 and ISO 1101 Standards. The specification and interpretation of the dimensional and geometric tolerances contained in these standards will be enhanced

with applications in design, manufacturing, and metrology. The class will conclude with an introduction to the operation of metrology hardware including Zeiss, OGP, and FARO contact and non-contact measuring machines. The preceding body of material will provide the students with a sound foundation of design and manufacturing knowledge that will serve them in subsequent design and manufacturing classes. Students are expected to have taken a prior class in probability and statistics.

IE 572: Discrete Part Metrology

3 Credits/Maximum of 999

Theoretical considerations and practical applications in the design, acquisition, and interpretations of measurements in discrete part metrology and quality control. Metrology plays an important role at all stages of industrial product realization. Students in manufacturing programs must be well versed in methods of discrete part data acquisition, analysis, and reliability. The main objective of this course is to provide interested students with theoretical and practical knowledge in discrete part metrology for the validation, monitoring, and control of the output of manufacturing processes. Students will learn the ISO GUM and ANOVA-based methods for analysis of measurement uncertainty and apply these methods to the design, data acquisition, and analysis of measurements. They will explore the hardware and software of a typical Coordinate Measuring Machine (CMM), learn to develop a rigid body error model for such a machine and apply the methodology to the development and analysis of error models for other machine tools or measuring machines configurations. They will use laser interferometry tools and other hardware to acquire estimates of some of the components of the error budget. They will also explore the formulation, application, and solution of least squares and minimum zone algorithms to the CMM measurements of ASME Y14.5 size and geometric tolerances. The course will conclude with a short insight into the process planning of metrology tasks using the development of constraint graphs, their analysis, and subsequent sequencing of measurements tasks.

IE 575: Foundations of Predictive Analytics

3 Credits

Survey course on the key topics in predictive analytics. IE 575 Foundations of Predictive Analytics (3) This will be a survey course on the various aspects of predictive data analytics. Students will learn methods associated with data analytics techniques and apply them to real examples using the R statistical system. The key survey topics will include linear regression models, classification methods, tree-based methods, dimensionality reduction, and clustering. The focus will be on providing a basic understanding of the fundamentals of these techniques with realistic applications in marketing, healthcare, engineering and web-based data. An introduction to predictive models based on text and network data will be provided.

Prerequisite: IE 323, STAT 500 or equivalent

IE 582: Engineering Analytics

3 Credits

Students will learn advanced information technology network science, big data, descriptive and predictive analytics, for manufacturing and service systems.

IE 583: Statistical and Machine Learning Methods for Response Surface Optimization

3 Credits

This course presents Statistical and Machine Learning Methods for the modeling and optimization of engineering systems, for approximating and optimizing complex computer models, and for use in engineering design. Contemporary topics in Response Surface Models, including modeling systems with multiple or high dimensional responses, Probabilistic latent variables models, Optimal experimental design and its connection to Active Learning, and Manifold learning methods for Response Surface modeling. The course also treats Bayesian optimization methods based on either a physical or computer experiments using parametric (e.g., regression) models or non-parametric (e.g., Gaussian Processes or "Kriging") models, and discusses classical Response Surface methods such as Ridge Analysis and Taguchi's Robust Parameter Design.

Recommended Preparation: Probability and Statistics at the level of STAT 414 and STAT 415. A Design of Experiments course such as IE 511, STAT 503, or STAT 512, or a Regression course such as STAT 511 are also recommended.

IE 584: Time Series Statistical Learning and Control

3 Credits

This course covers applications in industrial engineering such as statistical process control and supply chain modeling (controlling the "bullwhip" effect). Both polynomial and state-space models are discussed. The former includes ARIMA and Transfer Function (Box-Jenkins) models, while the later include Kalman filtering, smoothing, and optimal stochastic control. While the bulk of the course deals with equidistant observations over time, Time Series models for irregular observations over time are dealt with by introducing continuous time AR processes. Multivariate time series models are introduced next, emphasizing their interpretation by means of their graphical (network) representation and the use of Dynamic Mode Decomposition techniques. The course includes a discussion of Recurrent Neural Networks for forecasting, and concludes with an introduction to Spatio-temporal data and to the Topological data analysis of time series.

