Newark College of Engineering

One of the oldest and largest professional engineering schools in the United States, Newark College of Engineering offers 10 undergraduate degree programs, 21 master's and 9 doctoral degree programs. Undergraduate enrollment is more than 3,500, and more than 1,400 are enrolled in graduate study. The 150-member faculty includes engineers and scholars who are widely recognized in their fields.

Programs

- Biomedical Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/biomedical/ms/)
- Chemical Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/chemical-ms/)
- Civil Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/civil-ms/)
- Civil Engineering - M.S. online (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/civil-ms-online/)
- Computer Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/computer-ms/)
- Critical Infrastructure Systems - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/critical-infrastructure-systems-ms/)
- Electrical Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/electrical-ms/)
- Engineering Management - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/engineering-management-ms/)
- Engineering Science - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/interdisciplinary-engineering-science/ms/)
- Environmental Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/environmental-ms/)
- Healthcare Systems Management - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/healthcare-systems-management-ms/)
- Industrial Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/industrial-ms/)
- Manufacturing Systems Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/manufacturing-systems-ms/)
- Materials Science and Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/materials-science-engineering-ms/)
- Mechanical Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/mechanical-ms/)
- Occupational Safety and Health Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/occupational-safety-health-ms/)
- Pharmaceutical Engineering - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/pharmaceutical-ms/)
- Pharmaceutical Systems Management - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/pharmaceutical-systems-management-ms/)
- Power and Energy Systems - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/power-energy-systems-ms/)
- Telecommunications - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/telecommunications-ms/)
- Transportation - M.S. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/transportation-ms/)

Double Majors **(**http://catalog.njit.edu/graduate/academic-policies-procedures/special-programs/**)**

- Architecture - M.Arch. and Civil Engineering - M.S. (http://catalog.njit.edu/graduate/architecture-design/architecture/march-civil-engineering-ms/)

Programs

- Biomedical Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/biomedical/phd/)
- Chemical Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/chemical-phd/)
- Civil Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/civil-phd/)
- Computer Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/computer-phd/)
- Electrical Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/electrical-phd/)
- Environmental Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/environmental-phd/)
- Engineering Science - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/saet-seed/engineering-science-phd/)
- Industrial Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/industrial-phd/)
- Materials Science & Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/materials-science-engineering-phd/)
- Mechanical Engineering - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/mechanical-phd/)
- Transportation - Ph.D. (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/transportation-phd/)

Programs

- Biomedical Device Development (http://catalog.njit.edu/graduate/newark-college-engineering/biomedical/cert/)
- Climate Change Adaptation and Resilience (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/climate-change-adaptation-and-resilience-cert/)
- Construction Management (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/construction-management-cert/)
- Data Science for Chemical and Materials Engineers (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/data-science-for-chemical-and-materials-engineers-cert/)
- Environmental Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/environmental-engineering-studies-cert/)
- Geotechnical Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/geotechnical-cert/)
- Hydrology and Water Resources Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/hydrology-and-water-resources-engineering-cert/)
- Intelligent Transportation Systems (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/intelligent-transportation-systems-cert/)
- Pharmaceutical Management (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/pharmaceutical-management-cert/)
- Pharmaceutical Manufacturing (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/pharmaceutical-manufacturing-cert/)
- Pharmaceutical Technology (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/pharmaceutical-technology-cert/)
- Power Systems Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/power-systems-engineering-cert/)
- Polymers and Plastics (http://catalog.njit.edu/graduate/newark-college-engineering/chemical-materials-engineering/polymers-and-plastics-cert/)
- Project Management (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/project-management-cert/)
- Structural Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/structural-engineering-cert/)
- Supply Chain Engineering (http://catalog.njit.edu/graduate/newark-college-engineering/mechanical-industrial/supply-chain-engineering-cert/)
- Transportation Studies (http://catalog.njit.edu/graduate/newark-college-engineering/civil-environmental/transportation-studies-cert/)
- Wind Power Management (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/wind-power-management-cert/)
- Wind Power System Operation & Maintenance (http://catalog.njit.edu/graduate/newark-college-engineering/electrical-computer/wind-power-system-operation-and-maintenance-cert/)

BME 590. Graduate Co-Op Work Exper I. 1 credit, 1 contact hour.

BME 591. Graduate Co-Op Work Exper II. 1 credit, 1 contact hour.

BME 592. Graduate Co-Op Work Exper III. 1 credit, 1 contact hour.

BME 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Restriction: One immediately prior 3-credit registration for graduate co-op work experience with the same employer and approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

BME 601. Seminar. 1 credit, 1 contact hour.
Required every semester of all master's students in biomedical engineering who receive departmental or research-based support and all doctoral students. To receive a satisfactory grade, students must attend at least five seminars per semester, as approved by the seminar supervisor.

BME 611. Engineering Aspect of Molecular and Cellular Bio I. 1 credit, 1 contact hour.
Molecular and cellular biology is a foundation of the understanding of the biological sciences and is vital to the study of advanced biomedical engineering. This course is to be taken simultaneously with UMDNJ N551 to enrich the crossover between engieering and life sciences. Course topics parallel those covered in N551 and both add engineering relevance, and provide engineering students with a stronger understanding of molecular and cellular biology. For students in joint BME PhD program.

BME 612. Engineering Aspects of Molecular and Cellular Bio II. 1 credit, 1 contact hour.
Molecular and cellular biology is a foundation of the understanding of the biological sciences and is vital to the study of advanced biomedical engineering. This course is to be taken simultaneously with UMDNJ N552 to enrich the crossover between engineering and life sciences. Course topics parallel those covered in N552 and both add engineering relevance, and provide engineering students with a stronger understanding of molecular and cellular biology. For students in joint BME PhD program.

BME 650. Clinical Physiology & Neurophy. 3 credits, 3 contact hours.
Prerequisites: BME 111, BME 303, BME 382 or permission of the instructor. Topics to be covered include gastrointestinal tract, pulmonary respiratory system, renal and liver functions, blood and hemodynamic, cardiovascular and cerebrovascular function, and understanding of neurophysiology in human neurological diseases.

BME 651. Principles of Tissue Engineering. 3 credits, 3 contact hours.
Tissue Engineering is a therapeutic approach to treating damaged or diseased tissues in the biotechnology industry. In essence, new and functional living tissue can be fabricated using living cells combined with a scaffolding material to guide tissue development. Such scaffolds can be synthetic, natural, or a combination of both. This course will cover the advances in the fields of cell biology, molecular biology, and materials science towards developing novel "tissue engineered" materials.

BME 652. Cellular and Molecular Tissue Engineering. 3 credits, 3 contact hours.
This course explores molecular, cellular and tissue level interactions that are an important component of all tissue engineering strategies. Topics include how a cell moves, reacts and maintains viability and function based on its surroundings. We will discuss how to engineer our materials, tissue grafts and implants to integrate with the body. We will also liearn about bodily reactions and the biocompatibility of tissue engineered devices such as immunoreactivity and blood coagulation.

BME 653. Micro/Nanotechnologies for Interfacing Live Cells. 3 credits, 3 contact hours.
In this course, we will study technologies and tools available for interfacing live cells from a sub-cellular, single-cell, and multi-cellular (tissue models) approach. We will introduce key concepts of the biology of cells and tissues and will explore the technologies (micro-/nanotechnologies) and tools (sensors and actuators) available for the investigation of cell and tissue biology. Same as ECE 653.

BME 654. Cardiovascular Mechanic. 3 credits, 3 contact hours.
Fundamental biomechanical mechanisms at work in the cardiovascular system. Topics include the fundamental molecular structure of heart muscle, the biomechanical principles that transform the contraction of heart muscle into stress-strain functions of muscle fibers, pressure-volume flow relations in the vasculature when it is considered as a hemodynamic (blood hydraulic) system, growth and disease of the cardiovascular system, resistance, compliance, inertance, and catheter-tip transducers.

BME 655. Advanced Characterization of Biomaterials. 3 credits, 3 contact hours.
Prerequisites: MTSE 301 or undergraduate equivalent, BIOL 201 or undergraduate equivalent, one semester of undergraduate organic chemistry. With a focus on contemporary biomaterials in the published literature and clinical practice, biomaterial chemical and mechanical testing will complement synthesis theory. Communication and articulation of ideas will be honed in the form of literature debates, write-ups, demonstration/performance of analytical techniques, and concluding with translation of biomaterials that will include entrepreneurship and regulatory aspects.

BME 656. Research Skills in Stem Cell. 3 credits, 3 contact hours.
Stem cells have emerged as new therapeutic potential and offer great opportunities for regenerative medicine, biotechnology and the pharmaceutical industry. This course is intended for graduate students interested in stem cell bioengineering and tissue engineering. The course will cover stem cell biology and biomedical engineering applications for cell-based regeneration therapies. It will discuss techniques for engineering of stem cells and the current literature in this rapidly evolving field.

BME 661. Neural Engineering. 3 credits, 3 contact hours.
Neural Engineering focuses on understanding how the brain functions using engineering principles. The course discusses different instrumentation and signal processing algorithms to study how the brain functions, how to detect different pathologies and new applications for research. Topics include; basic overview of neurology, vector populations, neural networks, vision research, functional MRI, functional electrical stimulation, neural prosthetics, and other advanced research topics studying neurology.

BME 667. Bio-Control Systems. 3 credits, 3 contact hours.
The course provides an introduction to dynamic and control in biological systems, with particular emphasis on engineering aspects of biological oscillators/waves which govern the basic operations of all living organisms and especially higher order life forms. A combination of theoretical and simulation tools will be applied to analyze the qualitative and quantitative properties of selected biological systems. Feedback and control mechanisms in selected biological systems will be introduced. Same as ECE 667.

BME 668. Medical Imaging Systems. 3 credits, 3 contact hours.
This course provides a detailed introduction to medical imaging physics, instrumentation, data acquisition and image processing systems for reconstruction of multi-dimensional anatomical and functional medical images. Three-Dimensional medical imaging modalities including X-ray, Computer Tomography, Magnetic Resonance Imaging, Single Photon Emission Computer Tomography, Positron Emission Tomography, Ultrasound and optical imaging modalities are included. Same as ECE 668.

BME 669. Engineering Physiology. 3 credits, 3 contact hours.
To enable students to apply basic tools in engineering analysis, mathematics, computer science, general physics and chemistry courses so that they can develop models that quantitatively predict the functioning of physiological systems in the human body. To enable students to apply engineering systems analysis to systematic physiology and employ the ideas of feedback control, signal procession, mathematical modeling and numerical simulation. Same as ECE 669.

BME 670. Introduction to Biomechanical Engineering. 3 credits, 3 contact hours.
Prerequisites: undergraduate thermodynamics, statics, and dynamics. Introduction to biomechanical engineering of physiological systems; fluid flow, structural, motion, transport, and material aspects; energy balance of the body, and the overall interaction of the body with the environment. Same as ME 670.

BME 671. Biomechanics of Human Structure and Motion. 3 credits, 0 contact hours.
Prerequisites: undergraduate statics, kinematics, and dynamics. Principles of engineering mechanics and materials science applied to human structural and kinematic systems and to the design of prosthetic devices. Topics include anatomy; human force systems; human motion; bioengineering materials; and design of implants, supports, braces, and replacements limbs.

BME 672. Biomaterials. 3 credits, 3 contact hours.
Prerequisite: MECH 320 (see undergraduate catalog for description) or the equivalent. Materials and processes used to develop devices that are implanted in the human body; clinical aspects of biomechanical engineering; federal government requirements for design and testing of human implant devices; biocompatibility, metal implant devices, material design parameters, plastic and ceramic devices, sterilization techniques, and their effect on biocompatibility.

BME 673. Biorobotics. 3 credits, 3 contact hours.
Basics of control of a robot and telemanipulation are studied. Computer simulations, MATLAB are used to explore biomimetic autonomous robots. This is a studio-based course with hands-on exercises with small robots and actuators. Topics include understanding how biological robots (humans and animals) differ from designed robots, as well as sensors (touch, stereo and position), actuators (muscles, smart materials), and intelligent (neural and computer controlled systems.

BME 674. Principles of Neuromuscular Engineering. 3 credits, 3 contact hours.
Neurophysiology, motor control and robotics are used to study the human motor system. Sensorimotor learning and acquisition of new motor skills are emphasized. Topics include the central nervous system, muscle properties, spinal motor circuitry and dynamics of limb motion. The relation of motor control problems to neurophysiology of the motor system and how motor disorders affect movement control are studied. MATLAB and Simulink are used in simulations and movement date analysis.

BME 675. Computer Methods in Biomedical Engineering. 3 credits, 3 contact hours.
This course uses MATLAB to concentrate on methods that allow students to produce original software that can be used to acquire, process, analyze and present data. Topics include advanced graphics and animation, graphical user interfaces, interfacing to and data acquisition from laboratory instrumentation, filtering and processing of acquired data, and interfacing to user interfaces (e.g. joysticks). Applications in speech, bioelectrical signals, images and virtual reality will be included.

BME 676. Computational Biomechanics. 3 credits, 3 contact hours.
Prerequisites: None. The use of commercially available software to solve complex engineering problems has become standard practice to reduce time and cost and results in a better product. This is an intro course on computational methods and the use of commercial software such as ANSYS, Fluent, and MATLAB to solve problems related to the BME device industry. Suitable for students interested in Computer Aided Design and Engineering (CAD/CAE).

BME 677. CAD for Biomechanics and Biomaterials. 3 credits, 3 contact hours.
Introduction to Computer Aided Design theory and application using software. Topics include datum planes, extrude, cut, sweep, swept cuts, and parallel, rotational, and general blends. Assemblies and generating, dimensioning, editing, and modifying drawing views and creation of balloons, imaging and scanning techniques of anatomical structures such as bone and arteries and 3D printing are also covered.

BME 678. Design of Orthopedic Implants. 3 credits, 3 contact hours.
Prerequisite: BME 677. First of a two part course on design of orthopedic implants using ProEngineer. Additional topics include machanical properties of implant materials, material selection and introduction to FEA. Methods for prototype development with the use of 3D printing will also be discussed. A critical objective of this course is the preparetion of design reports and project presentations.

BME 679. Advanced Design of Orthopedic Implants. 3 credits, 3 contact hours.
Prerequisites: BME 677, BME 678 or equivalent. Advanced modeling techniques for the design of hip, knee, and spine implants. Mechanical properties of materials, including wear and failure modes associated with typical implants. Kinematics and surgical protocols of implants will be discussed. Course will cover assemblies and FEA analysis of implants. Additional topics include large deformations, fatigue, optimization, review and analysis of results.

BME 680. BioMEMS Design and Applications. 3 credits, 3 contact hours.
The advance of bioMEMS (Micro Electrical Mechanical Systems) technology is a key component in making the next generation medical diagnostic tools possible. We will learn how bioMEMS devices are fabricated and combine engineering analysis with knowledge of known biological responses and biomolecule interactions to understand how bioMEMS are designed and function. Topics will include biological, mechanical, electrical, and chemical biosensors, and microfluidics as applied to biotechnology.

BME 681. Cellular Mechanobiology. 3 credits, 3 contact hours.
Prerequisites: Fundamentals in biology. Mechanobiology is an emerging interdisciplinary field that focuses on the role of mechanical cues in governing cellular behavior. This course will address the means by which a cell utilizes its adhesions to neighboring cells and to the surrounding extracellular matrix to sense external forces and furthermore, how these forces are transduced within the cell to alter cellular behavior and regulate tissue architecture. This course will also discuss how the extracellular matrix influences cellular behavior during development, health, and disease. Furthermore, this course will also discuss the various tools and techniques developed that pushed the field of mechanobiology forward.

BME 682. System Mgmt for Medical Device. 3 credits, 3 contact hours.
This course will provide a detailed overview of Project Management techniques and methods applied to medical devices and show the integration of medical device Design Controls from 21 CFR820.30. General knowledge from the field of Project Management will be conveyed from the perspective of engineering or science personnel in the industrial medical field, particularlywith regard to FDA Quality System Regulations (QSR), ISO 13485 guidelines, and Good Clinical Practices (GCP's) for running clinical trials. Students will also take part in practical problem solving simulations based on real-world examples of medical device project anomalies. The combination of specialized project management knowledge for a heavily regulated area and realistic classroom simulation will provide a basis for those interested in commercial medical device development.

BME 684. Medical Device Development. 3 credits, 3 contact hours.
This course will provide a detailed overview of medical device development from a realistic industrial and academic perspective. The processes used in corporations and academic laboratories to conceive and develop devices will be explored from a research, regulatory, clinical, QA/QC, marketing, engineering, and legal perpective under the umbrella of project management techniques. Material will be presented as an aide to students who wish to decide on careers in either industry or academia.

BME 686. Intro. to Instrumentation for Physiomeasurements. 3 credits, 3 contact hours.
Introduction to instrumentation for students without instrumentation background only. This course teaches the hardware and instrumentation needed to measure variables from different physiological systems. Electrodes, sensors and transducers, bioelectric amplifiers safety and digital acquisition will be discussed. Hardware for measurement of the ECG, EEG, EMG, respiratory system, nervous system, clinical laboratory instruments, electrical safety and computers in biomedical instrumentation.

BME 687. Design of Medical Instrumentation. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in electronics. Principles and practice of medical instrumentation. Instrument components and medical instrument systems design. Examples taken from electrocardiography, clinical chemistry, medical imaging. Microprocessor-based systems emphasized.

BME 688. Virtual Biomedical Instrument. 3 credits, 3 contact hours.
Introductory course to the programming language, LabVIEWTM. Topics include loops, arrays, clusters, data acquisition, and file input/output. Students will learn how to apply these basic concepts into the development of algorithms. Examples relevant to the biomedical industry will be given how to debug and solve complex programming problems. By the completion of the course, students will be able to develop programs to automate processes and experimental designs.

BME 698. Selected Topics. 3 credits, 3 contact hours.
Selected topics for Biomedical Engineering.

BME 700B. Master's Project. 3 credits, 3 contact hours.
Restriction: written approval of project advisor. An extensive paper involving design, construction, and analysis, or theoretical investigation. Joint projects with industry or governmental agencies may be acceptable. Work is carried out under the supervision of a member of the department faculty. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course, if they have not already taken it.

BME 701B. Master's Thesis. 3 credits, 3 contact hours.
Restriction: written approval of project advisor. An extensive paper involving design, construction, and analysis, or theoretical investigation. Joint projects with industry or governmental agencies may be acceptable. Work is carried out under the supervision of a member of the department faculty. Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course, if they have not already taken it.

BME 701C. Master's Thesis. 6 credits, 3 contact hours.
Restriction: written approval of project advisor. An extensive paper involving design, construction, and analysis, or theoretical investigation. Joint projects with industry or governmental agencies may be acceptable. Work is carried out under the supervision of a member of the department faculty.

BME 725. Independent Study I. 3 credits, 3 contact hours.
Restriction: departmental approval. Program of study prescribed and approved by student's faculty coordinator. This special course covers areas of study in which one or more students may be interested but is not of sufficiently broad interest to warrant a regular course offering. Master's degree students cannot count BME 725 as degree credit but can count these credits to qualify for full-time status.

BME 726. Independent Study II. 3 credits, 3 contact hours.
Restriction: departmental approval. Program of study prescribed and approved by student's faculty coordinator. This special course covers areas of study in which one or more students may be interested but is not of sufficiently broad interest to warrant a regular course offering. Master's degree students cannot count BME 725 as degree credit but can count these credits to qualify for full-time status. This course is not available to master's students.

BME 741. Basic Plasma Physics with Spac. 3 credits, 3 contact hours.
Prerequisites: PHYS 611, PHYS 621 or other equivalent, or approval of the instructor. The course will introduce students to basic concepts of plasma physics and its applications to laboratory experiments and space research. The course will cover the following topics: particle motions in magnetic field, adiabatic invariants, magnetic traps, radiation belts, electromagnetic waves in plasma, electrostatic oscillations, waves in magnetized plasma, collisional processes in plasma, kinetic effects on plasma waves, Landau damping, wave instabilities, plasma as fluid, magnetohydrodynamics, magnetic configurations of laboratory and space plasma, MHD instabilities, reconnection, helicity, dynamo theories, the origin of cosmic magnetic fields, stochastic processes, Fermi process, particle acceleration, and cosmic rays.

BME 760. Modeling in Func Brain Imaging. 3 credits, 3 contact hours.
Prerequisites: Although no prerequisites are required, BME 310, ECE 640 or other undergraduate and graduate courses covering knowledge on signals and systems in discrete time domain are suggested to prepare for this course. This course will focus on introducing biomedical computing techniques needed for functional MRI data pre-processing, and individual-level and group-level analyses. Several projects will be assigned for hands-on training in implementing the introduced knowledge.