Recommended Preparation: Undergraduate probability such as IE 322 or STAT 414, and undergraduate Statistics IE 323 or STAT 415 strongly suggested. Experience with engineering mathematics (calculus and linear algebra) and elementary computer programming.

IE 585: Convex Optimization

3 Credits

This course is designed to provide students with necessary skills to recognize or build convex optimization problems coming from diverse application areas and to solve them efficiently. It consists of five parts: 1) convex sets, 2) convex functions, 3) convex optimization, 4) algorithms and 5) real life applications. In the first part, important examples of convex sets will be given and the operations that preserve convexity of sets will be discussed. The second part will focus on convex functions, their basic properties, and the operations that preserve convexity of functions. In the third part, which is built on the first two parts, convex optimization problems will be formally introduced along with important examples ranging from linear and quadratic to semi-definite programming; second, Lagrange duality and optimality conditions will

be covered. The fourth part will focus on the algorithms to solve convex problems and on their computational complexity. In the fifth part, various applications will be covered.

Prerequisite: IE 505

Cross-listed with: EE 585

IE 586: Machining Process Design and Theory

3 Credits/Maximum of 999

Machining process engineering, including process design, computer programming and control, metal cutting theory, and process analysis. Machining processes are used to either directly or indirectly create the functional surfaces of nearly all mechanical products in use. This "hands on" course provides a comprehensive study of machining process engineering, including machine tool technology, machining processes, process design specification, basic and advanced machine programming, machine tool set up and specification, metal cutting mechanics and heat transfer, cutting tool wear mechanisms, workpiece surface formation mechanisms, and cutting tool materials and coatings. Students will learn through both lecture and laboratory. Students will use computer controlled machining centers and turning centers for training, scientific experiments, and projects. This course is intended for engineers who wish to implement and optimize machining processes in industry. In order to be successful in this course, students should have completed undergraduate courses in manufacturing process, materials engineering, and mechanical design. Students who successfully complete this course will obtain sufficient skills to engineer and utilize CNC machining processes. They will understand the relevant scientific theory and advanced engineering analysis that is currently being used to advance the technology. They will also be prepared for further graduate studies in product design and manufacture.

IE 587: Nano and Nanocomposite Manufacturing

3 Credits

This is an advanced graduate course on nanomanufacturing and nanocomposite manufacturing, which explores the design and manufacturing of nanomaterials and nanocomposites, hierarchical structures, and functional devices. In particular, it focuses on the studies of different top-down and bottom-up approaches/processes and the process-structure-property correlations. Students will study the interaction forces between nanoscale building blocks to understand process physics. Based on the fundamental understanding, students will know how to manipulate various interaction forces (e.g., chemical bonds, intermolecular forces) and interfaces to regulate the properties and functions of manufactured macroscopic forms. Furthermore, students will be exposed to cutting-edge research in the field by studying the current literature and conducting hands-on projects.

Recommended Preparation: CHEM 110 Chemical Principles; or PHYS 211 General Physics: Mechanics; Student should know the basic knowledge of atom structures, chemical bonds, crystal structures, defects, intermolecular forces and etc.

IE 588: Nonlinear Networks

3 Credits

Foundation in congestion games, including elements of non-cooperative game theory, equilibrium network flows, Braess paradox, and the price of anarchy. IE 588 Nonlinear Networks (3) This course examines the theory of congestion games, developed originally to describe flows on