BME 772. Adv Biomats for Lab and Clinic. 3 credits, 3 contact hours.
Prerequisite: BME 672 or equivalent. Background in Materials Science is encouraged. Advanced course on the design, characterization and clinical/ research performance of biomaterials that have or may receive acceptance in medicine or as a biomedical research tool. The course requires the student to integrate background in chemistry, physics, cell and molecular biology, tissue engineering and materials science to review and summarize the scientific rationale for materials that have gained acceptance as medical devices, cell culture or diagnostic tools.

BME 774. Principles of Neurorehabilitation. 3 credits, 3 contact hours.
This is a research-focused course providing in-depth review of current studies in the following fields: Pathophysiology of disability; Advanced therapeutic interventions; Emerging neurorehabilitation technologies that are intended to encourage neural reorganization and relearning; Novel interfaces through chronic implementation in the brain, spinal cord and muscles used in deep brain stimulation, brain-machine interfaces, and functional electrical stimulation and Methods of assessing outcomes.

BME 777. Neuromodulation. 3 credits, 3 contact hours.
Restrictions: Course is designed for PhD Students in BME; All others need Instructor's approval. This course will first cover the fundamentals of electrical neural stimulation by looking at passive and active neuronal membrane models to prepare the students to better understand the mechanisms underlying neuromodulation applications. Then, the topics will expand into more practical aspects of neural stimulation, such as the electrode technologies used and various techniques of electrical neuromodulation in the central and peripheral nervous system. Throughout the course many sensory and motor neural prosthetic applications, e.g. spinal cord and deep brain stimulation devices, will be discussed from textbooks and journal publications. This is a lecture-based course covering a diverse area of materials borrowed mostly from electrophysiology and basic engineering concepts and students should be prepared to read one or two book chapters or journal papers before each class. Knowledge of basic circuits, such as RC circuits and KVL and KCL Analysis, is required. This course is built upon basic engineering concepts (e.g. basic electric circuits, differential equations) and programming skills (Matlab) that are covered at the undergrad level in electrical and biomedical engineering programs.

BME 788. Selected Topics. 3 credits, 3 contact hours.
Selected topics for Biomedical Engineering.

BME 790A. Doctoral Dissertation. 1 credit, 1 contact hour.
Required of all students working toward the Ph.D. in Biomedical Engineering. A minimum of 36 credits is required. The student must register for at least 6 credits of dissertation per semester; registration for additional credits may be permitted beyond the 6, with the approval of the advisor, up to a maximum of 12 credits per semester. If the student is still actively engaged in the research after completion of 36 credits, continued registration of 3 credits per semester is required.

BME 791. Graduate Seminar. 0 credits, 0 contact hours.

BME 792. Pre-Doctoral Research. 3 credits, 3 contact hours.
Restriction: Permission of the department. For students admitted to the program leading to the Ph.D. in Computer Engineering or Electrical Engineering. Research carried on under the supervision of a designated member of the department faculty. If the student's research activity culminates in doctoral research in the same area, up to a maximum of 6 credits may be applied toward the 36 credits required under BME 790 after the student fulfills requirements of doctoral candidacy.

CE 501. Introduction to Soil Behavior. 3 credits, 4 contact hours.
Prerequisites: MECH 320, MECH 235 with a grade of C or better and MECH 236 with a grade of C or better(see undergraduate catalog for descriptions). Open only to the students in bridge program. Permission from CEE department graduate advisor is required. Covers the necessary concepts in strength of materials, geology and soil mechanics required for the bridge program in M.S. in Environmental Engineering and Geoenvironmental Engineering option.

CE 502. Civil Construction Methods. 3 credits, 3 contact hours.
Prerequisites: PHYS 111 and MATH 112, or equivalents Open only to students in Online M.S. in Civil Engineering, Construction Management Option. Covers essential concepts in civil and construction engineering including site surveys, construction materials, and soil behavior to partially satisfy bridge requirements.

CE 506. Remote Sensing of Environment. 3 credits, 3 contact hours.
Prerequisite: PHYS 234 (see undergraduate catalog for description). Covers the principles of remote sensing, general concepts, data acquisition procedures, data analysis and role of remote sensing in terrain investigations for civil engineering practices. Data collection from airborne and satellite platforms will be emphasized. Photographic and non-photographic sensing methodologies will be covered as well as manual and computer assisted data analysis techniques for site investigations and examination of ground conditions.

CE 531. Design of Masonry and Timber Structures. 3 credits, 3 contact hours.
Prerequisite: CE 332 (see undergraduate catalog for description). Study of basic properties of clay and concrete masonry units and wood. The masonry segment includes discussion of unreinforced bearing walls subjected to concentric as well as eccentric loads. Lateral-force resistance of unreinforced and reinforced masonry systems are introduced and new developments to strengthen and retrofit unreinforced masonry walls are discussed. The timber design portion includes design and behavior of wood fasteners, beams, columns, and beam-columns as well as introduction to plywood and glued laminated members.

CE 552. Geometric Design of Transportation Facilities. 3 credits, 3 contact hours.
Prerequisite: CE 350 or equivalent (see undergraduate catalog for description). Design principles and criteria related to highways and railroads resulting from requirements of safety, vehicle performance, driver behavior, topography, traffic, design speed, and levels of service. Elements of the horizontal and vertical alignments and facility cross-section, and their coordination in the design. Computer-aided design procedures including COGO, CADAM, Digital Terrain Modeling. Same as TRAN 552.

CE 553. Design and Construction of Asphalt Pavements. 3 credits, 3 contact hours.
Importance of designing proper asphalt pavements. Topics include the origin of crude, refining crude, types of asphalts, desired properties of asphalt cement, specification and tests for asphalt cement, aggregates for asphalt mixtures, aggregate analysis, gradation and blending, hot-mix asphalt (HMA) mix design, manufacture of HMA and HMA-paving, hot and cold recycling. Same as TRAN 553.

CE 590. Grad Coop Work Experience I. 1 credit, 1 contact hour.
Restriction: permission from the civil engineering department and the Division of Career Development Services. Cooperative education/internship providing on-the-job reinforcement of academic programs in civil engineering. Work assignments and projects are developed by the co-op office in consultation with the civil engineering department; and evaluated by civil engineering faculty co-op advisors.

CE 591. Grad Coop Work Experience II. 1 credit, 1 contact hour.
Restriction: permission from the civil engineering department and the Division of Career Development Services.

CE 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Restriction: permission from the civil engineering department and the Division of Career Development Services.

CE 593. Graduate Co-Op Work Exp IV. 0 credits, 0 contact hours.
Restriction: One immediately prior 3-credit registration for graduate co-op work experience with the same employer and approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

CE 602. Geographic Information System. 3 credits, 3 contact hours.
Restriction: course or working knowledge of CADD or permission of instructor. Geographical/Land Information System (GIS/LIS) is a computerized system capable of storing, manipulating and using spatial data describing location and significant properties of the earth's surface. GIS is an interdisciplinary technology used for studying and managing land uses, land resource assessment, environmental monitoring and hazard/toxic waste control. Introduces this emerging technology and its applications. Same as MIP 652 and TRAN 602.

CE 605. Research Methods in Remote Sensing. 3 credits, 3 contact hours.
Prerequisites: CE 601 and MATH 661. Major components of RS data acquisition systems, overview of image processing techniques with emphasis on neural network and traditional pattern recognition, principal component transformations, and data reduction. Emphasizes geometric and mapping aspects of RS/GIS techniques for linking RS images with spatial data, sources of error, and accuracy assessment techniques. Hands-on experience with existing hardware/software (ERDAS & GENESIS).

CE 606. Geospatial Data Applications. 3 credits, 3 contact hours.
Prerequisite: CE 602. The course focuses on geospatial data processing, information extraction and analysis tools. It provides visualization and decision support applications using desktop GIS software. Examples of the student projects include: Applications of integrated geospatial date in environmental, infrastructure, urban planning and homeland security.

CE 610. Construction Management. 3 credits, 3 contact hours.
Restriction: B.S. degree in CE, technology, architecture, or related field. Managerial aspects of contracting. Study of an individual firm in relation to the entire construction industry. Topics include contractor organization and management, legal aspects of construction, and financial planning.

CE 611. Project Planning and Control. 3 credits, 3 contact hours.
Prerequisite: CE 610. Management tools as related to construction projects are analyzed and applied to individual projects. Emphasis is on network scheduling techniques, time-cost analysis, resource allocation and leveling, cost estimating, bidding strategy, and risk analysis.

CE 612. Machine Learning and Data Analytics for Civil Engineering Systems. 3 credits, 3 contact hours.
Prerequisites: CS 101, MATH 211, and MATH 279, or approval of instructor. This course provides students with hands-on and fundamental knowledge of machine learning, data science, and data mining methodologies for scraping, manipulating, transforming, cleaning, visualizing, summarizing, and modeling large-scale data in civil engineering and infrastructure systems using analytical tools. This course includes data management and analysis, data wrangling and exploration, unsupervised learning, pattern recognition, supervised learning for classification and regression purposes, data preprocessing, and model training and evaluation. Students will explore the capabilities of these concepts in addressing the challenging and interesting problems in the field of civil engineering, and they will develop skills to apply these techniques to solve multiple real-world civil engineering problems. Python programming language will be introduced and used throughout this course to illustrate practical examples and to show students how to apply the learned techniques in the civil engineering practice.

CE 613. Resilient Systems Planning and Design. 3 credits, 3 contact hours.
Prerequisites: CS 101, MATH 211, MATH 279, CE 320, or approval of instructor. This course provides an overview of natural hazards and resilient systems planning and design with a focus on flood-related considerations. This course reviews state-of-the-art responses to disasters and floods, the limitations of traditional resilience approaches, and recent developments in floodproofing and retrofitting solutions according to the requirements and recommendations provided by the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE). The course further discusses the different physical, economic, and social impacts of disasters on infrastructures, communities, and economies as well as presents contemporary considerations in resilience risk management, planning, and design. The course also examines how to assess, measure, model, and quantify uncertainty and resilience as well as perform sound economic analysis and make informed decisions for flood mitigation projects. Case studies of critical infrastructure resilience, floodproofing, and other natural disaster-related events, impacts, and strategies are discussed in this course.

CE 614. Underground Construction. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in soil mechanics. Various aspects of underground construction, including rock and soft ground tunneling; open cut construction; underpinning; control of water; drilling and blasting rock; instrumentation; and estimating underground construction costs. Case studies and a field trip to an underground construction site will be included.

CE 615. Infrastructure and Facilities Remediation. 3 credits, 3 contact hours.
Restriction: graduate standing in civil engineering and basic knowledge of structures, and material science. Examines the methodology of inspection, field testing, evaluation and remediation of existing infrastructure and facilities, which include pipelines, tunnels, bridges, roadways, dams, and buildings. Typical materials distress and failure scenarios will be covered with remediation options through the use of case studies.

CE 616. Construction Cost Estimating. 3 credits, 3 contact hours.
Prerequisite: CE 610. Full range of construction cost-estimating methods including final bid estimates for domestic building and heavy/highway projects; computerized takeoff and estimating techniques; international construction; financial and cost reporting; databases; indices; risk; competition; performance; and profit factors.

CE 617. Historic Preservation. 3 credits, 3 contact hours.
This course addresses the many aspects of structural preservation from both an engineering and aesthetic perspective. Course topics include: permits and regulations, an overview of architectural styles, designation of historic structures, past methods of construction, current methods of preservation and the availability of grants and funding. Knowledge gained from the course will be applied directly to course projects involving the evaluation and recommendations needed for the proposed preservation of an existing structure.

CE 618. Applied Hydrogeology. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in earth science/geology, fluid mechanics, and calculus or permission of instructor. Examines ground water and contaminant movement through the subsurface environment. A basic understanding of the aquifer geology is emphasized. Hydrogeologic applications including well design, pumping tests, and computer modeling of subsurface flow, and methods to monitor and remediate contaminated groundwater are introduced.

CE 620. Open Channel Flow. 3 credits, 3 contact hours.
Prerequisite: undergraduate fluid mechanics. The principles developed in fluid mechanics are applied to flow in open channels. Steady and unsteady flow, channel controls, and transitions are considered. Application is made to natural rivers and estuaries.

CE 621. Hydrology. 3 credits, 3 contact hours.
Prerequisite: undergraduate fluid mechanics. The statistical nature of precipitation and runoff data is considered with emphasis on floods and droughts. The flow of groundwater is analyzed for various aquifers and conditions. Flood routing, watershed yield, and drainage problems are considered.

CE 622. Coastal Engineering. 3 credits, 3 contact hours.
Prerequisite: fluid mechanics and calculus. An introductory course covering basic wave theory, sediment transport and ocean circulation. The application of these principles to various coastal engineering problems will be discussed, including beach erosion, pollution transport in coastal waters, and the design of shore protection structures.

CE 623. Groundwater Hydrology. 3 credits, 3 contact hours.
Prerequisites: undergraduate fluid mechanics and computer programming, or consent of instructor. Basic principles of groundwater hydraulics; Darcian analysis of various aquifer systems; unsaturated flow into porous mediums; transport of contaminants in soil media; and mathematical models for fluid and contaminant transport.

CE 630. Matrix Analysis of Structures. 3 credits, 3 contact hours.
A review of matrix operations and energy methods, and development of flexibility and stiffness methods used in linear-elastic structural analysis. Behavior of continuous beams, plane trusses, space trusses, and frames are studied.

CE 631. Advanced Reinforced Concrete Design. 3 credits, 3 contact hours.
Prerequisites: an undergraduate course in theory and design of reinforced concrete. A review of basic concepts of elastic and ultimate strength theories and a study of the present design codes. Topics include: design of concrete building frames, two-way slabs, flat slabs, deep beams, and other structural elements using the above two theories.

CE 632. Prestressed Concrete Design. 3 credits, 3 contact hours.
Prerequisites: undergraduate course in theory and design of reinforced concrete. Analysis and design of pre-tensioned and post-tensioned prestressed concrete elements for both determinate and indeterminate structures will be studied. Examples of prestressed elements used in buildings and bridges will be discussed, as well as the source and magnitude of prestress losses.

CE 634. Structural Dynamics. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in structural analysis. Dynamic analysis of beams, frames, and other types of structures. Practical methods developed are applied to problems such as the analysis of the effects of earthquakes on buildings and moving loads on bridges.

CE 635. Fracture Mechanics of Engineering Materials. 3 credits, 3 contact hours.
Restriction: graduate standing in civil and/or mechanical engineering and basic knowledge of structures and mechanics of materials. Basic principles of fracture mechanics to increase understanding of cracking and fracture behavior of materials and structures. Emphasis on practical applications of fracture mechanics.

CE 636. Mechanics and Stability of Structures. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in theory of structural analysis. Topics include structural design concept; stability criteria; elastic and inelastic buckling; column buckling; lateral buckling of beams; stability of frames; stability of plates and shell; local buckling and post-buckling.

CE 637. Short Span Bridge Design. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in steel design and concrete design, and some knowledge of prestressed concrete fundamentals. Design and performance of highway and railroad bridges, particularly steel and prestressed concrete structures since they are most common in the northeast; and computer applications including bridge geometry, abutment design and composite beam design.

CE 638. Nondestructive Testing Methods in Civil Engineering. 3 credits, 3 contact hours.
Familiarizes the civil engineering student with nondestructive testing (NDT) techniques currently employed for evaluation and condition monitoring of civil structures and construction materials. Major emphasis in the application of NDT methodologies to steel, concrete, and timber as the construction material. Covers theories, principles, and testing methodologies associated with individual technologies from specific material point of view. Discusses advantages and limitations pertaining to the application of individual NDT technologies to construction materials.

CE 639. Applied Finite Element Methods. 3 credits, 3 contact hours.
Prerequisites: CE 332 and CS 101. Introduction to application of finite element method to problems of structural analysis and design. Review of matrix algebra and the stiffness method of structural analysis. Applications include trusses, frames, plates, shells, and problems of plane stress/strain. Application of finite element method to design.

CE 641. Engineering Properties of Soils. 3 credits, 3 contact hours.
Prerequisite: approved undergraduate course in soil mechanics within last five years. An in-depth study of physical and mechanical properties of soils. Topics include clay mineralogy, shear behavior and compressibility of fine and coarse grained soil; and in-situ measuring techniques such as vane shear, core penetration and pressure meter. Laboratory work includes consolidation test and triaxial test, with emphasis on analysis, interpretation and application of data to design problems.

CE 642. Foundation Engineering. 3 credits, 3 contact hours.
Prerequisites: approved undergraduate courses in soil mechanics and foundation engineering. The salient aspects of shallow foundation design such as bearing capacity and settlement analyses. Topics are relevant to the deep foundation, selection of the type and the determi-nation of load bearing capacity from soil properties, load tests, and driving characteristics utilizing wave equation analyses. Earth pressure theory and retaining wall design.

CE 643. Advanced Foundation Engineering. 3 credits, 3 contact hours.
Prerequisites: Approved undergraduate or graduate course in foundation designs within the last five years is required. Computer applications in the design of shallow and deep foundations. Lateral and earth pressure computations for the design of retaining walls, bulkheads, cellular cofferdams, and sheet piles. Also considers the design of internal bracing systems and anchors, soil nailing and reinforced earth.

CE 644. Applied Engineering Geology. 3 credits, 3 contact hours.
Prerequisites: Permission of instructor for approved undergraduate or graduate course in geology or soil mechanics or construction engineering within the last seven years or equivalent. Geology has a significant influence on how we plan, design, and construct engineering works. This course examines how geologic formations and natural features can potentially and ultimately affect the planning, design, data collection, and construction of engineering infrastructures. This course helps students learn how to apply engineering principles to predict and mitigate natural and artificial geo-hazards, including the availability, selection, and use of geomaterials. The course also explores on a field scale the engineering impacts of natural geologic hazards, including landslides, sinkholes, earthquakes, and subsiding geomaterials. Case study applications and individual field trips within New Jersey are included.

CE 645. Rock Mechanics. 3 credits, 3 contact hours.
Prerequisites: Permission of instructor for approved undergraduate or graduate course in soil mechanics or geology or construction engineering within the last seven years or equivalent. The integrity of large buildings, dams, tunnels, bridges, and many other forms of engineering infrastructure is vitally dependent upon the rock behavior under loading conditions that impact their foundations. This course focuses on theoretical and experimental rock mechanics and rock engineering; review of laboratory and field rock testing; empirical and analytical methods for describing strength; deformability and conductivity of intact rock and rock masses; fracture mechanics and mechanics of discontinuous media, including fluid flow through discontinuous media; and design and analysis of rock slopes/rock fall, underground engineering structures in rock and foundations on rock. Includes numerical modeling software training and a term paper/design project.

CE 646. Geosynthetics & Soil Imp. 3 credits, 3 contact hours.
Prerequisite: CE 341 (see undergraduate catalog for description). Includes engineering properties of geosynthetics and their application in civil engineering, such as filtration, seepage, and erosion control; subgrade and slope stabilization. Soil improvement topics include preloading, electrokinetic stabilization, soil modification, admixtures and grouting.

CE 647. Geotechnical Aspects of Solid Waste. 3 credits, 3 contact hours.
Prerequisites: CE 341, CE 341A or equivalents (see undergraduate catalog for descriptions). Geotechnical aspects of solid waste such as municipal landfill, dredged materials, coal and incinerator ashes, identification and classification of waste materials, geological criteria for siting, laboratory and field testing, design for impoundment and isolation of waste, methods of stability analyses of landfill sites, techniques for stabilizing waste sites, leachate and gas collection and venting systems. Primary emphasis is on municipal wastes.

CE 648. Flow Through Soils. 3 credits, 3 contact hours.
Prerequisites: Approved undergraduate or graduate course in soil mechanics within the last five years is required. Explains the fundamentals of fluid flow through saturated and unsaturated soils and the use of computer programs for the solution of boundary value fluid flow problems in soils. The first two-thirds of the course are devoted to flow through saturated soils. The topics are mathematical description of flow through soils, solutions for steady state and transient state fluid flow and geotechnical applications. The last one-third is devoted to flow through unsaturated soils. Topics include steady state of transient state fluid flow and a presentation of how these concepts are applied to geoenvironmental problems.

CE 649. Design & Construction of Concr. 3 credits, 3 contact hours.
Importance of designing concrete pavements to resist distress or failure. Topics include the stresses in Rigid Pavement, Traffic and Loading, Material Characterization, Drainage, Pavement Performance, Rigid Pavement Design and Overlay Design.

CE 659. Flexible and Rigid Pavements. 3 credits, 3 contact hours.
Prerequisite: CE 341 or equivalent (see undergraduate catalog for description). Types of rigid (Portland cement) and flexible (bituminous) pavements. Properties of materials, including mineral aggregates. Design methods as functions of traffic load and expected life. Importance and consequences of construction methods. Maintenance and rehabilitation of deteriorated pavements. Same as TRAN 659.

CE 662. Deep Underground Engineering and Resources. 3 credits, 3 contact hours.
Prerequisites: Permission of instructor for approved undergraduate or graduate course in soil mechanics or geology or construction engineering within the last seven years or equivalent. This course will provide students with fundamental and applied engineering knowledge critical for identifying, designing, managing, and harnessing various materials from deep underground using geotechnical principles so as to provide society with valuable resources and promote sustainability. This course will also explore the governing mechanisms controlling the excavation of underground geomaterials (rock and soil) to create optimum space for extraction or storage of economically valuable and sustainable materials/resources at varying deep underground conditions. This course covers essential geo-engineering and geotechnical concepts and topics related to advancing underground geo-infrastructure, such as underground drilling; borehole/wellbore mechanics; vertical and directional drilling; wellbore cementing; foundations of solar and wind energy systems; underground carbon transport and sequestration; underground nuclear waste disposal; geothermal energy pile; and risk assessment of underground engineering. Case study applications are included to show students how to apply the learned techniques in various underground engineering practices.

CE 671. Performance and Risk Analysis of Infrastructure Systems. 3 credits, 3 contact hours.
This course presents a comprehensive systems approach to infrastructure asset management across areas of public and private infrastructure. Topics include the framework of integrated asset management illustrated in transportation, water and wastewater systems, the economic evaluation of infrastructure options, using life cycle cost analysis (LCCA) and cost-benefit analysis (CBA). The elements of performance measurement and modeling, including condition assessment and information management, failure and impact analysis are covered. Decision and risk analysis are covered to enable students to develop a holistic economic, performance and risk analysis approach to infrastructure management illustrated in a term project.

CE 672. Security Management of Critical Infrastructure. 3 credits, 3 contact hours.
This course focuses on the areas of vulnerability assessment and security management of critical infrastructure systems. A review of techniques for facility and network modeling and performance simulation, leads to sector-specific approaches to vulnerability analysis and critical infrastructure protection strategies using a Model-Based Vulnerability Analysis (MBVA). Covered critical infrastructure systems include water supply/environmental, transportation, power and energy systems, SCADA systems, cyber-infrastructure and telecommunications. The course ends with a review of the combined use of multi-criteria analysis techniques, expert heuristic response to scenarios and network analysis techniques in a general framework for vulnerability and security management of infrastructure systems in its key aspects: prevention, warning/detection and event mitigation and response planning and execution.

CE 700B. Masters Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in civil engineering. A written report must be submitted to the project advisor. The student cannot register in CE 700B more than once and the incomplete (I) grade is not allowed. Master's students registering for the first time in Master's Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

CE 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in civil engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in CE 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

CE 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in civil engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (CE 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

CE 702. Special Topics in Civil Engineering. 3 credits, 3 contact hours.
Restriction: advisor's approval. Topics of special current interest in civil engineering.

CE 703. Concrete Durability. 3 credits, 3 contact hours.
Prerequisites: Undergraduate course in construction materials or reinforced concrete design, or permission of the instructor. This course will cover the design and maintenance of concrete structures and pavements from a material choice point of view. Students will learn how to design concrete mixtures, choose alternative and sustainable concrete materials, produce concrete specifications, protect concrete from long-term deterioration, and design solutions for repairing existing concrete. Students will learn about the mechanisms and chemistry and concrete deterioration. The following key topics will be covered: cement production, supplementary cementitious materials, mixture design and proportioning, concrete durability, dimensional stability, freeze-thaw attack, sulfate attack, corrosion, alkali-silica reaction, alternative cements, concrete specifications, and concrete construction.

CE 705. Mass Transportation Systems. 3 credits, 3 contact hours.
Prerequisites: CE 625 and TRAN 610 or IE 610. An investigation of bus, rapid transit, commuter railroad, and airplane transportation systems. Existing equipment, economics, capacity, and terminal characteristics are discussed, as well as new systems and concepts. Long- and short-range transportation systems are compared. Same as TRAN 705.

CE 711. Methods Improvement in Construction. 3 credits, 3 contact hours.
Prerequisite: CE 610. Improved methods in construction; various techniques of work sampling and productivity measurement; and current innovations in the construction industry for increasing efficiency.

CE 720. Water Resource Systems. 3 credits, 3 contact hours.
Prerequisites: CE 620, CE 621. A system methodology is applied to the analysis of water resource development and operation. Topics include operational hydrology, water quality criteria, streamflow requirements, resource allocation, and economics. Mathematical models are developed and employed in the evaluation of a case study.

CE 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

CE 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for CE 726 if they have taken CE 725 in a prior semester.

CE 727. Independent Study III. 3 credits, 3 contact hours.
Restriction: written permission from department chairperson plus courses to be prescribed by the supervising faculty member. Covers areas of study in which one or more students may be interested but which is not of sufficiently broad interest to warrant a regular course offering.

CE 730. Plastic Analysis and Design. 3 credits, 3 contact hours.
Prerequisite: CE 639. Theory of plasticity applied to structural design. Study of methods of predicting strength and deformation of single and multi-story steel frames in the plastic range. Comparison of plastic and prestressed concrete.

CE 733. Design of Metal Structures. 3 credits, 3 contact hours.
Prerequisites: CE 639 and CE 636. Methods of design of metal structural systems. Topics include combined action of unsymmetrical sections, torsion of open and closed sections, buckling of columns and plates with various end conditions, and design of curved and boxed girders.

CE 734. Design of Tall Buildings and Space Structures. 3 credits, 3 contact hours.
Prerequisites: CE 639 and CE 636. Design of tall buildings and space structures emphasizing framing systems, and recent developments and current research related to the design of such structures.

CE 736. Finite Element Methods in Structural and Continuum Mechanics. 3 credits, 3 contact hours.
Prerequisites: MECH 630 and CE 630. Restriction: a working knowledge of computer programming. Finite element approaches for analysis of plane stress problems, plates in flexure, shells, and three-dimensional solids; and choice of interpolation functions, convergence, and the capabilities of the methods.

CE 737. Earthquake Engineering. 3 credits, 3 contact hours.
Prerequisite: CE 634. Practical design solutions for resisting the damaging effects of earthquake ground motions and other severe dynamic excitations. Factors which control dynamic response in elastic and inelastic ranges, and the nature of severe dynamic excitations. Theories of structural analysis and dynamics, and modern design methodologies on the behavior of structures.

CE 739. Structural Optimization. 3 credits, 3 contact hours.
Prerequisite: CE 639. Application of methods of mathematical programming to problems of optimal structural design. Optimal criteria methods, discrete and continuous systems, and code design will be covered.

CE 742. Geotechnology of Earthquake Engineering. 3 credits, 3 contact hours.
Prerequisites: Approved undergraduate course in soil mechanics within the last seven years, or permission of instructor. Explains the fundamentals of propagation of the earthquakes through soils to supporting structures and the use of computer programs in the solution of boundary value problems in soils. The first half is devoted to synthesis of earthquakes, mathematical formulation of the problem, measurement of applicable soil parameters, use of computer programs to solve 1-D wave propagation problems in soils with structures. The second half is devoted to soil liquefaction, soil-structure interaction, and design of machine foundations.

CE 753. Airport Design and Planning. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or EM 693 and CE 660. Planning of individual airports and statewide airport systems. Functional decision of air and landside facilities. Orientation, number and length of runways. Concepts of airport capacity. Passenger and freight terminal facility requirements. Airport access systems. FAA operating requirements. Financial, safety and security issues. Same as IE 753 and TRAN 753.

CE 765. Multi-modal Freight Transportation Systems Analysis. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or equivalent and CE 650 or EM 602 or equivalent. Quantitative methods for the analysis and planning of freight transportation services. The supply-performance-demand paradigm for freight transportation systems. Cost and performance as determined by system design and operations. Relationship of traffic and revenue to service levels and pricing. Optimal service design and redesign for transportation enterprises and operations planning. Fleet and facility investment planning. Applications to various modes. Same as EM 765 and TRAN 765.

CE 790A. Doct Dissertation & Res. 1 credit, 1 contact hour.
Co-requisite: CE 791. Approval of the dissertation advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in civil engineering. For PhD students who have successfully defended their dissertation proposal. The student must register in CE 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members. Students enrolled in the PhD program before 2015 Fall must accumulate a minimum number of credits in Doctoral Dissertation Research and Pre-Doctoral Research (see graduate catalog for program-specific details; the same requirement may apply to joint PhD programs with other universities).

CE 791. Graduate Seminar. 0 credits, 1 contact hour.
A seminar in which faculty or others present summaries of advanced topics suitable for research. Students and faculty discuss research procedures, thesis organization, and content. Students present their own research for discussion and criticism. Required of all doctoral students registered for CE 790 unless requirement is waived, in writing, by the dean of graduate studies.

CE 792. Pre-Doctoral Dissertation. 3 credits, 3 contact hours.
Co-requisite: CE 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in civil engineering. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

CE 793B. Professional Project. 3 credits, 3 contact hours.

CHE 501. Fundamentals of Chemical Engineering I. 6 credits, 6 contact hours.
Prerequisites: MATH 222 or equivalent, CHEM 231 or equivalent(see undergraduate catalog descriptions). An intensive course in basic chemical engineering science intended for students in the bridge program. Topics include material and energy balances, thermodynamics, kinetics and reactor design, and staged separation processes. May not be taken for degree credit in any chemical engineering program.

CHE 502. Fundamentals of Chemical Engineering II. 4 credits, 4 contact hours.
Prerequisites: MATH 222 or equivalent (see undergraduate catalog for description), CHE 501 or equivalent. A continuation of CHE 501. An intensive course in basic chemical engineering science intended for students in the bridge program. Topics include fluid mechanics, heat transfer and diffusion-controlled processes. May not be taken for degree credit in any chemical engineering program.

CHE 590. Graduate Co-op Work Experience I. 1 credit, 1 contact hour.
Restriction: permission from department and Division of Career Development Services. Cooperative education internship provides on-the-job reinforcement of the academic program by placement in major-related work situations. Work assignment developed or approved by the co-op office and evaluated by the department. Cannot be used for degree credit.

CHE 591. Graduate Co-op Work Experience II. 1 credit, 1 contact hour.
Restriction: permission from department and Division of Career Development Services.

CHE 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Restriction: permission from department and Division of Career Development Services.

CHE 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Restriction: One immediately prior 3-credit registration for graduate co-op work experience with the same employer and approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

CHE 599. Methods for Teaching Assistants and Graduate Assistants. 3 credits, 3 contact hours.
Restriction: graduate standing. Required for all chemical engineering teaching assistants and graduate assistants. Covers techniques of teaching, interaction with students, and safety. Does not count as degree credit.

CHE 602. Selected Topics in Chemical Engineering I. 3 credits, 3 contact hours.
Restriction: graduate standing. Topics of current interest in chemical engineering.

CHE 603. Separation Process Principles. 3 credits, 3 contact hours.
Prerequisites: CHE 342, CHE 349, CHE 363, CHE 364, CHE 367, CHE 471. The course covers the basic principles of separation with or without chemical reaction in phase equilibrium-based, external field-driven and membrane-based separation processes.

CHE 604. Membrane Separation Processes. 3 credits, 3 contact hours.
Prerequisites: CHE 342, CHE 349, CHE 363, CHE 364, CHE 367, CHE 471. This course covers the science, technology, engineering analysis and design of membrane separation processes, membrane reactors, membrane-based equilibrium separation processes and hybrid membrane processes.

CHE 611. Thermodynamics. 3 credits, 3 contact hours.
Prerequisite: undergraduate courses in physical chemistry and thermodynamics, or equivalent. Principles of thermodynamics developed quantitatively to include thermodynamic functions and their application to chemical engineering processes.

CHE 612. Kinetics of Reactions and Reactor Design. 3 credits, 3 contact hours.
Prerequisites: Undergraduate course in chemical engineering kinetics or equivalent. Elements of optimum design for various reactor types, multiple reactions, and temperature effects. Yield and selectivity optimization with emphasis on small-scale pharmaceutical production. Introduction to non-ideal reactor design. Study of various models for catalytic and non-catalytic solid-fluid reactions.

CHE 619. Nano-scale Characterization of Materials. 3 credits, 3 contact hours.
The course presents the basics of nanotechnology and the principles and application of advanced instrumentation for the characterization of nanostructures. Topics include atomic force microscopy; near-field optics, dielectric spectroscopy, and light scattering. The significant component of the course is laboratory work at the W. M. Keck Foundation Laboratory and research project.

CHE 623. Heat Transfer. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in heat transfer. Heat transmission applied to practical problems in design. An introduction will include review of conduction, convection and radiation heat transfer modes. Related topics covered will be heat exchangers, types and design principles (including Kern & Bell?s methods), effectiveness, (NTU Design and Rating methods), Fired Heaters, Design & Rating and Cooling Towers, Design & Rating.

CHE 624. Transport Phenomena I. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in fluid mechanics, heat transfer, and mass transfer. A unified treatment of molecular and turbulent momentum, energy, and mass transport. Emphasis is on the mathematical description of physical mechanisms in momentum and energy transport.

CHE 626. Mathematical Methods in Chemical Engineering. 3 credits, 3 contact hours.
Prerequisites: MATH 222 or equivalent undergraduate degree in Chemical Engineering. This course aims to provide students with advanced knowledge–skills to formulate mathematical models, derive analytical solutions, and find numerical solutions of steady- and unsteady-state problems encountered in chemical engineering systems. First and higher order ordinary differential equations as well as their systems are presented along with applications to dynamic systems. Sturm-Liouville eigenvalue problems, eigenfunction expansion, orthogonality of functions, and Fourier and generalized Fourier series are presented with the dual purpose of solving boundary-value problems and building the foundation needed for solving partial differential equations. Separation of variables is used to solve partial differential equations in 2D-3D steady-state and 1D-3D transient problems that arise in Cartesian, cylindrical, and spherical coordinates. Laplace transform and similarity transformation are used to solve semi-infinite domain problems. Numerical methods based on finite differences, full or semi-discretization of partial differential equations, accuracy, and error estimates are covered.

CHE 627. Introduction to Biomedical Engineering. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in thermodynamics and differential equations. Introduction to the structure and composition of the body followed by an exploration of the properties of blood and its flow in the cardiovascular system; the body as a heat source and as a series of compartments involved in mass transfer of materials (such as those in the kidneys and lungs). Design of artificial kidneys and heart-lung machines is also explored. Same as BME 627.

CHE 628. Biochemical Engineering. 3 credits, 3 contact hours.
Prerequisite: undergraduate degree in chemical engineering. The application of chemical engineering to biological processes, biochemical reaction systems, and their technological use. Special attention given to problems in momentum, energy, and mass transport, as well as chemical reaction kinetics in biological systems.

CHE 632. Visual Communication with Chemical & Materials Engineering Data. 3 credits, 3 contact hours.
Prerequisites: BS degree in Chemical, Mechanical, Electrical or Biomedical Engineering, or in Physics or Chemistry. This course will focus on training students to communicate data relevant to chemical and materials engineering and related professions. Students will learn both the theoretical and practical aspects of data communication, including visualization aesthetics and design principles, as well as how to critically analyze and interpret engineering data. Throughout the course, students will also gain a broader understanding of data visualization best practices and how data can be used to enhance engineering analysis, using digital tools. A special emphasis will be placed on making engineering data accessible to all individuals, using the principles of Universal Design. Students will incorporate each of these design principles into a capstone multimedia course project.

CHE 654. Corrosion. 3 credits, 3 contact hours.
Prerequisite: undergraduate courses in Chemistry. Fundamental principles including thermodynamics and kinetics of corrosion; forms of corrosion (e.g. galvanic, crevice and stress); methods of corrosion measurement; high temperature corrosion; and special case histories.

CHE 675. Statistical Thermodynamics. 3 credits, 3 contact hours.
Prerequisites: CHE 611 or permission of instructor. Application of equilibrium statistical mechanics to chemical engineering problems. Basic postulates and relationships of statistical thermodynamics, including the ideal gas, ideal crystal, and virial equation; statistical theories of fluid mixtures and other advanced topics.

CHE 683. Polymer Processing. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in transport phenomena, fluid flow, or heat transfer or approval of graduate advisor. The course provides a systematic approach to the physical phenomena occurring in polymer processing machinery. The synthesis of the elementary steps of polymer processing are shown in relation to the development of extrusion die flow and extrusion products and injection mold flows and molded products. Structural and residual stresses are examined.

CHE 684. Materials and Process Selection for Polymer Product Design. 3 credits, 3 contact hours.
Prerequisites or corequisites: CHE 681, CHE 682, CHE 683 or approval of graduate advisor. The course provides methodologies for designing polymer-based products by considering materials and processing methods. Methods for selecting homopolymers, polymer blends and composites for specific appilcations will be presented in terms of properties, processability, manufacturing methods and economics. Process/structure/property correlations are presented as well as approaches to product design including CAD, prototyping, and strength and failure criteria. Case studies from biomedical, packaging and other applications are discussed.

CHE 700B. Masters Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in chemical engineering. A written report must be submitted to the project advisor. The student cannot register in CHE 700B more than once and the incomplete (I) grade is not allowed. Master's students registering for the first time in Master's Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

CHE 701B. Masters Thesis. 3 credits, 3 contact hours.
Corequisite for full-time students: CHE 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in chemical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in CHE 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

CHE 701C. Masters Thesis. 6 credits, 6 contact hours.
Co-requisite for full-time students: CHE 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in chemical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (CHE 701B course) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

CHE 702. Selected Topics in Chemical Engineering II. 3 credits, 3 contact hours.
Restriction: graduate standing. Topics of current interest in chemical engineering.

CHE 705. Independent Study. 3 credits, 3 contact hours.
Restriction: permission from the graduate advisor (not dissertation advisor) in chemical engineering. Students working on their PhD or MS theses cannot register for this course with their respective thesis advisors. This special course covers areas of study in which one or more students may be interested, but which isn't of sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once with the same supervising faculty member.

CHE 706. Independent Study II. 3 credits, 3 contact hours.
Pre-requisite: CHE 705. Restriction: permission from the graduate advisor (not dissertation advisor) in chemical engineering. Students working on their PhD or MS theses cannot register for this course with their respective thesis advisors. This special course covers areas of study in which one or more students may be interested, but which isn't of sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once with the same supervising faculty member.

CHE 709. Adv Separation Processes. 3 credits, 3 contact hours.
Prerequisites: CHE 612, CHE 624 and CHE 626 or permission of instructor. Students having a background in undergraduate separations courses will be introduced to advanced concepts in separations. These include: descriptions of separation; forces causing separation in equilibrium, field and membrane separation processes; flux-force relations; chemical potential profiles; role of chemical reactions in separations; four different combinations of directions of force and bulk motions in separators; time-dependent processes. Advanced analysis of important individual separation processes of three types, namely, equilibrium-based, membrane-based and external field-based processes will be carried out.

CHE 710. Adv Membrane Separation Proc. 3 credits, 3 contact hours.
Prerequisites: CHE 624, CHE 626 or permission of instructor. This course will provide advanced treatments of science, technology, engineering analysis and design of the following membrane separation processes: reverse osmosis, nanofiltration, ultrafiltration, dialysis, electrodialysis, Donnan dialysis, liquid membrane permeation, microfiltration, gas permeation through polymeric membranes, pervaporation, membrane-based equilibrium separation processes, membrane reactors and hybrid membrane processes. Membrane structure/function and device design for each technology are of interest.

CHE 714. Micromechanics of Part Tech Pr. 3 credits, 3 contact hours.
Prerequisite: CHE 624 or equivalent. Corequisite: PHEN 601 or equivalent (not required but suggested). Presents methodologies for analyzing the macroscopic properties of particulate systems. Includes characterization and processing of particulate systems at the microlevel, predicting macroscopic properties from microlevel models, and analysis of particulate manufacturing processes involving solids processing, such as solids characterization, blending, milling, granulation, tableting, etc. Course includes laboratory demonstrations and a class project involving use of surface modification.