congested transport networks but recently embraced to model data networks. Students will learn how to formulate descriptive models of traffic and data network flows in the presence of congestion as Nash games expressed as variational inequalities (VIs). These models will be used to derive theoretical bounds on the price of anarchy (the social costs of not achieving a truly cooperative or system optimal flow). Students will also learn how to formulate normative network design problems and Stackelberg games or so-called mathematical programs with equilibrium constraints (MPECs) to avoid the Braess paradox. Numerical techniques for solving VIs and MPECs will be discussed and illustrated. The course begins with an introduction to so-called system optimal network flow models that explicitly incorporate network congestion. The study of system optimal flows contains an introduction to nonlinear network optimization algorithms, including feasible direction, gradient projection, simplicial decomposition and affine scaling algorithms. Following the consideration of system optimal flows, both atomic and non-atomic network equilibrium models in the form of non-cooperative Nash games are discussed in-depth. The price of anarchy is presented as the ratio of the cost of Nash equilibrium flows to the cost of system optimal flows within the network of interest. Various theoretical bounds on the price of anarchy are derived. Numerical experiments to determine the price of anarchy are also described. The Braess paradox, wherein global congestion can increase when local capacity is added to a nonlinear network, is introduced and its relationship to the price of anarchy demonstrated. Discrete and continuous equilibrium network design models that eliminate any possibility for the Braess paradox to arise are articulated. Each such design model is shown to be equivalent to a Stackelberg game, which is a type of mathematical program with equilibrium constraints (MPEC). Mechanism design in the form of network congestion pricing to alleviate the effects of congestion is also considered and shown to have an MPEC structure as well. Algorithms for solving MPECs to ascertain efficient network topology/efficient tolling will be discussed in detail, including simulated annealing and other types of computational intelligence on the one hand; and duality, penalty, decomposition and other types of nonlinear programming algorithms on the other. Students interested in taking this course should have completed a course in linear programming (IE 505); a course in nonlinear programming is also recommended.

Prerequisite: IE 505

IE 589: Dynamic Optimization and Differential Games

3 Credits

Dynamic optimization and dynamic non-cooperative games emphasizing industrial applications. IE 589 Dynamic Optimization and Differential Games (3) This course provides an introduction to dynamic optimization and dynamic noncooperative games from the perspective of infinite dimensional mathematical programming and differential variational inequalities in topological vector spaces. The objective of this course is to give a working knowledge of computational methods for and applications of dynamic games. It builds on two prerequisite courses - introduction to operations research and linear programming - and also on co-requisite course in non linear programming. Coverage includes descent, projection and penalty algorithms for infinite dimensional mathematical programming and their extension to differential variational inequalities and dynamic games. Cournot-Nash-Bertrand and Stackelberg dynamic games are then studied from the point of view of differential variational inequalities and optimal control problems constrained by differential variational inequalities. Manufacturing and service engineering applications are employed to illustrate the tools developed

in the course. Students will be evaluated on the basis of a set of assigned problems (30%), a semester paper (30%), and a final examination (40%).

Prerequisite: I E 425 and I E 505; Concurrent: I E 521

IE 590: I E Colloquium

1-3 Credits/Maximum of 3

Continuing seminars that consist of a series of individual lectures by faculty, students, or outside speakers.

Prerequisite: graduate standing in Industrial Engineering

IE 596: Individual Studies

1-9 Credits/Maximum of 9

Creative projects, including nonthesis research, which are supervised on an individual basis and which fall outside the scope of formal courses.

IE 597: Special Topics

1-9 Credits/Maximum of 9

Formal courses given infrequently to explore, in depth, a comparatively narrow subject which may be topical or of special interest.

IE 598: Special Topics

1-9 Credits/Maximum of 9

Formal courses given on a topical or special interest subject which may be offered infrequently.

IE 600: Thesis Research

1-15 Credits/Maximum of 999

No description.

IE 601: Ph.D. Dissertation Full-Time

0 Credits/Maximum of 999

No description.

IE 610: Thesis Research Off Campus

1-15 Credits/Maximum of 999

No description.

IE 611: Ph.D. Dissertation Part-Time

0 Credits/Maximum of 999

No description.

IE 894: Capstone Design

3 Credits

Students will apply the analytical and design skills learned in previous courses to solve an industrial problem based on their workplace or industrial partner. Students who do not have an identifiable work-related problem will work collaboratively with the instructor to develop a suitable topic. This is an individual project culminating in a final report.

Recommended preparations: Recommended preparation is for the student to take this course after taking most of the courses in the program because prior knowledge is needed to perform a capstone design project.