CHE 721. Combustion Reaction Engineering. 3 credits, 3 contact hours.
Restriction: undergraduate degree in Chemical or Mechanical Engineering. Topics related to the engineering of combustion systems will be discussed. These include laminar flames, turbulent combustion, ideal reactor modeling of complex combustion systems, combustion chemistry, heterogeneous combustion and incineration.

CHE 722. Additive Manufacturing & Appl. 3 credits, 3 contact hours.
Prerequisites: CHE 624 and CHE 626 are both prerequisites or can be taken concurrently. Other equivalent courses can be acceptable for non-chemical engineering students with permission of the instructor. This course describes additive manufacturing technologies and current (and emerging) applications of 3D printing. The course will be composed of a lecture and a hands-on laboratory session, during which students will create 3D designs and print functional prototypes.

CHE 724. Sustainable Energy. 3 credits, 3 contact hours.
The course is a project-based advanced graduate course which requires strong background in engineering thermodynamics and transport phenomena. The main goals of this course are to gain an understanding of the cost-benefit ratio of various alternative energy sources and to understand some of the various obstacles associated with current and conventional technologies and industrial applications. Different renewable and conventional energy technologies will be discussed in class. Course materials include biomass energy, fossil fuels, geothermal energy, nuclear power, wind power, solar energy, hydrogen fuel, hydropower, and fuel cells. Students will learn a quantitative framework to aid in evaluation and analysis of energy technology systems in the context of engineering, political, social, economic, and environmental goals.

CHE 725. Transport Phenomena II. 3 credits, 3 contact hours.
Prerequisite: CHE 624 or equivalent. Transport in laminar and turbulent flow: in solids, between phases, and macroscopic transport in flow systems.

CHE 734. Chem Process Dynamic & Control. 3 credits, 3 contact hours.
Prerequisite: CHE 626 or equivalent. Corequisites: CHE 611, CHE 612 or equivalent Mathematical principles of process dynamics and control; derivation and solution of differential equations describing the behavior of typical chemical engineering processing units; and mathematical analysis and design of control systems. Digital and sampled data control systems also discussed.

CHE 750. Environmental Catalysis. 3 credits, 3 contact hours.
Prerequisites: CHE 612 or equivalent. An introduction to catalytic processes used for environmental abatement. The course provides background information necessary to understand environmental catalytic processes. Mobile and stationary pollution abatement technologies are reviewed.

CHE 756. Industrial Catalysis. 3 credits, 3 contact hours.
Prerequisites: CHE 612 or equivalent. The class provides an introduction to catalytic phenomena as well as catalysts with the background information necessary to understand industrial catalytic processes. Examples discussed are hydrogen, ammonia and methanol synthesis, inorganic and organic oxidation reactions, petrochemical processes, pollution abatement and other important processes. The course provides insight into the theory of catalytic phenomena and information about related technologies from an industrial perspective.

CHE 775. Molecular Simulations in CHE. 3 credits, 3 contact hours.
Prerequisites: CHE 611 and CHE 626. Minimal programming experience in any programming language (e.g. Matlab, Python or Fortran). The course is aimed to introduce graduate students to the basics of molecular simulation. Two simulation techniques will be discussed in detail: Monte Carlo and molecular dynamics methods. The students will study the algorithms, and the statistical mechanics basis of these algorithms. Then they will use popular open source codes to simulate systems relevant for chemical engineers.

CHE 781. Polymerization-Principles and Practice. 3 credits, 3 contact hours.
Pre or Corequisite: CHE 611. The course focuses on the structural and synthetic aspects of polymers and examines in detail a number of bench and industrial scale polymerization methods. In addition to kinetics and mechanisms of commercially important polymerization systems, the course examines reactive modification of synthetic and natural polymers and provides an introduction to applicable characterization methods.

CHE 782. Polymer Structures and Properties. 3 credits, 3 contact hours.
Pre or Corequisite: CHE 611. The course provides an overview of polymer structures and properties and their relationships from the molecular viewpoint to phenomenological descriptions. Topics include thermodynamics of a single molecule, dynamic theory and viscoelasticity of polymers, polymer solids and mechanical properties, rubbers, polymer blends and composites, biological polymers, and special applications. New areas and innovative applications of polymers will be introduced.

CHE 790A. Doct Dissertation & Res. 1 credit, 1 contact hour.
Co-requisite: CHE 791. For students admitted to the Doctor of Philosophy Program in Chemical Engineering who have passed the Qualifying Examination and Research Proposal. Required of all students for the degree of Doctor of Philosophy. Approval of dissertation advisor is necessary for registration. Experimental or theoretical investigation of a topic in chemical engineering. Students must register for 1 credit of dissertation per semester until a written dissertation is approved.

CHE 791. Graduate Seminar. 0 credits, 1 contact hour.
Required of all chemical engineering students receiving departmental or research-based awards and all doctoral students. The student must register each semester until completion of the degree. Outside speakers and department members present their research for general discussion.

CHE 792. Pre-Doctoral Research. 3 credits, 3 contact hours.
Co-requisite for full time students: CHE 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in chemical engineering. For students who have not passed the dissertation proposal. Permission is needed of the academic advisor for students who have completed the required coursework but have not passed the qualifying examination.

CHE 794. Professional Presentations for Ph.D. Students. 0 credits, 0 contact hours.
Intended to help students make better technical presentations. Each student is required to make a presentation on a research topic; guest lectures will occur during the semester.

CHE 795. Research Methods for Doctoral. 3 credits, 3 contact hours.
Prerequisites: Doctoral standing in CBPE or permission of the instructor. This course is designed to enhance professional development of our doctoral students in order to significantly increase their research productivity, communications, and leadership skills while preparing them for a successful career. Concepts include setting priorities, time management, and learning best practices in research planning, execution, communication, writing and presentation. Advanced topics include understanding innovation, intellectual property and writing better proposals.

ECE 590. Graduate Co-op Work Experience I. 1 credit, 1 contact hour.
Restriction: permission from Department of Electrical and Computer Engineering and Division of Career Development Services. Cooperative education/ internship providing on-the-job reinforcement of academic programs in electrical and computer engineering. Assignments and projects are developed by the co-op office in consultation with the electrical and computer engineering department. Work assignments are related to student's major and are evaluated by faculty coordinators in the ECE department. Credits for this course may not be used to fulfill any electrical or computer engineering degree requirement.

ECE 591. Graduate Co-op Work Experience II. 1 credit, 1 contact hour.
Prerequisites: ECE 590 and permission from Department of Electrical and Computer Engineering and Division of Career Development Services. See ECE 590 course description. Credits for this course may not be used to fulfill any electrical or computer engineering degree requirement.

ECE 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Restriction: graduate standing and permission from Department of Electrical and Computer Engineering and Division of Career Development Services. See ECE 590 course description. Credits for this course may not be used to fulfill any electrical or computer engineering degree requirement.

ECE 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Restriction: One immediately prior 3-credit registration for graduate co-op work experience with the same employer. Requires approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

ECE 601. Linear Systems. 3 credits, 3 contact hours.
Methods of linear-system analysis, in both time and frequency domains, are studied. Techniques used in the study of continuous and discrete systems include state-variable representation, matrices, Fourier transforms, LaPlace transforms, inversion theorems, sampling theory, discrete and fast Fourier transforms, and Z-transforms. Computer simulation of linear systems is used, and, where feasible, computer solutions are obtained.

ECE 605. Discrete Event Dynamic Systems. 3 credits, 3 contact hours.
Covers the theory of discrete event dynamic systems with applications in modeling, control, analysis, validation, simulation, and performance evaluation of computer systems, flexible manufacturing systems, robotic systems, intelligent supervisory control systems, and communication networks. Emphasis on Petri net and automation based approaches.

ECE 610. Power System Steady-State Analysis. 3 credits, 3 contact hours.
Steady-state analysis of power system networks, particularly real and reactive power flows under normal conditions and current flows under faulty conditions. Symmetrical components and digital solutions are emphasized. An undergraduate background in Electrical Engineering or Mechanical Engineering is necessary.

ECE 611. Transients in Power Systems. 3 credits, 3 contact hours.
Prerequisite: ECE 610. Transient performance of power systems with lumped properties, interruption of arcs, restriking voltage, re-ignition inertia effects, switching of rotational systems, magnetic saturation in stationary networks, harmonic oscillations, saturated systems, transient performance of synchronous machines.

ECE 612. Computer Methods Applied to Power Systems. 3 credits, 3 contact hours.
Digital computer techniques proven successful in the solution of power system problems, particularly in the electric utility industry. Emphasis on short-circuit, load flow, and transient stability problems. Matrix sparsity is considered. Prior basic trainings on programming are necessary.

ECE 613. Protection of Power Systems. 3 credits, 3 contact hours.
Prerequisite: ECE 610 or equivalent Coils, condensers, and resistors as protective devices; fundamental principles of protective relaying; relay operating characteristics; power and current directional relays; differential relays; distance and wire pilot relays; heating and harmonic effects; and Computer-based protective device coordination.

ECE 616. Power Electronics. 3 credits, 3 contact hours.
Principles of thyristor devices, dynamic characteristics of choppers, commutation, protection, voltage-fed and current-fed inverter drives, cycloconverters, pulse width modulation, phase control, and microcomputer control, with case studies. An undergraduate background in Electrical Engineering or similar is necessary.

ECE 617. Economic Control of Interconnected Power Systems. 3 credits, 3 contact hours.
Economic Control of Interconnected Power Systems: Advanced techniques for operating power systems in the most economic manner while meeting various network constraints; economic dispatch, penalty factors, optimal power flow, short-term electricity markets and locational marginal prices will be studied.

ECE 618. Photovoltaic Semiconductors and Renewable Energy. 3 credits, 3 contact hours.
This course introduces renewable energy systems. It covers the fundamental concepts of energy and radiation with specific solar energy applications and photovoltaics, electrical energy storage systems, and thermal energy and storage. The second part covers the basic science of wind energy systems and their electrical sytem designs. The third part covers the bioenergy systems from resources to final products and conversion technologies. It finally introduces other promising energy sources.

ECE 619. Intelligent Sensing for Smart Grid and Smart City. 3 credits, 3 contact hours.
This course introduces the fundamentals and applications of intelligent sensing technology to smart grid and smart city. The course covers the fundamental sensing principles, types and selection of sensors including electromagnetic field sensors, amplifiers and bridge circuits, and sensing system architecture. Estimation and evaluation of sensor calibration and their responses by using finite element method, sensor noise and shielding design will be addressed. Signal analysis techniques such as wavelet analysis and sensor fusion will be discussed. Anomaly detection, fault classification and prediction and decision making on sensor data by machine learning, and the applications of electromagnetic sensing in power systems will be covered. Advanced sensor applications topics in IoT, smart grid and smart city will also be included. Prior undergraduate trainings in basic electromagnetics and circuit theories are necessary.

ECE 620. Electromagnetic Field Theory. 3 credits, 3 contact hours.
Maxwell's equations, boundary conditions and formulation of potentials. LaPlace and Poisson equations for electrostatic and magnetostatic problems and the method of images. Dielectric and magnetic materials, force and energy concepts. Quasi-static and time varying fields, plane, cylindrical and spherical waves. Green's functions, transmission lines. Prior undergraduate trainings in electromagnetic field theories are necessary.

ECE 622. Wave Propagation. 3 credits, 3 contact hours.
Prerequisite: ECE 620 or equivalent. Fundamentals of electromagnetics; radiation and scattering; Green's functions; integral equations; numerical methods; ray optics and asymptotics.

ECE 624. Optical Engineering. 3 credits, 3 contact hours.
This course covers basic optical concepts, emphasizing those common to many optical instruments, such as light sources and their characteristics, polarization, coherence, and interferometry. The course introduces CAD tools for lenses, optical filters, and instrument design. The course also focuses on topics concerning optical systems, such as flat panel displays and micromechanical optical systems.

ECE 625. Fiber and Integrated Optics. 3 credits, 3 contact hours.
Prerequisite: undergraduate electromagnetic field theory and solid-state circuits. Planar dielectric waveguides, step and graded index fibers and dispersion in fibers. The p-n junction and heterostructures, light emitting diodes and semiconductor lasers, p-i-n and avalanche photodetectors, optical transmitter and receiver designs, optical fiber communication system design concepts.

ECE 626. Optoelectronics - Nonlinear Modulators for Optical Communication. 3 credits, 3 contact hours.
Optical propagation in anisotropic materials, polarization, birefringence and periodic media. Concepts of electro-optics and acousto-optic devices, optical modulators, switches, active filters for optical communication and optical processing. Prior undergraduate trainings on electromagnetic field theories and solid-state circuits are necessary.

ECE 628. Power Grid Modernization. 3 credits, 3 contact hours.
This course provides a comprehensive exploration of the modernization of the power grid, focusing on the evolving infrastructure and technologies driving the next generation of electrical systems. The course delves into power transformers, substations, distribution automation, advanced metering infrastructure, and the resilience challenges posed by climate change, such as fire and storm damage. Emphasis will be placed on the integration of renewable energy sources like solar and wind, energy storage systems, and electric vehicles, as well as the role of intelligent substations, reliability, and resiliency improvements through smart grid technologies. Other key topics include power system planning, load forecasting, real and reactive power transfer, cybersecurity, system protection, and the development of microgrids and virtual power plants. By the end of the course, students will gain a comprehensive understanding of the critical elements driving power grid modernization.

ECE 629. Power System Modeling. 3 credits, 3 contact hours.
This graduate-level course provides an in-depth exploration of power system modeling and simulation, emphasizing hands-on experience with essential industry-standard software tools. Designed for students interested in careers as power grid planners, operators, or researchers, the course prepares students to address key challenges in renewable integration, energy storage, and power system stability. Students will gain expertise in specialized software tools. One of the tools is commonly used for steady-state analysis and grid planning tasks. It can be used for studying power flow, contingency analysis, and voltage stability with focus on grid operations and planning, gaining insight into grid planning and decision-making processes. Another tool specializes in dynamic simulations and is used for studying the transient stability and detailed behavior of power system components, particularly in scenarios involving power electronics and renewable energy integration. Students can apply it in operational studies, where understanding the system’s response to disturbances or the integration of renewable sources (like wind or solar) is critical. A final project will involve constructing and analyzing a renewable project model, incorporating industry standards and producing a comprehensive report based on simulated results.

ECE 630. Microwave Engineering. 3 credits, 3 contact hours.
Review of transmission line theory and the Smith chart; scattering matrix representation, LC and microstrip matching networks; signal flow graph analysis; micro-wave transistor amplifier design, which includes power gain, stability, noise figure circles; oscillator design. Prior undergraduate trainings in electromagnetic field theories are necessary.

ECE 632. Antenna Theory. 3 credits, 3 contact hours.
Fundamentals of electromagnetic field theory; far field approximation, antenna characteristics (gain, impedance, pattern, etc.); elementary antenna types (dipoles, loops, etc.), antenna array theory, wire antennas; broadband antennas. Prior undergraduate trainings in electromagnetic field theories are necessary.

ECE 636. Computer Networking Laboratory. 3 credits, 3 contact hours.
This course provides students with hands on training regarding the design, troubleshooting, modeling and evaluation of computer networks. In this course, students are going to experiment in a real test-bed networking environment, and learn about network design and troubleshooting topics and tools such as: network addressing, Address Resolution Protocol (ARP), basic troubleshooting tools (e.g. ping, ICMP), IP routing (e,g, RIP), route discovery (e.g. traceroute), TCP and UDP, IP fragmentation and many others. Student will also be introduced to the network modeling and simulation, and they will have the opportunity to build some simple networking models using the OPNET modeling tool and perform simulations that will help them evaluate their design approaches and expected network performance.

ECE 637. Internet Protocols and their Evolution with Artificial Intelligence. 3 credits, 3 contact hours.
The course analyzes the protocols that govern the Internet and discusses their evolution motivated by a variety of emerging networks and applications. The course also explores how these protocols adopt artificial intelligence (AI), such as machine learning algorithms, used to improve performance across the different layers of the protocol stack, with applications in areas such as security. Students will be also immersed in principles of protocol design through practical examples.

ECE 638. Network Management and Security. 3 credits, 3 contact hours.
Prerequisites: ECE 683 or CS 652, and ECE 637 or CS 656. Thorough introduction to current network management technology and techniques, and emerging network management standards. In-depth study of the existing network security technology and the various practical techniques that have been implemented for protecting data from disclosure, for guaranteeing authenticity of messages, and from protecting systems for network-based attacks. SNMP family of standards including SNMP, SNMPv2, and RMON (Remote Monitoring), OSI systems management. Various types of security attacks (such as intruders, viruses, and worms), Conventional Encryption and Public Key Cryptology. Various security services and standards (such as Kerberos, Digital Signature Standard, Pretty Good Privacy, SNMPv2 security facility). Same as CIS 696.

ECE 639. Principles of Broadband Networks. 3 credits, 3 contact hours.
Prerequisites: ECE 673, ECE 683 or CS 652 or equivalent. This course covers fundamental concepts of broadband networks. Topics include Broadband ISDN, Switching Techniques, ATM, SONET/SDH, Congestion Control, High-Speed Switching Architectures, Traffic Modeling of Broadband Services, Admission Control, Traffic Scheduling, IP/ATM Convergence, QoS Provisioning in IP Networks, and Optical Networks.

ECE 640. Digital Signal and Data Processing. 3 credits, 3 contact hours.
Prerequisite: ECE 601 or equivalent. The fundamentals of signal theory and transforms are introduced in this course. The representation of signals in the time and complex domains is covered. Z-transform is presented and Laplace transform to Z-transform mapping techniques are studied. Fourier analysis tools for analog and discrete-time signals are developed and tied with popular engineering applications. The subspace methods and eigendecomposition are studied. Their big data applications are presented. Basic design techniques to design digital filters are covered in this course.

ECE 641. Laboratory for High Performance Digital Signal Processing. 3 credits, 3 contact hours.

ECE 642. Introduction to Communication Systems: Evolution to 5G and Beyond. 3 credits, 3 contact hours.
Corequisite: ECE 673. Principles of communication theory applied to the representation and transmission of information, starting from analog communication to digital communication and ending at modern cellular systems as 5G and beyond. Topics include analysis of deterministic and random signals, amplitude modulation, angle modulation, sampling, quantization, geometric representation of signals, digital modulation as QAM, PSK, and OFDM, error probability, matched filter and correlation receivers, and the performance analysis of communication systems.

ECE 643. Digital Image Processing I. 3 credits, 3 contact hours.
Prerequisite: ECE 601. Introductory course in digital image processing. Topics include image models, digitization and quantization, image enhancement in spatial and frequency domains, image restoration, image segmentation and analysis.

ECE 644. Wireless Communications: Fundamentals to 5G. 3 credits, 3 contact hours.
This course is focused on the technical challenges and solutions to physical and link layer design of wireless communication systems. Course topics include characterization of the wireless channel, the cellular concept, digital modulation techniques, spread spectrum, multiple access techniques including CDMA and OFDM, diversity techniques. Advanced techniques such as LTE, MIMO, 5G NR technologies are introduced. Matlab is used for examples and assignments. Prior undergraduate trainings in Random Signals and Noise (ECE 321) or Probability and Statistics (MATH 333) are necessary.

ECE 645. Design of Wireless Networks: 5G Architecture and Services. 3 credits, 3 contact hours.
This course focuses on the upper-level design of wireless networks, especially the 5G architectures that intend to provide a common platform for everything connected to everything. It also introduces optional architectures in 5G to support services such as internet of things (IoT), autonomous vehicles, big data, mobile positioning, etc. The course prepares students to be constructive in engineering design in the new environment of 5G wireless communications. Upon completion of the course, students are expected to have a solid understanding of the capabilities and limitations of 5G networks, as well as the knowledge necessary to design, implement, and troubleshoot 5G systems from system engineering point of view. In addition, they would be prepared to conduct research on the current and future trends in 5G technology. To take this course, basic knowledge is required on probability and statistics, or trainings on random signals and noises.

ECE 650. Electronic Circuits. 3 credits, 3 contact hours.
Prerequisite: senior undergraduate level semiconductor circuits. Methods of analysis and design of linear and digital semiconductor circuits are studied. Topics include low and high frequency models, passive and active biasing techniques, I-C analysis and design, op-amp circuits, and active filters.

ECE 651. Wind Power Transmission and Grid Interconnection. 3 credits, 3 contact hours.
Restrictions: Students are required to electrical engineering background or related engineering or physical science backgrounds. This course aims to give the students advanced competences for the connection to the onshore power grid and the integration of offshore wind power. It involves offshore grid technology, operation principles, and the control of power converters and grids. It will provide knowledge about the role of wind power in the overall grid operation. The students will learn technical design aspects as well as related current economic conditions, including various regulation aspects of wind power and its influence on overall energy system operation. It will include an introduction of offshore wind power status and trends, electrical design aspects in offshore wind farms, grid connection and integration of offshore wind power, grid codes, dynamic models for offshore wind power plants, converter modelling and converter control.

ECE 652. HVDC Design, Operation and Maintenance. 3 credits, 3 contact hours.
Restrictions: Students are required to have electrical engineering background or related engineering or physical science backgrounds. This course covers the design, operation, and maintenance of HVDC (High-Voltage Direct Current) transmitted wind power. The course starts with a short review of the challenges that the transmission of offshore wind power faces. Next it is discussed how HVDC components are designed and what their main properties are. Subsequent lectures focus on the use of HVDC transmission as a technical solution addressing the issues described above. Basic mathematical models and control strategies are presented to analyze the impact of these devices on power system stability. Operating procedures and maintenance guidelines of the various HDVC transmission components are studied based on systems that are currently being deployed in offshore wind farms.

ECE 653. Micro/Nanotechnologies for Interacing Live Cells. 3 credits, 3 contact hours.
In this course, we will study technologies and tools available for interfacing live cells from a sub-cellular, single-cell, and multi-cellular (tissue models) approach. We will introduce key concepts of the biology of cells and tissues and will explore the technologies (micro-/nanotechnologies) and tools (sensors and actuators) available for the investigation of cell and tissue biology. Same as BME 653.

ECE 654. US Offshore Renewable Energy Policy. 3 credits, 3 contact hours.
This course will examine the statutory and regulatory frameworks that govern offshore wind farm leases and the permitting requirements associated with project development and construction. It will provide an overview of the legal regimes relevant to offshore wind, including property rights, climate change and energy, marine environmental protection, and maritime safety and security. Students will obtain a firm understanding of the permitting framework for offshore wind projects and the potential legal challenges associated with their development, construction, and finance. The course aims to equip students with an enhanced framework for evaluating US offshore energy and environmental policies that goes beyond traditional economic and regulatory perspectives.

ECE 656. Power System Dynamics. 3 credits, 3 contact hours.
Restrictions: Students are required to have electrical engineering background or related engineering or physical science backgrounds. The aim of this course is to provide students with knowledge in the analysis of power system dynamics and stability, focusing on practical applications in the energy market. The course presents power system stability, representation of synchronous machines, AC transmission modeling in stability studies, static and dynamic load models, steam and hydro turbines, governing systems, HVDC systems and their representation in stability studies, small-signal stability, small-signal stability of a single machine and multimachine systems, transient stability, simulation of power system dynamic response, direct method of transient stability analysis, voltage stability and voltage collapse, wide-area monitoring, and the impact of wind integration on power system dynamics. Additionally, the course explores the operation of wind energy in the power market to provide a comprehensive understanding of the evolving energy landscape.

ECE 657. Semiconductor Devices. 3 credits, 3 contact hours.
Fundamental principles of solid state materials necessary for understanding semiconductor devices. Topics include crystal structure; energy bands; electron and hole generation, and transport phenomena; generation and recombination processes, and high field effects. P-N junction diode, metal semiconductor contact, and bipolar and metal oxide semiconductor transistors, including switching phenomena and circuit models. Introduction to: photonic devices~light emitting diodes, semiconductor lasers, photodetectors, and solar cells; microwave devices~tunnel and IMPATT diodes, transferred electron devices, and charge-coupled capacitors.

ECE 658. VLSI Design I. 3 credits, 3 contact hours.
Analysis and design of digital integrated circuits; basic building blocks and dependence on circuit parameters of propagation delay; noise margin; fan-out; fan-in; and power dissipation for circuits of different logic families, including NMOS, CMOS and BiCMOS; subsystem designs in combinational and sequential logic; Memory Systems; HSPICE circuit simulation is used for digital characteristics evaluation. Mentor Graphics Layout design tools are used for chip design.

ECE 659. Fabrication Principles of Electronic and Optoelectronic Devices. 3 credits, 3 contact hours.
Prerequisite: ECE 657 or equivalent. Overview of all major processing steps in fabrication of integrated circuits such as crystal growth, epitaxy, oxidation, diffusion, ion implantation and etching. Formation of thin film structures along with techniques for defining submicron structures. Emphasizes silicon device technology but also includes processing of compound semiconductors such as gallium arsenide.

ECE 660. Control Systems I. 3 credits, 3 contact hours.
Prerequisites: ECE 601 or equivalent. Introduction to feedback control. Review of state-space analysis. Frequency-domain methods for analysis: Routh-Hurwitz stability algorithms, Root-loci; Nyquist and Bode plots; system ?type.? Controllability and observability. The separation principle and design by pole placement. Linear observers. Optimization of quadratic performance criteria. Elements of random processes. The Kalman filter as an optimum observer. Robustness considerations. Prior undergraduate trainings in Signals and Systems (ECE 333) or Dynamic Systems (ME 305) are necessary.

ECE 661. Control System Components. 3 credits, 3 contact hours.
Prerequisite: ECE 660. The theoretical and practical requirements for analog and digital state-of-the-art control system components are covered. Actuators, amplifiers, sensors, encoders, resolvers and other electromagnetic devices are included. A complete system is designed using current vendor catalog data. Problems affecting the system performance are analyzed using measures of functionality, reliability and cost.

ECE 664. Applied Advanced Control Systems. 3 credits, 3 contact hours.
The course focuses on the practical aspects of modern computer-controlled systems. Topics include 1. fundamentals such as Z-transformation, discrete signals and systems, conversion between continuous systems and discrete systems; 2. control law designs such as state feedback control, optimal control, observers, compensators, PID, input shaping, feedforward control, deadbeat control, and Smith predictor; 3. practical design issues such as actuator saturation, anti-windup, selection of sampling rate, etc.; 4. case studies and 5. a software- and simulation-based term project. Prior undergraduate trainings in Control Systems (ECE 431) is necessary.

ECE 667. Bio-Control Systems. 3 credits, 3 contact hours.
The course provides an introduction to dynamic and control in biological systems, with particular emphasis on engineering aspects of biological oscillators/waves which govern the basic operations of all living organisms and especially higher order life forms. A combination of theoretical and simulation tools will be applied to analyze the qualitative and quantitative properties of selected biological systems. Feedback and control mechanisms in selected biological systems will be introduced. Same as BME 667.

ECE 670. Management Strategies in the Offshore Wind Industry. 3 credits, 3 contact hours.
This course offers students the opportunity to build their knowledge and skills and acquire managerial insights on various stages of the life cycle of a wind farm project including development and planning, wind resource assessment, project design, financing, offshore construction, power generation, monitoring and optimization, and decommissioning. through class discussions, interactions with leaders in the U.S. offshore wind industry. Skills examined and practiced in this course include developing and communicating a vision and leadership brand, systems thinking, team building, and decision making. An important goal of the course is to review an offshore wind business's strengths and weaknesses and formulate strategies to explore renewable energy opportunities as well as to cope with the policy and environmental threats in the United States and beyond. The overall pedagogical objectives are to sharpen the student’s ability to "think strategically" and to diagnose situations from a strategic perspective. Leaders from the U.S. offshore wind industry will be invited to be guest lecturers and teach students the models they use to analyze the internal and external environments of an organization as well as the industry and competitive environments of a company, and examine how they are used in the formulation, implementation, and control of competitive strategy.

ECE 671. Financing Offshore Wind. 3 credits, 3 contact hours.
The course begins with an overview of fundamental financial and economic concepts related to commercial-scale wind energy projects. It will dive into the fundamental aspects of site selection, feasibility studies, and the intricacies of wind resource assessment. The course will explore financial aspects of wind turbines and layout design, addressing considerations for optimal energy production and environmental impact. Students will gain insights into project financing, permitting processes, and regulatory compliance specific to the wind energy sector. Through case studies and real-world examples, students will develop a practical understanding of the entire project life cycle, from initial development to construction, operation, and eventual decommissioning. In addition, the course investigates energy policy, and students will gain insights into the historical and contemporary aspects of the Production Tax Credit (PTC) and Investment Tax Credit (ITC), as well as the evolution of subsidies within the industry.

ECE 673. Random Signal Analysis. 3 credits, 3 contact hours.
Fundamentals of the theory of random variables. Introduction to the theory of random processes. Topics include functions of random variables, sequences of random variables, central limit theorem, properties of random processes, correlation, spectral analysis and linear systems with random inputs.

ECE 681. High-Performance Network Function, Data Center, and Virtualization. 3 credits, 3 contact hours.
The course introduces network algorithms for pragmatic implementations of network functions that target high-performance communications used at different network zones and Internet applications. Examples of such functions are Internet packet address (IP) lookup, packet classification, firewalling, scheduling, service chaining, WAN access, and operations at various levels of the protocol stack. The course also introduces architectures of data-center networks and data-center transport protocols, and the use and impact of virtualization on network functions.

ECE 683. Cloud and IoT Networking and Security. 3 credits, 3 contact hours.
This course will introduce the students to the basic networking concepts that enable the management and security of cloud and IoT networks. This course will start with the study of the fundamentals of computer networking and layering. Then, several techniques and protocols that enable and secure these technologies will be studied such as, specialized and advanced packet capture tips, virtualization / IEEE 802.15 Bluetooth / IEEE 802.15.4 ZigBee / IEEE 802.16e WiMAX / Home RF / ZWave / RFID / Infrared / PBCC / 3G / 4G / 5G, and specialized data traffic reconstruction and viewing techniques.

ECE 684. Advanced Microprocessor Systems. 3 credits, 3 contact hours.
Architecture of advanced microprocessors; CPU architecture, memory management and protection, interrupt and exception facilities, instruction sets, systems aspects including peripheral interfaces, communications ports, and real-time systems. Prior undergraduate trainings in computer architecture, microprocessors, and assembly language programming are necessary.

ECE 689. Computer Arithmetic Algorithms. 3 credits, 3 contact hours.
Data representation, integers, floating point and residue representation. Bounds on arithmetic speed, algorithms for high speed addition, multiplication, and division. Pipelined arithmetic. Hardware implementation and control issues. Prior undergraduate trainings in logic design are necessary.

ECE 690. Computer Systems Architecture. 3 credits, 3 contact hours.
Discusses advanced topics in modern computer systems architecture such as pipelined and superscalar processors, parallel computers (vector, SIMD, MIMD), multithreaded and dataflow architectures, cache and memory hierarchy, and system interconnect architectures. Also discusses relevant system software design issues such as shared memory and message-passing communication models, cache coherence and synchronization mechanisms, latency-hiding techniques, virtual memory management, program partitioning and scheduling. Examples are drawn from real systems. Prior undergraduate trainings in computer architecture are necessary.

ECE 692. Embedded Computing Systems. 3 credits, 3 contact hours.
Introduction of the methodology for the design and implementation of embedded computing systems, and its application to real-world problems. Topics include Embedded System Design Process, UML, ARM Instruct Set Architectures, CPU's Hardware Platforms, Software Design and Analysis, Embedded Operating Systems, Real-Time Scheduling, Hardware Accelerators, Distributed Embedded Systems, and Design Methodology and Quality Assurance. Prior undergraduate trainings in computer architecture are necessary.

ECE 698. Selected Topics in Electrical and Computer Engineering. 3 credits, 3 contact hours.
Special area course given when suitable interest develops. Advance notice of forthcoming topics will be given.

ECE 699. Selected Topics in Electrical and Computer Engineering II. 3 credits, 3 contact hours.
See description for ECE 698 above.

ECE 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in electrical or computer engineering. A written report must be submitted to the project advisor. The student cannot register in ECE 700B more than once and the incomplete (I) grade is not allowed. Master's students registering for the first time in Master's Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ECE 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in electrical or computer engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in ECE 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ECE 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in electrical or computer engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (ECE 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

ECE 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

ECE 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for ECE 726 if they have taken ECE 725 in a prior semester.

ECE 739. Laser Systems. 3 credits, 3 contact hours.
Prerequisite: ECE 620 or permission of instructor. Optical resonators, laser radiation and oscillation. Laser characteristics: semiconductor lasers, gas and glass lasers; mode-locking, Q-switching. Quantum-well lasers, noise; modulation and detection of laser light, optical systems for communication and computation.

ECE 740. Advanced Digital Signal Processing. 3 credits, 3 contact hours.
Prerequisites: ECE 601, ECE 640 and ECE 673. Topics in stationary discrete time stochastic processes; modeling of discrete time processes, Yule-waker equations, aspects of discrete wiener theory; principle of orthogonality, linear predictors; Levinson-Durbin recursion and algorithm, lattice predictors, method of least squares (RLS) algorithm, systolic array implementation of QRD-Ls.

ECE 742. Communication Systems II. 3 credits, 3 contact hours.
Prerequisites: ECE 642 and ECE 673 or equivalents. Principles of digital communication. Topics include fundamentals of information theory, digital modulation techniques, optimum detector receivers for digitally modulated signals, the bandlimited gaussian channel and intersymbol interference, equalization, spread spectrum, CDMA.

ECE 743. Image Data Hiding, Forensics. 3 credits, 3 contact hours.
Prerequisites: ECE 643 or CS 659 or equivalent As we have entered digital world, information forensics and security have become critically important. With digital images as media, this course covers digital watermarking, reversible data hiding, steganography and steganalysis, forensics and counter-forensics, including image tampering detection, classification of double JPEG/MPEG compressions, camera classification from given images, classification of photographic images from computer graphic images, and so on.

ECE 744. Optimization for Data Engineering. 3 credits, 3 contact hours.
With the emergence of advanced sensing and monitoring technologies, data has become the new oil of our digital economy. In all the engineering fields, ranging from power systems and transportation systems to online shopping, web servers, sensors and cameras are continuously collecting huge amounts of data, but this data will not have any meaning without proper processing, analysis, and learning. Optimization techniques provide the core foundation for the processing of the data and learning from it. This course covers the basic analytical and algorithmic optimization tools that lay the foundation for the data analytics and deep learning systems. Specific topics include single-objective convex optimization (duality, optimality conditions, algorithms), gradients-based methods, and the fundamentals of multi-objective optimization and game theory. The theoretical foundation and the fundamental algorithms are applied to real-world scenarios that utilize supervised learning models, including nonlinear regression, logistic regression, support vector machines, and deep neural networks.

ECE 747. Signal Decomposition Techniques: Transforms, Sub-bands, and Wavelets. 3 credits, 3 contact hours.
Prerequisites: ECE 640 and ECE 673. Multiresolution signal decomposition techniques, transforms, sub-bands, and wavelets. Time-frequency localization properties of multiresolution algorithms. Evaluation and critique of proposed decomposition strategies from compression and performance standpoints. Applications to speech and video compression, and localized feature extraction. These are basic signal processing tools used in diverse applications such as speech and image processing and storage, seismology, machine vision.

ECE 754. Statistical Machine Learning for Engineers and Data Scientists. 3 credits, 3 contact hours.
Prerequisites: Good knowledge of statistics and probability, as covered in ECE 673 or similar courses, and linear algebra; or permission of instructor. With the explosion of “Big Data” problems, statistical learning has become a very hot field in many scientific areas as well as in marketing, finance, and business. Statistical learning refers to a vast set of tools for understanding data. Specifically, supervised statistical learning involves building a statistical model to predict or estimate an output or pattern based on one or more inputs. For unsupervised learning there are inputs, but no supervising output, and here the goal is to learn relationships and structure from the data. This course provides a systematic introduction to statistical machine learning and pattern recognition using fundamental performance criteria as guiding principles and studies how these principles affect real-world performance. Topics covered include practical techniques as linear and kernel models for classification and regression, unsupervised probabilistic modeling, probabilistic graphical models, and approximate inference, but also theoretical underpinnings as VC dimension and sample complexity.

ECE 755. Advanced Topics in Digital Communications. 3 credits, 3 contact hours.
Prerequisites: ECE 642 and ECE 673 or equivalent. Advanced topics in digital communication systems in the presence of intersymbol interference, noise, and fading: modulation and demodulation in the presence of gaussian noise, efficient signaling with coded modulation, trellis decoding, Viterbi algorithm, digital transmission with intersymbol interference, and digital signaling over imperfect channels.

ECE 756. Advanced Topics in Semiconductor Devices. 3 credits, 3 contact hours.
Prerequisite: ECE 657 or permission of instructor. Builds on ECE 657. Covers photonic devices particularly semiconductor laser and photodetectors for optical systems; microwave and other high speed devices; scaled advanced MOS, FET, and bipolar transistors.

ECE 758. VLSI Design II. 3 credits, 3 contact hours.
Prerequisite: ECE 658 (with ECE 657 suggested). Use of CMOS, biCMOS and bipolar semiconductor technology for VLSI design. Digital techniques are emphasized with minor coverage of analog design. Application areas for full custom, gate arrays, standard cell, and compiled designs are compared. Mentor VLSI design tools running on the HP and Sun workstations are used in the course projects for each enrollee. The course attempts to provide a design environment for projects that is similar to that encountered by VLSI designers in industry.

ECE 760. Control Systems II. 3 credits, 3 contact hours.
Prerequisites: ECE 601 and ECE 660. Properties of nonlinear systems and basic concepts of stability including small-signal linearization. State plane methods are introduced, with emphasis on controller design for systems that can be represented by second-order approximations. Concepts of equivalent gain, describing function, and dual-input describing function as applied to a large class of nonlinear systems. Representation of linear sampled-data systems in discrete state variable form, stability and performance of discrete-event systems. Full-state feedback, pole placement and observer design. Linear quadratic control and Kalman filtering.

ECE 776. Information Theory. 3 credits, 3 contact hours.
Prerequisites: ECE 642 and ECE 673 or equivalents. Classical theory of information developed from Shannon's theory. Information measure, Markov sources and extensions, the adjoint source, uniquely decodable and instantaneous codes and their construction, Shannon's first and second theorems, mutual information, and performance bounds on block and convolutional codes.

ECE 777. Statistical Decision Theory in Communications. 3 credits, 3 contact hours.
Prerequisite: ECE 642 or equivalent. Relation between detection theory and statistical hypothesis testing problem. Use of Bayes decision criteria, Neyman-Pearson, and mini-max tests; receiver operating characteristics. Representation of signals in signal space, probability of error calculations. Estimation of random and non-random signal parameters, Cramer-Rao Inequality. The general Gaussian problem and the use of covariance matrices.

ECE 783. Computer Communication Networks. 3 credits, 3 contact hours.
Prerequisites: ECE 673 and ECE 683. Data link control and communication channels. Delay models in data networks. Queueing analysis techniques are taught in detail. Multi-access communication techniques. Routing in computer communication networks.

ECE 788. Selected Topics in Electrical and Computer Engineering. 3 credits, 3 contact hours.
Special-area course given when suitable interest develops. Advance notice of forthcoming topics will be given.

ECE 789. Selected Topics in Electrical and Computer Engineering II. 3 credits, 3 contact hours.
See description for ECE 788.

ECE 790A. Doctrl Dissrtn & Research. 1 credit, 1 contact hour.
Co-requisite: ECE 791. Approval of the dissertation advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in electrical or computer engineering. For PhD students who have successfully defended their dissertation proposal. The student must register in ECE 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members. Students enrolled in the PhD program before 2015 Fall must accumulate a minimum number of credits in Doctoral Dissertation Research and Pre-Doctoral Research (see graduate catalog for program-specific details; the same requirement may apply to joint PhD programs with other universities).

ECE 791. Graduate Seminar. 0 credits, 0.5 contact hours.
All master's and doctoral students must register for two semesters and six semesters of ECE 791 Graduate Seminar, respectively. To receive a satisfactory grade, students must attend at least five seminars during the semester, as approved by the seminar supervisor.

ECE 792B. Pre-Doctoral Research. 3 credits, 3 contact hours.
Co-requisite: ECE 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in electrical or computer engineering. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

EM 501. Industrial Management. 3 credits, 3 contact hours.
Prerequisite: approval from the engineering management graduate advisor or program director. Operational aspects of management techniques: organization, product design and development, distribution logistics, marketing, plant location and layout, materials handling, production planning and control, inventory control, quality control, work analysis, and incentive plans.

EM 502. Engineering Cost Analysis. 3 credits, 3 contact hours.
Restriction: approval from the engineering management graduate advisor or program director. Financial, engineering, economic, and cost-control aspects of industrial management; the accounting cycle; cost accounting procedure; and cost-model techniques of making cost comparisons through engineering economic studies.

EM 503. Methods and Applications of Industrial Statistics and Probability. 3 credits, 3 contact hours.
Restriction: approval from the engineering management graduate advisor or program director, undergraduate course in calculus. An analytical approach to basic engineering probability and statistics, with applications drawn from both manufacturing and process industries. Emphasis is placed upon the utility of statistical inference derived from engineering data.

EM 602. Management Science. 3 credits, 3 contact hours.
Prerequisite: undergraduate calculus and probability and statistics. Linear programming: formulation, methodology, and application; the transportation problem; the assignment problem; Markov chains and their applications in decision making; queueing systems; deterministic and stochastic inventory models.

EM 617. Environmental Risk Assessment. 3 credits, 3 contact hours.
Prerequisite: undergraduate courses in calculus and economics. Application of management technique methodology to recognize, evaluate, and make decisions regarding expenditures for the mitigation of potentially hazardous environmental risks. Basic analytical techniques applicable to social and economic risk assessment; methodology and application to current air and water resources; and rationale for cost-benefit and trade-off analysis. Technical characteristics of materials: half-life, decomposition rates, and temperature sensitivity determining environmental probabilities and expectations.

EM 631. Legal Aspects in Environmental Engineering. 3 credits, 3 contact hours.
Control of air, water, and solid waste pollution by federal, state, and local government statutes and international law. Preparation of environmental impact statements and the right of private citizens to bring suit under federal clean air and water pollution legislation are discussed, as well as limitations on these rights.

EM 632. Legal Aspects in Construction. 3 credits, 3 contact hours.
Introduction to the legal factors affecting construction activities: contract responsibilities of contractors, engineers, and owners; subcontracts and third-party liability; construction law and code compliance; and insurance and bonds.

EM 633. Legal Aspects of Health and Safety. 3 credits, 3 contact hours.
Review of key laws and regulations pertaining to occupational health, safety, and product liability; methods to determine which codes apply in given situations and to prepare operating procedures to be used for internal compliance.

EM 634. Legal, Ethical and Intellectual Property Issues for Engineering Managers. 3 credits, 3 contact hours.
Introduction to various environmental, product liability, health and safety, and intellectual property, legal, as well as ethical, issues facing engineering managers. Current New Jersey and federal laws and pending legal actions in these fields. Case studies and advanced multimedia learning tools are used.

EM 635. Management of Engineering Research and Development. 3 credits, 3 contact hours.
Prerequisites: principles of management and statistics, or EM 501 and EM 503. A systems approach to management of resources, and tasks needed for engineering research and development. Identification, analysis, and evaluation of the operational characteristics and structure of the research laboratory and engineering office; functions of planning, organizing, staffing, direction, control, innovation, and representation; and planning and control theories, techniques, and current practices in scientific and engineering management.

EM 636. Project Management. 3 credits, 3 contact hours.
Introduction to concepts of project management and techniques for planning and controlling of resources to accomplish specific project goals. While the focus is on technically oriented projects, the principles discussed are applicable to the management of any project. Topics include time, cost considerations, cash flow forecasting, financial and performance control, documentation.

EM 637. Project Control. 3 credits, 3 contact hours.
Prerequisites: EM 636 or MGMT 641. Focuses on the methodology that can be employed to plan project implementation and control progress. Topics include work breakdown construction, task and schedule development budgetary control, earned value analysis, and behavioral considerations. Project management software utilization is emphasized.

EM 640. Distribution Logistics. 3 credits, 3 contact hours.
Distribution logistics emphasizing systems engineering techniques used to optimize corporate profit and customer service: transportation modes; inventory policies; warehousing and order processing; and the best logistics gross margin.

EM 641. Engineering Procurement and Materials Management. 3 credits, 3 contact hours.
Prerequisites: EM 602, EM 640, and EM 674 or equivalents. Study of the logistics life cycle, involving planning, analysis, design, testing, distribution and life cycle support. Make versus buy engineering design decision. Various tools and techniques for an effective life cycle support program. Benchmarking approach to survey available internal and external resources and competitor solutions. Constructing life cycle cost models for acquisitions. Build adequate specification. Application of the latest techniques in supplier chain quality management. Case studies and advanced multimedia learning tools are used.

EM 655. Management Aspects of Information Systems. 3 credits, 3 contact hours.
Prerequisite: computer programming experience. Information flow in an organization as an integrated system and management resource: techniques of data analysis, design, and processing; characteristics of computerized information-handling equipment; data acquisition, storage, processing, retrieval, and transmission to decision-makers; and information systems for finance, production, inventory, accounting, marketing, and distribution.

EM 660. Financing an Industrial Enterprise. 3 credits, 3 contact hours.
Prerequisites: undergraduate economics, accounting, and engineering economy. Principles of financial practice and management in modern business corporations emphasizing financial planning and control; capital project and working capital needs; internal and external financing; and finance as a major function of the management process.

EM 661. Advanced Engineering Economics. 3 credits, 3 contact hours.
Prerequisite: undergraduate engineering economics or equivalent. Economic use of a firm's capital resources. Feasibility studies of potential major capital investments likely to be considered by an enterprise. Risk assessment, cost engineering, effect of financing sources, life cycle, and technologies forecasting models. Case studies are used.

EM 674. Benchmarking and Quality Function Deployment. 3 credits, 3 contact hours.
Prerequisite: IE 673 or equivalent. Continuation of IE 673. Benchmarking surveys of competition, process analysis of engineering activities, statistical process control mathematics, Taguchi methods of process and product design, current total quality management innovations, quality functional deployment. Case studies and advanced multimedia learning tools are used.

EM 691. Cost Estimating for Capital Projects. 3 credits, 3 contact hours.
Cost estimating techniques and procedures for budgeting used in evaluation, planning, and control of capital investments. Emphasis on updating for change, escalation, and statistical and computer methods.

EM 693. Managerial Economics. 3 credits, 3 contact hours.
Prerequisite: undergraduate economics. Internal and external influences on the economic practices of business; classical and current theories of economic behavior; contemporary analytical techniques; behavior of costs, prices, and profits; demand analysis, competition and monopoly; capital expenditure planning; profit theories and business cycles; and econometric models of market strategies, competitive action, and demand behavior.

EM 695. Public Utility Energy Management. 3 credits, 3 contact hours.
Prerequisite: EM 602 or equivalent. Managing loads on electric power systems. Influence of variable rate structure and description of several projects currently in progress.

EM 696. Nuclear Power Reactor Management. 3 credits, 3 contact hours.
Prerequisites: undergraduate economics and physics. Nuclear power reactor management and power generation alternatives: optimum performance; maximum control; minimum cost; capacity planning; cost estimating; investment requirements; plant location and safety; separation technology for fuel enrichment; transportation and storage of spent fuel; reprocessing and nuclear waste storage; and regulatory aspects of nuclear power.

EM 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in engineering management. A written report must be submitted to the project advisor. The student cannot register in EM 700B more than once and the incomplete (I) grade is not allowed. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

EM 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in engineering management that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in EM 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

EM 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in engineering management that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (EM 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

EM 714. Multicriteria Decision Making. 3 credits, 3 contact hours.
Prerequisite: some background in operations research. Multiobjective programming and conflict analysis to evaluate alternatives in decision making, utility, assessment methodology, interactive and noninteractive multiple mathematical programming methods, and surrogate worth trade-off methods are covered.

EM 715. Design of an Enterprise. 3 credits, 3 contact hours.
Prerequisites: undergraduate economics, industrial management accounting, engineering economy, probability and statistics; 9 credits of EM courses at 600-level or above; and advisor's approval. Organization and management of an enterprise, from initial planning through production and distribution of manufactured products. Students choose the industry that they study.

EM 716. Seminar in the Design of an Enterprise. 3 credits, 3 contact hours.
Prerequisite: EM 715. Continuation of EM 715. Depending on the student's interest, report on design of the particular enterprise emphasizing either the management of research and development; the management of production; the management of distribution; or the management of manpower.

EM 725. Independent Research. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

EM 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for EM 726 if they have taken EM 725 in a prior semester.

EM 740. Management of Transportation Carriers. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or equivalent and TRAN 650 or EM 602 or equivalent. Presents theory and practice of managing transportation carriers, including the concepts of costing, pricing, designing and marketing transportation service; the concepts of financial efficiency and resource productivity with application to the selected freight carriers in each mode of transportation. Selected case studies of carriers? operations management practices in various modes. Comparative studies of service characteristics, market share, cost structures both within a particular transportation mode and between the modes. Same as TRAN 740.

EM 765. Multi-modal Freight Transportation Systems Analysis. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or equivalent and TRAN 650 or EM 602 or equivalent. Quantitative methods for the analysis and planning of freight transportation services. The supply-performance-demand paradigm for freight transportation systems. Cost and performance as determined by system design and operations. Relationship of traffic and revenue to service levels and pricing. Optimal service design and redesign for transportation enterprises and operations planning. Fleet and facility investment planning. Applications to various modes. Same as TRAN 765 and CE 765.

EM 771. Operations Cost and Management Control. 3 credits, 3 contact hours.
Prerequisites: 6 credits of EM courses at 600-level or above. Analysis and control of cost and other operational aspects of enterprises: manufacturing, distribution and overhead budgets; cost accounting; management information systems; relevant behavioral factors; financial and other management reports. Case studies used.

ENE 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Prerequisite: One immediately prior 3-credit registration for graduate co-op work experience with the same employer. Requires approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

ENE 630. Physical Processes of Env Syst. 3 credits, 3 contact hours.

ENE 660. Introduction to Solid and Hazardous Waste Problems. 3 credits, 3 contact hours.
Pre or Corequisite: ENE 663. (May be taken concurrently.) Introduction to solid waste disposal. Industrial and urban sources of solid waste and conventional methods of waste disposal. Application of engineering principles related to these topics.

ENE 661. Environmental Microbiology. 3 credits, 3 contact hours.

ENE 662. Site Remediation. 3 credits, 3 contact hours.
Prerequisite: EM 631. Can be taken concurrently with EM 631. Examines site remediation from start to finish. Includes regulations, cleanup standards, remedial investigations, feasibility studies, risk assessment, and safety. Examines established and innovative cleanup technologies such as incineration, containment, bioremediation, vapor extraction and ground water recovery.

ENE 663. Water Chemistry. 3 credits, 3 contact hours.
Prerequisite: undergraduate general chemistry. The ability to analyze and solve a wide range of chemical equilibrium problems in water chemistry is developed.

ENE 664. Physical and Chemical Treatment. 3 credits, 3 contact hours.
Prerequisite: ENE 663. Physical and chemical operations and processes employed in the treatment of water and wastewater. Topics include gas transfer, coagulation, flocculation, solid-liquid separation, filtration, and disinfection.

ENE 665. Biological Treatment. 3 credits, 3 contact hours.
Pre or Corequisites: ENE 663, ENE 661. (May be taken concurrently.) Principles of evaluation and control of water pollution that describe aerobic treatment processes: oxidation ponds, trickling filters, and activated sludge. Anaerobic digestion and sludge handling and disposal as well as biodegradability study techniques for various wastes.

ENE 666. Analysis of Receiving Waters. 3 credits, 3 contact hours.
Pre or Corequisites: ENE 663 and ENE 661. Ecological responses of various types of receiving waters to municipal and industrial waste loadings. Mathematical models for water quality prediction and planning.

ENE 667. Solid Waste Disposal Systems. 3 credits, 3 contact hours.
Prerequisite: ENE 663. Review and evaluation of design criteria, methods, and equipment employed in handling and disposal of industrial and municipal solid wastes. Emphasis is on hazardous toxic waste, resource recovery, and regulatory constraints.

ENE 671. Environmental Impact Analysis. 3 credits, 3 contact hours.
Pre or Corequisite: ENE 663. A graduate course dealing with physical aspects of the environment. Overview of environmental problems, federal and state standards, methodology for developing impact statements, case studies based on recent experience, basis for assessment and decision making.

ENE 672. Stormwater Management. 3 credits, 3 contact hours.
This course provides a comprehensive study of stormwater management with emphasis on design practices. Topics include regulatory framework, an overview of structural and non-structural BMPs, groundwater recharge analysis, estimate of runoff, and design of detention basin and drainage systems.

ENE 673. Sustainability and Life Cycle Analysis. 3 credits, 3 contact hours.
The course provides a systematic foundation for the connection between evolving technology and human activity impacts on natural systems by emphasizing the sources of environmental degradation and energy use and strategies to reduce risk and promote sustainability. The course provides hands-on experience with life cycle assessment computer tools and approaches. The course emphasizes relationships between industrial activities and regional and global natural systems-physical, chemical and biological-focusing on the importance of sustainability goals and practices.

ENE 700B. Master's Project. 3 credits, 3 contact hours.
Prerequisite: student must have sufficient experience and/or graduate courses in major field to work on the project. Subject matter to be approved by the department. Permission to register must be obtained from the project advisor. Extensive investigation, analysis, or design of environmental engineering problems not covered by regular graduate course work is required. A student with an exceptional project in ENE may, upon his/her own initiative and with the approval of his/her advisor, substitute the work of this course as the equivalent of the first 3 credits for ENE 701 Master's Thesis. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ENE 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in environmental engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in ENE 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ENE 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in environmental engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (ENE 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

ENE 702. Special Topics in Environmental Engineering. 3 credits, 3 contact hours.
Restriction: advisor's approval. Topics of special current interest in environmental engineering.

ENE 703. Biogeochemical Applications in Environmental Engineering. 3 credits, 3 contact hours.
Pre or Corequisites: ENE 663 Water Chemistry, ENE 661 Environmental Microbiology. This class will combine theoretical concepts (lectures) with laboratory and field studies to integrate the basic principles of environmental engineering, chemistry and microbiology to solve practical problems of assessment and treatment of contaminated sites. In the lectures, the students will be introduced to environmental regulations, the theoretical concepts for environmental sampling design, the procedures for analytical techniques, and traditional and cutting-edge remediation approaches. These lectures will be supplemented with peer-reviewed articles, technical reports, and operational methods. The field studies will consist in sampling collection methods, where the students will participate in a one-day sampling trip to a contaminated site to collect water, sediments, and plants samples. The students will then process the samples in the laboratory for further analysis for the contaminants of interest. Using this information, the students will prepare a Feasibility Study/Remedial Investigation (FS/RI) for their targeted site where they will evaluate three to five remediation strategies and will propose one final remediation design. The final RI/RD will be presented to the whole class in a mock Community Advisory Group (CAG) session.

ENE 705. Technologies for Treatment of Emerging Contaminants. 3 credits, 3 contact hours.
The growing presence of 'emerging contaminants' (ECs) is a significant concern because these synthetic and naturally occurring chemicals often go unmonitored, yet they enter the environment and negatively impact both environmental and human health. Some examples of ECs include PFAS, 1,4-dioxane, pharmaceuticals, personal care products, and many others, which are found in various water sources and food chains. Unfortunately, traditional water and wastewater treatment processes do not effectively remove them, and thus advanced and novel technologies have been developed over recent decades to address these contaminants. This course will introduce students to the theoretical concepts and design of such novel systems for treating ECs. These lectures will be supplemented with peer-reviewed articles, technical reports, and case studies. Required background: undergraduate and/or graduate courses in environmental microbiology, water chemistry, water quality and treatment, or permission of instructor.

ENE 720. Environmental Chemodynamics. 3 credits, 3 contact hours.
Introduction to concepts, mechanisms and models used to describe the transport of chemicals in the environment. Concepts and models are applied to air-water, sediment-water and soil-air interfaces.

ENE 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

ENE 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for ENE 726 if they have taken ENE 725 in a prior semester.

ENE 790A. Doctoral Dissert & Res. 1 credit, 1 contact hour.
Co-requisite: ENE 791. Approval of the dissertation advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in environmental engineering. For PhD students who have successfully defended their dissertation proposal. The student must register in ENE 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members. Students enrolled in the PhD program before 2015 Fall must accumulate a minimum number of credits in Doctoral Dissertation Research and Pre-Doctoral Research (see graduate catalog for program-specific details; the same requirement may apply to joint PhD programs with other universities).

ENE 791. Graduate Seminar. 0 credits, 0 contact hours.
Seminar in which faculty or others present summaries of advanced topics suitable for research. Students and faculty discuss research procedures, thesis organization, and content. Students present their own research for discussion and criticism. Required of all doctoral students registered for ENE790 unless requirement is waived, in writing, by the dean of graduate studies.

ENE 792. Pre-Doctoral Research. 3 credits, 3 contact hours.
Co-requisite: ENE 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in environmental engineering. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

ESC 601. Fundamentals of Geomatics Engineering. 3 credits, 3 contact hours.
Prerequisites: Fundamental knowledge of calculus, MATH 111 or MATH 138 or equivalent. Restrictions: Graduate Standing or Approval from the Course Instructor. Covers basic knowledge of spatial reference systems and geodetic coordinates. Examines the first fundamental form and theory of distortion in map projection with application to conformal mapping within state plane coordinate systems. Introduction of the geopotential model and computational methods for geodetic positioning, physical and geometric heights, and gravity anomalies to quantify crustal movement and change detection. Examines geomatics engineering methodologies for sustainable development and risk mitigation through case studies.

ESC 603. Artificial Intelligence for Geospatial Decisions. 3 credits, 3 contact hours.
Prerequisites: Fundamental knowledge of statistics MATH 105 or equivalent and computer programming CS 106 or equivalent. Restrictions: Graduate Standing or Approval from the Course Instructor. Statistical learning theory with a focus on artificial intelligence (AI) for geospatial data. Two perspectives through machine learning include supervised and unsupervised learning of geospatial patterns. Course outcomes include knowledge and skills necessary to investigate patterns in geospatial data to support decision-making within the context of engineering and geoscience disciplines.

ESC 690. Graduate Co-op Work Experience in Engineering Science. 3 credits, 3 contact hours.
Prerequisites: Must have completed 18 credits of graduate course work. Restrictions: Approval of the departmental co-op advisor and the Division of Career Development Services. This cooperative educational opportunity allows students to engage in experiential learning with industry to develop an applied industry-oriented research proposal. The course will follow the requirements outlined by NJIT's Division of Career Development Services and the School of Applied Engineering and Technology. Students must have completed 18 credits of graduate course work prior to the commencement of the co-op. Approval of departmental co-op advisor and the Division of Career Development Services is required for registration.

ESC 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in engineering science that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in ESC 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ESC 701C. Master's Thesis. 6 credits, 6 contact hours.
Restrictions: Approval of the thesis advisor is required for registration.

ESC 702. Special Topics in Engineering Science. 3 credits, 3 contact hours.
Restrictions: Advisor's approval, Graduate standing. This course will cover special interest topics in applied engineering and science. This includes interdisciplinary and multidisciplinary graduate-level areas in the applied field.

ESC 705. Advances in Engineering Education Research. 3 credits, 3 contact hours.
For PhD students in an engineering program. For master’s students, approval from Instructor/Course Coordinator (to confirm completion of core courses in the program). This course prepares students to apply theoretical work and research methodologies from the field of education to improve teaching of engineering students. Students will be able to conduct assessment and translate research findings into classroom and instructional methods. Topics include learning theories and conceptual frameworks, research design, qualitative and quantitative data collection and analysis, assessment and accreditation in engineering, student-centered instructional design and development of teaching statements.

ESC 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

ESC 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

ESC 790A. Doctoral Dissertation. 1 credit, 1 contact hour.
Restrictions: Approval of graduate advisor. Required of all students working toward the Ph.D. in Engineering Science. Approval of the dissertation advisor is required for registration. For PhD students who have successfully defended their dissertation proposal. The student must register in ESC 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members.

ESC 792B. Pre Doctoral Research. 3 credits, 3 contact hours.
Restrictions: Approval of graduate advisor. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in engineering science. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

IE 501. Fundamentals of Industrial Engineering. 3 credits, 3 contact hours.
Basic concepts of industrial engineering for students who lack an undergraduate degree in the discipline, including: manufacturing processes, work methods and measurement concepts, basics of human factors, quality control, facilities design, production planning, operations research tools, and simulation models.

IE 590. Graduate Co-op Work Experience I. 1 credit, 1 contact hour.
Restriction: permission from the industrial engineering program director and the Division of Career Development Services. Cooperative education internship providing on-the-job reinforcement of academic programs in industrial engineering. Work assignments and projects are developed by the co-op office in consultation with the industrial engineering program director. Work assignments are related to student's major and are evaluated by faculty coordinators in the IE department. Course cannot be applied toward degree credit.

IE 591. Graduate Co-op Work Experience II. 1 credit, 1 contact hour.
Restriction: permission from the industrial engineering program director and the Division of Career Development Services. Course cannot be applied toward degree credit.

IE 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Restriction: graduate standing and permission from the industrial engineering program director, and the Division of Career Development Services. Course cannot be applied toward degree credit.

IE 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Prerequisite: One immediately prior 3-credit registration for graduate co-op work experience with the same employer. Requires approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

IE 601. Measurement Methods for Performance Analysis of Operations. 3 credits, 3 contact hours.
Prerequisite: undergraduate mathematics for management science, or EM 602. Quantitative study of various analytical methods for designing and evaluating systems employed in the management of complex enterprises such as decision-making, efficiency measurement, and methods for obtaining optimal system performance.

IE 603. Behavioral Science in Engineering Organization. 3 credits, 3 contact hours.
A study of scientific research on human behavior in organizations. Processes and problems of communication in engineering activities; line-staff and supervisor-subordinate relationships; formal and informal organizations; organization models; and technical and social structure of organizations.

IE 604. Advanced Engineering Statistics. 3 credits, 3 contact hours.
Prerequisite: IE 331 (see undergraduate catalog for description) or equivalent. The foundations of modern quality improvement, scientific basis of quality engineering, probability, statistical inference, statistical experimental design issues such as randomized blocks, factorial design at different levels, application to factorial design, building models, and implementation and critique of Taguchi's contributions. Statistical software is used in the data analysis.

IE 605. Engineering Reliability. 3 credits, 3 contact hours.
Prerequisite: statistics. Concepts of modern reliability applied to practical industrial problems: statistical concepts, reliability through design, reliability through testing, analysis of reliability data, and the organization and management of a reliability program. Offered alternate years.

IE 606. Maintainability Engineering. 3 credits, 3 contact hours.
Prerequisite: statistics. Factors affecting maintainability design applied to military and industrial problems: statistical concepts; maintainability prediction, allocation, and demonstration; availability, system and costeffectiveness; provisioning; optimal maintenance policies; and management of a maintainability program.

IE 608. Product Liability Control. 3 credits, 3 contact hours.
Product liability and the effect of legal doctrines on minimizing hazards of design and manufacture. Use of actuarial techniques and legal precedents applicable to design, manufacturing, advertising, and marketing problems: warranties, notices, disclaimers, definition of liability, use of expert witnesses, reliability prediction and analysis methods, safety engineering concepts, and design review. A review of government regulations for safety and protection, as well as mandatory and voluntary standards will also be included.

IE 609. Advanced Analytical Engineering Statistics. 3 credits, 3 contact hours.
Prerequisite: IE 604. An extension of the techniques of engineering statistical analysis to industrial applications. Emphasis is placed on the design of experiments and analysis of tests for multivariate level problems.

IE 610. Transportation Economics. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in economics. Principles of engineering economy. Costs of highway and public transportation facilities. Economic comparisons and evaluations. Financing approaches, tax allocation theory. Programming highway and public transit improvements. Same as TRAN 610.

IE 614. Safety Engineering Methods. 3 credits, 3 contact hours.
Prerequisites: introductory course in statistics and industrial or construction management. Application of selected safety engineering methods to detect, correct, and prevent unsafe conditions and procedures in future practice. Methods selected are from safety management and programs; loss prevention; fire protection; systems safety; the design of buildings and other facilities; and the design of products, machinery, and equipment. Engineering problems in designing and constructing a hazard-free environment.

IE 615. Industrial Hygiene and Occupational Health. 3 credits, 3 contact hours.
Prerequisites: one year of college physics and one semester of college chemistry or biology. Introduction to industrial hygiene. Recognition, evaluation and control of human exposure to noise, heat, bio-hazards, chemicals, radiation, and improper lighting. Government standards, field measurements, work practices, engineering designs, and the effects of excessive exposure on worker health and productivity.

IE 618. Engineering Cost and Production Economics. 3 credits, 3 contact hours.
Cost management of operational activities. Focuses on capital investment decision making and efficient resource utilization to achieve cost-effective operations. Topics include alternative investment evaluation, budgeting activity based costing, quality costs, life cycle management and relevant behavioral science. These are considered in the context of manufacturing and service industry application.

IE 621. Systems Analysis and Simulation. 3 credits, 3 contact hours.
Prerequisites: IE 331, IE 466 (see undergraduate catalog for descriptions), or equivalent or department approval. The application of well-integrated systems approach, systems and systems engineering in the system life cycle, system design process, mathematical tools and techniques applied to systems analysis, design for operational feasibility, systems engineering management, modeling techniques including simulation, application of discrete simulation techniques to model industrial systems, design of simulation experiments using software, output data analysis.

IE 622. Simulation and Risk Analysis in Operations Management. 3 credits, 3 contact hours.
Prerequsite: IE 331 (see undergraduate catalog for description) or equivalent. Introduction to the concepts, methodologies and applictions of simulation in operations management. Foundations of simulation, Monte Carlo approaches, simulation models using spreadsheets, generating probabilistic outcomes using random number generation techniques, applying risk analysis software to spreadsheets for various decisions making. Variety of applications in operations management, finance and marketing. Software to develop models of practical operations management applications, is provided.

IE 623. Linear Programming. 3 credits, 3 contact hours.
Prerequisite: EM 602 or introductory course in operations research. Principles, methodology, and practical applications of linear programming to complex problems in production and marketing, simplex techniques, duality theory, parametric analysis, Wolfe and Dantzig's decomposition methods, ellipsoid method, and Karmakar's method.

IE 624. Heuristic Methods. 3 credits, 3 contact hours.
Prerequisites: EM 503 or equivalent. Techniques and concepts used to develop intelligent decision support systems. Application of rules called heuristics and models of reasoning to solve problems in engineering design and manufacturing. Topics include set theory, fuzzy subset theory, decision theory, logic, inference expert systems and single and multi-fault diagnostics.

IE 641. Operations Analysis. 3 credits, 3 contact hours.
Prerequisites: EM 602 and computer programming experience. Management systems and business behavior using industrial models. Special attention is given to the interaction of individual elements that make up the total system.

IE 642. Network Flows and Applications. 3 credits, 3 contact hours.
Prerequisite: EM 602 or equivalent. Theories, algorithms, computation complexity, and application of networks, shortest path, network flow, and minimum cost flow problems. Models of industrial service systems as network problems.

IE 643. Transportation Finance. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in economics. Balance sheets and income statements. Asset and liability management, sources and costs of debt and equity financing. Financial performance measures in the private sector (airlines, railroads, trucking and bus companies). Financing issues associated with the public sector (highways and mass transit). Equity and efficiency in pricing. Subsidy allocation formulae. Innovative financing schemes in the public sector. Same as TRAN 643.

IE 644. Application of Stochastic Modeling in Systems Control. 3 credits, 3 contact hours.
Stochastic processes applied to control of various types of systems: Markov chains, queueing theory, storage theory applications to measure performance of flexible manufacturing systems, telecommunication and distributions networks and similar service systems. Knowledge of probability theory and linear algebra is essential.

IE 650. Advanced Topics in Operations Research. 3 credits, 3 contact hours.
Prerequisite: introductory course in operations research or equivalent. Current topics in deterministic models of operations research: linear programming, large scale decomposition, integer programming, dynamic programming, and nonlinear programming. Emphasis on optimization techniques for solving mathematical programming problems.

IE 651. Industrial Simulation. 3 credits, 3 contact hours.
Prerequisite: introductory course in statistics/simulation or instructor's permission. Statistical design and analysis of Monte Carlo simulation experiments from an engineering view. Examples are provided with emphasis on industrial and manufacturing applications of simulation modeling. Markovian processes simulation, random number generation, mathematical programming, heuristics and decision theory.

IE 652. Facilities Location and Plant Layout. 3 credits, 3 contact hours.
Prerequisite: introductory course in operations research or instructor's approval. Basic con-cepts of facilities location and plant layout. Quantitative and qualitative tools needed in industrial engineering, including single and multiple facilities location problems, site selections and allocation models, use of Duality theory in location and plant layout problem, and computerized layout planning.

IE 653. Facility Maintenance. 3 credits, 3 contact hours.
Prerequisite: EM 501 or equivalent. Intended for those individuals who manage the functioning and maintenance of physical facilities. Emphasis on planning and control of facilities use, maintenance, utility management, managerial control, budgets and costs, personnel administration, legal and safety, flexibility measurement, and design.

IE 655. Concurrent Engineering. 3 credits, 3 contact hours.

IE 659. Supply Chain Engineering. 3 credits, 3 contact hours.
Coordination of product manufacturing and logistic activities across the global supply chain is studied. Focus is on supply chain design, implementation, and control. Topics include transportation and distribution networks, inventory control, demand planning, materials handling and warehousing, supply chain contracts, manufacturing flexibility, product design for responsiveness, and ERP systems. Supply chain analytics concepts and relevant case studies are introduced.

IE 661. Man-Machine Systems. 3 credits, 3 contact hours.
Prerequisite: human factors engineering. Analysis of integrated man-machine systems: physical and psychological effects of systems of deterministic and conditional responses of individuals and groups, and the resulting interaction between individuals, groups, and machine systems; also current research and development pertaining to man-machine systems.

IE 662. Cognitive Engineering. 3 credits, 3 contact hours.
Prerequisite: IE 355 or equivalent. The purpose of this course will be to introduce the application of human factors and cognitive psychology principles to the user interface design of information technology, including computer systems, groupware and communications, handheld devices and Internet applications, and automatic speech recognition interfaces. The course will provide grounding in the engineering design processes used to enhance the usability of products and services, and usability testing methods used by user interface designers. Secondly, major areas and design problems in human-computer interaction and Information Technology will be covered, with real world examples. The course would be appropriate for advanced undergraduates in engineering, computer science, and psychology.

IE 664. Advanced Ergonomics. 3 credits, 3 contact hours.
Prerequisite: IE 355 or equivalent. The course covers important topics for ergonomics, including functional anatomy of the human body, work physiology and body energy expenditure, and biomechanics for people at work. Commonly used analytical tools for ergonomics will be introduced in the course.

IE 665. Applied Industrial Ergonomics. 3 credits, 3 contact hours.
Prerequisites: IE 355 (see undergraduate catalog for description) or IE 699. Introduces the fundamentals and applications of industrial ergonomics for improving equipment, tool, workplace, and job design. Engineers, as well as safety and health professionals, will benefit from the course by understanding the design principles for human operators and current issues in industrial ergonomics, and a variety of evaluating methodologies for the design.

IE 669. Human Design Factors in Engineering. 3 credits, 3 contact hours.
Prerequisite: engineering statistics. Human factors research related to workplace and equipment design and development. Capabilities and limitations of the human sensory-motor system. Design of displays and resulting interaction between individuals, groups, environments and machine systems. Current research in engineering pertaining to the man-machine interface. Not for IE students who have had an undergraduate course in human factors.

IE 670. Industrial Work Physiology. 3 credits, 3 contact hours.
Prerequisite: IE 669 or equivalent. A study of human physiological responses to industrial environmental factors emphasizing knowledge of human anatomy and physiological tolerances: skeletal, muscle, and neuromuscular systems, evaluation of physical work capacity and performance, changes in circulation and respiration during work. Semester project under the instructor's supervision is also required.

IE 672. Industrial Quality Control. 3 credits, 3 contact hours.
Prerequisite: engineering statistics. The management of quality assurance: operational and statistical principles of acceptance sampling and process control; quality problems in production lines, and introduction to total quality management concepts.

IE 673. Total Quality Management. 3 credits, 3 contact hours.
Introduces the concept of total quality management as applicable to industrial systems. Presents methods for product quality improvement. Emphasis is on prevention through quality engineering and design, and goes beyond traditional statistical process quality control. Presentation of recent methods in supplier management, quality assurance, process control, and competitor analysis. Includes Taguchi methods and quality function deployment. Description of ISO 9000 and Baldridge Award.

IE 674. Quality Maintenance and Support Systems. 3 credits, 3 contact hours.
Prerequisites: probability and statistics, IE 331 (see undergraduate catalog for description) or equivalent. Consideration of factors necessary for cost effective maintenance and support of technical operating systems. Topics discussed include service organization and management, spare parts and logistics, quality assurance, ISO9003 training. Examples from automation, computer systems, clinical engineering, power, and transportation will be used to illustrate application areas.

IE 675. Safety in Facility and Product Design. 3 credits, 3 contact hours.
Prerequisite: IE 614 or equivalent. Application of safety principles to minimize the health and safety hazards in the design and manufacture of various products. Practical techniques for, and economic ramifications of, conformance with the many statutes enacted to assure safe workplaces and products.

IE 677. Applied Statistics and Epidemiology for Hazard Analysis. 3 credits, 3 contact hours.
Prerequisite: IE 604 or equivalent. Application of statistical concepts to the field of hazard analysis including: investigation of root causes of accidents, their patterns and trends; rules for systematic data analysis; determination of commonality factors; availability and use of customized computer software.

IE 681. Interdisciplinary Seminar in Occupational Safety and Health. 1 credit, 1 contact hour.
Restriction: OSHE students, or permission of instructor. This is a required course for students who receive the trainee scholarship from the Occupational Safety and Health Engineering Program sponsored by the National Institute for Occupational Safety and Health (NIOSH). Other graduate students are also welcome and encouraged to take the interdisciplinary seminar course. Students and residents in the ERC programs will be able to participate in an interdisciplinary course with students in industrial hygiene, occupational medicine and occupational safety.

IE 682. Industrial Safety and Health Evaluation. 3 credits, 3 contact hours.
Restriction: OSHE students, or permission of instructor. This is a required course for students who receive the trainee scholarship from the Occupational Safety and Health Engineering Program sponsored by the National Institute for Occupational Safety and Health (NIOSH). Other graduate students are also welcome and encouraged to take this site visit course. Upon completion of this course, students will be able to plan and conduct a walk-through evaluation of health and safety hazards in a workplace. Students will also understand the role of occupational health and safety disciplines in the recognition and prevention of occupational injury and illness.

IE 685. Systems Safety. 3 credits, 3 contact hours.
Prerequisites: applied probability/statistics and introductory safety. Safety decision making and systems engineering applications to safety, including planning, managing and conducting system safety programs.

IE 686. Intro to Healthcare Systems. 3 credits, 3 contact hours.
This course provides a systems analysis view of healthcare services, combining economic, quality, enterprise data and activity costing perspectives. Operations, processes and activities that characterize the US Healthcare system are introduced. System costs, reimbursement methods and financial aspects in the healthcare. Focus on the application of information technologies and system engineering tools to effectively create and deliver value in the care process. Analytical tools for identifying opportunities for systems efficiency and effectiveness.

IE 687. Healthcare Enterprise Systems. 3 credits, 3 contact hours.
Prerequisite: IE 686. Provide a thorough understanding of the role of Healthcare Enterprise Systems in healthcare organizations. A detailed study of electronic health records, computerized physician order entry, and meaningful use standards. Design and implementation of enterprise level healthcare information systems, advanced desicion support tools, and process mapping methods for optimal delivery of cost effective care. Analytical and quantitative methods that can be used to evaluate healthcare business processes, determine data requirements, and plan operating procrdures.

IE 688. Healthcare Sys Perfor Modeling. 3 credits, 3 contact hours.
Prerequisite: IE 686. Presents advanced techniques and methods for modeling and evaluating the performance of healthcare systems, including operations research, and productivity analysis, and statistical analysis methods. Introduces the performance dynamics of healthcare systems, identifies key decision variables and formulates their effect on systems performance. Develop and optimize healthcare staffing models. Application of operations research methods to a wide range of healthcare scheduling, facility design and patient flow problems.

IE 699. Special Topics in Industrial Engineering. 3 credits, 3 contact hours.
Restriction: approval from the industrial engineering graduate advisor. Special course given when interest in a subject area develops. Advanced notice of topics will be given before registration.

IE 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in industrial engineering. A written report must be submitted to the project advisor. The student cannot register in IE 700B more than once and the incomplete (I) grade is not allowed. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

IE 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in industrial engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in IE 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

IE 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in industrial engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (IE 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

IE 704. Sequencing and Scheduling. 3 credits, 3 contact hours.
Prerequisite: IE 650 or equivalent. Advanced sequencing and scheduling for job shops, flow lines, and other general manufacturing and production systems are discussed in this course. Both deterministic and stochastic scheduling models are covered in detail. Heuristics and worst case analysis for unsolvable hard scheduling problems (NP-C problem) are introduced.

IE 705. Mathematical Programming in Management Science. 3 credits, 3 contact hours.
Prerequisites: IE 623 and IE 650. An advanced study of various mathematical programming techniques such as linear and non-linear, parametric, integer, stochastic and dynamic programming. Readings and discussions emphasize mathematical advances and applications in operations research.

IE 706. A Queueing Approach to Performance Analysis. 3 credits, 3 contact hours.
Prerequisite: IE 644 or equivalent. Newly developed techniques in the area of queueing networks that play a critical role in studying several aspects of discrete event stochastic systems such as FMS, computer-aided communication systems, transportation systems and service systems.

IE 725. Independent Research. 3 credits, 3 contact hours.
Prerequisite: approval from the industrial engineering program director. Program of study prescribed and approved by student's advisor. This special course covers areas in which one or more students may be interested but is not of sufficiently broad interest to warrant a regular course.

IE 726. Independent Research II. 3 credits, 3 contact hours.

IE 753. Airport Design and Planning. 3 credits, 3 contact hours.
Prerequisite or corequisite: TRAN 610 or EM 693. Planning of individual airports and statewide airport systems. Functional decision of air and landside facilities. Orientation, number and length of runways. Concepts of airport capacity. Passenger and freight terminal facility requirements. Airport access systems. FAA operating requirements. Financial, safety and security issues. Same as CE 753 and TRAN 753.

IE 754. Port Design and Planning. 3 credits, 3 contact hours.
Prerequisite: TRAN 610 or EM 693. Functional design of the water and landsides for general cargo, liquid and dry bulk, and container operations. Yard and storage systems. Port capacity in an intermodal network. Economic, regulatory, and environmental issues. Same as CE 754 and TRAN 754.

IE 760. Quantitative Methods in Human Factors. 3 credits, 3 contact hours.
Prerequisite: IE 661. More advanced human factors engineering concepts analyzed quantitatively: systems modeling, control theory, human error, and decision making. Discussion of human factors, research design and data analysis. Operator/computer interaction is also emphasized.

IE 761. Advanced Studies in Human Factors. 3 credits, 3 contact hours.
Prerequisite: one year of graduate work in human factors or the equivalent. The course integrates various areas of graduate studies in human factors such as: work physiology, occupational safety, environment and human-machine systems. Detailed discussion of selected current papers covering theoretical review, experimental design, results, applications, and future research. Completion of semester project under instructor's guidance is mandatory.

IE 762. Psychophysical Methods in Human Factors. 3 credits, 3 contact hours.
Prerequisite: one year of graduate work in human factors or instructor's approval. This course considers various classical and modern psychophysical methods, signal detection theory, information theory, and human information processing applicable to advanced human factors/occupational safety research measurement and normative modeling.

IE 790A. Doctoral Dissertation. 1 credit, 1 contact hour.

IE 791. Graduate Seminar. 0 credits, 0 contact hours.
A seminar in which faculty or others present summaries of advanced topics suitable for research. Discussion of research procedures, thesis organization, and content. Students engaged in research will present their own research for discussion and criticism.

IE 792B. Pre Doctoral Research. 3 credits, 3 contact hours.
Co-requisite: IE 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in industrial engineering. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

ME 590. Graduate Co-op Work Experience I. 1 credit, 1 contact hour.
Prerequisites: permission from Department of Mechanical Engineering and Division of Career Development Services. Cooperative education internship providing on-the-job reinforcement of academic programs in mechanical engineering. Work assignments and projects are developed by the co-op office in consultation with the mechanical engineering department. Work assignments are related to student's major and are evaluated by faculty coordinators in mechanical engineering. Course cannot be used for mechanical engineering degree credit.

ME 591. Graduate Co-op Work Experience II. 1 credit, 1 contact hour.
Prerequisites: permission from Department of Mechanical Engineering and Division of Career Development Services. Course cannot be used for mechanical engineering degree credit.

ME 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Prerequisites: permission from Department of Mechanical Engineering and Division of Career Development Services. Course cannot be used for mechanical engineering degree credit.

ME 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Prerequisite: One immediately prior 3-credit registration for graduate co-op work experience with the same employer. Requires approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

ME 607. Advanced Thermodynamics. 3 credits, 3 contact hours.
Prerequisite: undergraduate thermodynamics. Basic laws of thermodynamics are applied to various thermodynamic systems. Topics include: availability, stability requirements, equation of state, property relations, properties of homogeneous mixtures, optimization applied to power generation and refrigeration cycles, and thermodynamic design of system components.

ME 608. Non-Equilibrium Thermodynamics. 3 credits, 3 contact hours.
Prerequisites: undergraduate thermodynamics and heat transfer, and ME 616. (May be taken concurrently.) Principles and mathematical techniques of non-equilibrium thermodynamics applied to mechanical engineering problems. Topics include field theory, energy and entropy balances, variational principles, and applications to fluid flow, heat exchangers and combustion.

ME 609. Dynamics of Compressible Fluids. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations, fluid mechanics, and thermodynamics. One-dimensional reversible and irreversible compressible fluid flow, including effects of variable area, friction, mass addition, heat addition, and normal shock; two-dimensional reversible subsonic and supersonic flows, and an introduction to the method of characteristics and two-dimensional oblique shock.

ME 610. Applied Heat Transfer. 3 credits, 3 contact hours.
Prerequisites: undegraduate fluid mechanics, thermodynamics, heat transfer and differential equations. Fundamentals of conduction, convection and radiation heat transfer. Practical engineering applications of heat exchangers including the design approaches by Mean Temperature Difference and Effectiveness-NTU methods, fins, convection fouling factors, and variable property analysis.

ME 611. Dynamics of Incompressible Fluids. 3 credits, 3 contact hours.
Prerequisites: undergraduate fluid mechanics and ME 616. (May be taken concurrently.) An introduction to the hydrodynamics of ideal fluids; two-dimensional potential flow and stream functions; conformal mapping; and differential equations of viscous flow. Boundary layer theory and dimensional analysis are introduced.

ME 612. Gas Dynamics. 3 credits, 3 contact hours.
Prerequisite: ME 616. (May be taken concurrently.) Physical phenomena of gas dynamics and mathematical methods and techniques needed for analysis. Dynamic and thermodynamic relations for common flow situations are described through vector calculus. The nonlinearity of resulting equations and solutions such as numerical analysis, linearization or small perturbation theory, transformation of variables, and successive approximations are discussed. The method of characteristics is reviewed in detail for shock flows.

ME 613. Radiation Heat Transfer. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations, thermodynamics, heat transfer and ME 616. (May be taken concurrently.) Heat radiation of solid bodies, gases and flames; angle factors; radiative properties of electrical conductors and non-conductors; application of radiative networks to multi-body problems; diffuse specular reflectors: artificial satellites and space vehicles; analogy between heat transfer by radiation and electrical networks; and combined conduction and radiation problems.

ME 614. Continuum Mechanics. 3 credits, 3 contact hours.
Prerequisites: Undergraduate courses in mechanics, fluid mechanics, solid mechanics, and mathematics (linear algebra, differential equations, and vector calculus) or approval of the instructor. Fundamentals of the mechanics of continuous media. Specific topics include vector and tensor analysis; kinematics associated with finite deformation; the stress tensor; and the conservation laws of mass, linear momentum, angular momentum, and energy. Constitutive equations for linear and non-linear elastic solids and for inviscid and Newtonian fluids are discussed. The role of material invariance under superimposed rigid body motion and material symmetry in the formulation of appropriate constitutive equations are emphasized.

ME 615. Advanced Mechanical Vibrations. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations and system dynamics. One-, Two- and Multiple degree of freedom systems, Lagrange's equation of motion, Runge-Kutta computation, Finite Element Method and classical methods for normal mode analysis, matrix notation and iteration procedure, and Fourier series representation for the solution of vibration problems.

ME 616. Matrix Methods in Mechanical Engineering. 3 credits, 3 contact hours.
Prerequisite: undergraduate differential equations. Applications of matrix algebra and matrix calculus to engineering analysis; matrix methods in solid and fluid mechanics; vibration, elasticity, viscous fluids, and heat transfer. Matrix theory is used to show the basic unity in engineering analysis.

ME 618. Selected Topics in Mechanical Engineering. 3 credits, 3 contact hours.
Prerequisite: departmental approval. Given when interest develops. Topics may include analysis and/or design of energy or mechanical systems of current interest to mechanical engineers.

ME 619. Nano-scale Characterization of Materials. 3 credits, 3 contact hours.
The course presents the basics of nanotechnology and the principles and application of advanced instrumentation for the characterization of nanostructures. Topics include atomic force microscopy, near-field optics, dielectric spectroscopy, and light scattering. The significant component of the course is laboratory work at the W. M. Keck Foundation Laboratory and research project.

ME 620. Mechanics of Materials. 3 credits, 3 contact hours.
Prerequisites: Undergraduate differential equations and mechanics of materials or linear elasticity. Governing equations and other balance laws; stress and strain distributions in solids subjected to various loading conditions; posing and solving boundary value problems for isotropic linear elastic solids; instabilities and other failure modes of linear elastic solids; and numerical techniques to solve the governing equations.

ME 621. Advanced Mechanics of Material. 3 credits, 3 contact hours.
Prerequisites: ME 620. ME 614 is strongly recommended Governing equations and other balance laws for the mechanics of solids; large deformation kinematics and non-linear material behavior; advanced constitutive models for solids; fundamentals of fracture mechanics; numerical techniques for the solution of non-linear solid mechanics problems.

ME 622. Finite Element Methods in Mechanical Engineering. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations and strength of materials. Using variational formulation and Ritz approximation, element equations for bar, beam, potential flow, heat transfer, torsion of a solid bar and plane elasticity problems are derived and solved with computer programs.

ME 624. Microlevel Modeling in Particle Technology. 3 credits, 3 contact hours.
Presents methodologies for analyzing the macroscopic properties of particulate systems in terms of the underlying microlevel processes. Significant components are the mathematical modeling of particulate systems at the microlevel, analytical and numerical methods for predicting macroscopic properties from microlevel models, and comparison of theoretical predictions with experimental results. Demonstrates the importance of the interaction of these three components in the scientific process. The first part concerns the flow of dry particles where any interstitial fluid can be ignored. The second part considers the flow of particles suspended in an interstitial fluid. Also includes a class project involving development of simulations. Same as CHE 625.

ME 625. Introduction to Robotics. 3 credits, 3 contact hours.
Prerequisites: Undergraduate differential equations and kinematics. Introduction to the field of robotics, including analysis of robot geometries; kinematics of robot manipulators; path planning and sensor processing; introduction to multi-robot systems. Students should have competence in computer programming and familiarity with MATLAB.

ME 626. Fatigue Fracture of Solids. 3 credits, 3 contact hours.
A comprehensive introduction to the linear elastic fracture mechanics covering the basics of linear elasticity, crack-tip stress, displacement, and strain fields; energetics of fracture; and fracture toughness testing. This will be followed by a brief introduction to plasticity and elastic-plastic fracture parameters such as J-integral. The state-of-the-art in fracture mechanics, such as cohesive zone models and fracture of emerging materials (e.g., battery materials), will be discussed along with the mechanisms of fracture and toughening in various materials. The course will include assignments and a group project where students undertake critical review of a peer reviewed journal paper on a fracture topic (approved by instructor).

ME 628. Machine Vision Principles and Applications. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations and demonstrated competence in computer programming. Fundamentals of machine vision as applied to inspection, recognition, and guidance in mechanical and manufacturing processes. Emphasis on real-time machine vision algorithms for machine parts inspection and identification. Topics include lighting and optics, camera selection and calibration, image segmentation, edge detection, feature extraction, and pattern classification.

ME 630. Analytical Methods in Machine Design. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations, machine design, and ME 616. (May be taken concurrently.) Theory and analytical methods used in machine design. Comparisons are made between approximate and exact engineering methods for evaluation of the range of applicability of solutions. Topics include advanced analysis of threaded members; keyed, splined, and shrink fits when subjected to torque; preloaded bearings; surging, presetting and buckling of coiled springs; and accurate analysis of impact stresses and stresses beyond the yield point.

ME 631. Bearings and Bearing Lubrication. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations, machine design and ME 616. (May be taken concurrently.) The theoretical and physical aspects of lubrication: hydrostatic and hydrodynamic problems. Reynold's differential equation for pressure distribution applied to slider bearing and journal bearing problems with and without end leakage.

ME 632. Mechanical Engineering Measurements. 3 credits, 3 contact hours.
This course offers extensive mechanical engineering lab experience, including measurement fundamentals, hands-on experiments, uncertainty analysis, technique comparison, and professional engineering reports. It also focuses on the fundamental principles behind each methodology and relevant applications. The topics cover measurement in major mechanical engineering areas including thermodynamics, thermofluids, and control. Specialized experiments include fluidization, CAD/CAM, and NC machining. Comparisons of experimental results against theoretical or computational results are also required.

ME 633. Dynamics of Machinery. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations and matrix analysis. Consideration of kinematics, constraints and Jacobians, linear and angular momentum and potential energy and conservative forces of mechanical systems. Application of principle of virtual work, D?Alembert's principle, method of virtual power and Lagrange's equation to systems of particles and systems of rigid bodies.

ME 635. Computer-Aided Design. 3 credits, 3 contact hours.
Prerequisites: undergraduate linear algebra (matrices operation) and differential equations. Adaptation of computer for solving engineering design problems; design morphology; simulation and modeling; algorithms; problem-oriented languages; use of available software; computer graphics, and automated design.

ME 636. Mechanism Design: Analysis and Synthesis. 3 credits, 3 contact hours.
Prerequisites: undergraduate kinematics, dynamics and demonstrated competence in computer programming and ME 616. (May be taken concurrently.) Kinematic principles combined with computer-assisted methods for designing mechanisms; complex polar notation; and dynamic and kinetostatic analysis of mechanisms. Kinematic synthesis of planar mechanisms; graphical Burmester theory for plane linkage synthesis; and planar linkage synthesis for function and path generation.

ME 637. Kinematics of Spatial Mechanisms. 3 credits, 3 contact hours.
Prerequisites: undergraduate kinematics, dynamics, knowledge of matrices and ME 616. (May be taken concurrently.) Advanced techniques for the dual-number coordinate-transformation matrix modeling to perform the displacement, velocity, static and dynamic force analysis of spatial mechanisms. Applications considered will include shaft couplings, skew four-bars, wobble plates, generalized slider-cranks and robotic manipulators.

ME 638. Computer-Aided Machining. 3 credits, 3 contact hours.
Prerequisites: demonstrated competence in computer programming, ME 305, ME 616 and ME 635 or equivalent. Introduction of computer applications to understand integrated computer-aided machining process. Included in the course are the fundamentals of motion control and NC/CNC/DNC machining, part programming and post-processors, and advances in CAM. Student projects are carried out using appropriate manufacturing software.

ME 641. Refrigeration and Air Conditioning. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations, fluid mechanics and thermodynamics. Refrigeration and air conditioning cycles; comfort analysis, psychometric chart analysis, heat and mass transfer steady and transient processes, heating and cooling design loads, energy loads and standards requirements.

ME 643. Combustion. 3 credits, 3 contact hours.
Prerequisites: Undergraduate thermodynamics & fluid mechanics. Chemical & physical process of combustion: ideal combustion, actual combustion, mass balance, energy of reaction, maximum adiabatic combustion temperature, chemical equilibrium, heating values of fuels, combustion in furnaces, internal combustion engines & other heat engines, with emphasis on the analysis & control of the products of combustion in light of environmental considerations.

ME 644. Building Environmental Control Principles. 3 credits, 3 contact hours.
Prerequisites: undergraduate thermodynamics, fluid mechanics, heat transfer and differential equations. Control systems for buildings including control of temperature, moisture and air quality. Optimization of systems for control of building energy use. Modern microprocessor-based control systems, including direct digital control, proportional and integral controllers, predictive control, adaptive control, optimum start controllers and optimal control.

ME 653. Control of Electro-Mechanical Networks. 3 credits, 3 contact hours.
Prerequisites: undergraduate electrical circuits and mechanical vibrations or equivalent. Electro-mechanical systems; control loops; use of mechanical networks in dynamic systems; and stability and response to various inputs in electro-mechanical networks.

ME 655. Introduction to Modern Control Methods. 3 credits, 3 contact hours.
Prerequisites: undergraduate system dynamics and automatic controls. Introduction to modern control methods applied to mechanical and manufacturing systems. Topics include state variable feedback, observer theory, nonlinear control, optimal control, and adaptive control for both continuous and discrete systems.

ME 660. Noise Control. 3 credits, 3 contact hours.
Prerequisites: undergraduate differential equations and physics. Engineering methods for reducing noise pollution; reduction of intensity at the source; limitation of transmission paths and absorption; application to structures, machinery, ground transportation, aircraft, and noise measurement.

ME 670. Introduction to Biomechanical Engineering. 3 credits, 3 contact hours.
Prerequisites: undergraduate thermodynamics, statics, and dynamics. Introduction to biomechanical engineering of physiological systems; fluid flow, structural, motion, transport, and material aspects; energy balance of the body, and the overall interaction of the body with the environment.

ME 671. Biomechanics of Human Structure and Motion. 3 credits, 3 contact hours.
Prerequisites: undergraduate statics, kinematics, and dynamics. Principles of engineering mechanics and materials science applied to human structural and kinematic systems and to the design of prosthetic devices. Topics include anatomy; human force systems; human motion; bioengineering materials; and design of implants, supports, braces, and replacements limbs.

ME 675. Mechanics of Fiber Composites. 3 credits, 3 contact hours.
Prerequisites: ME 315 (see undergraduate catalog for course description) and demonstrated competence in computer programming. Introduces various design problems using fiber composites. Analysis of general fiber composite laminate and short fiber composites, fracture mechanics, fatigue, creep and viscoelasticity, thermal stresses, special layups and associated optimization problems.

ME 676. Applied Plasticity. 3 credits, 3 contact hours.
Prerequisite: ME 620 or equivalent. Fundamentals of plasticity applied to mechanical and manufacturing engineering problems. Topics include elastic-plastic analysis for beams, rings and plates. Plastic instability and slip-line fields are considered.

ME 678. Engineering Design of Plastic Products. 3 credits, 3 contact hours.
Prerequisite: Knowledge of Pro/Engineer (or IDEAS). Structure and properties of plastics including stress-strain behavior and the effect of fillers and reinforcements. Designing for impact, flexure, shear, friction, puncture, creep and fatigue. Case studies of structural, electrical, and optical applications.

ME 679. Polymer Processing Techniques. 3 credits, 3 contact hours.
Prerequisites: undergraduate courses in fluid dynamics and heat transfer. Techniques for processing of plastics: extrusion, injection molding, compression molding, thermoforming, casting.

ME 680. Polymer Processing Equipment. 3 credits, 3 contact hours.
Prerequisites: CHE 645 or equivalent and undergraduate heat transfer. Application of heat transfer, fluid mechanics, and thermodynamics to the design and control of polymer processing equipment. Detailed consideration of extrusion, collandering, rotational molding, stamping, and injection molding.

ME 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in mechanical engineering. A written report must be submitted to the project advisor. The student cannot register in ME 700B more than once and the incomplete (I) grade is not allowed. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ME 701B. Master's Thesis. 3 credits, 3 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in mechanical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in ME 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master’s students registering for the first time in Master’s Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

ME 701C. Master's Thesis. 6 credits, 6 contact hours.
Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in mechanical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (ME 701B) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

ME 710. Conduction Heat Transfer. 3 credits, 3 contact hours.
Prerequisites: ME 610 and ME 616 or equivalent. Heat transfer by conduction: differential and integral forms of the energy equation for isotropic and anisotropic material. Analytical and numerical studies of transient and steady one-, two-, and three-dimensional heat transfer problems for a variety of boundary conditions including phase change. In addition, variational and boundary element methods are applied to heat conduction problems.

ME 711. Convection Heat Transfer. 3 credits, 3 contact hours.
Prerequisites: ME 610 and ME 616 or equivalent. Development of convective heat transfer theory: currently available methods, analytical and numerical, for predicting heat rates in forced, natural, and mixed convection in laminar and turbulent flow regimes are thoroughly studied. Studied techniques are applied to the thermal design of complex systems.

ME 712. Mechanics of Viscous Fluids. 3 credits, 3 contact hours.
Prerequisites: ME 611 and ME 616. (May be taken concurrently.) Properties and behavior of real fluids in laminar and turbulent motion. Review of tensor analysis; current mathematical and empirical laws and methods; flows in ducts; exact solutions of Navier-Stokes equations; boundary layers over surfaces and flow past bodies.

ME 713. Non-Newtonian Fluid Dynamics. 3 credits, 3 contact hours.
Prerequisites: ME 611, ME 616. Review of Newtonian fluid mechanics. Time dependent response and transport properties of non-Newtonian fluids in simple shear and extensional flows. Experimental techniques for measuring dynamic response and transport properties. Continuum and micromechanical constitutive models; solutions of constitutive equations.

ME 714. Principles of Particulate Multiphase Flows. 3 credits, 3 contact hours.
Prerequisite: Courses in fluid mechanics or approval of the instructor. This course provides an introduction to the fundamental principles of mass, momentum and heat transfer in particulate multiphase flows. Theories and governing equations for distinctive responses and motions of each phase and the dynamic interactions among phases are formulated. Typical industrial applications will be illustrated.

ME 717. Selected Topics in Mechanical Engineering I. 3 credits, 3 contact hours.
Prerequisite: department approval. Given when interest develops. Topics may include advanced mechanisms, aerodynamics, analysis of ME systems, design optimization, and case studies in design.

ME 718. ST:. 3 credits, 3 contact hours.

ME 721. Thermal Stresses. 3 credits, 3 contact hours.
Prerequisites: vector analysis or ME 616 or equivalent and theory of elasticity or ME 785. Thermoelasticity; reduction of thermoelastic problems to constant temperature equivalents; fundamentals of heat transfer; and elastic and inelastic stress analysis.

ME 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

ME 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for ME 726 if they have taken ME 725 in a prior semester.

ME 727. Independent Study III. 3 credits, 3 contact hours.
Prerequisites: written permission from department chairperson plus prerequisite courses prescribed by a supervising faculty member. Areas of study in which one or more students may be interested but which is not of sufficiently broad interest to warrant a regular course offering. A maximum of two independent studies courses may be applied to a degree.

ME 735. Advanced Topics in Robotics. 3 credits, 3 contact hours.
Prerequisite: ME 625. Introduction to advanced topics and techniques in robotics. Subjects covered include differential kinematics, calibration and accuracy, trajectory control, and compliant motion control as well as an in-depth treatment of topics discussed in ME 625.

ME 736. Advanced Mechanism Design. 3 credits, 3 contact hours.
Prerequisites: ME 636 and ME 616. Advanced methods for the synthesis of mechanisms. Topics include synthesis of planar mechanisms for three, four and five positions, multiloop linages, change of branch and order problems, and optimal synthesis of mechanisms. Synthesis of linkages for special types of motion including straight line motion, cusp points on coupler curves and adjustable mechanisms.

ME 738. Computer Aided Engineering. 3 credits, 3 contact hours.
Prerequisites: ME 635. This course covers advanced CAD and CAE tools for visual computing simulation and analysis. Topics include modeling, assembly, CAD data exchange by exporting and importing various CAD model formats, computer simulation and analysis of structure, thermal, fluid and animation of the results of analysis. Multi-physics analyses such as thermal-structure, electric-thermal-structure in MEMS and fluid-structure interactions are studied. The laboratory component involves use of most current commercial CAD/CAE software packages.

ME 752. Design of Plates and Shells. 3 credits, 3 contact hours.
Prerequisites: ME 616 or equivalent and ME 620. A study of plates and shells. Mechanical engineering design solutions for typical loading and boundary conditions through analytical and numerical methods. Plate and shell interfaces and vibration are also considered.

ME 754. Pressure Vessel Design. 3 credits, 3 contact hours.
Prerequisites: ME 616 or equivalent and ME 620. Theories in designing pressure vessels; analysis of circular plates; cylindrical and spherical shells; pressure vessel heads; pipe bends; and attachments. Consideration is also given to pressure vessel materials in fatigue and creep designs.

ME 755. Adaptive Control Systems. 3 credits, 3 contact hours.
Prerequisite: ME 655. Theory and application of self-tuning and model reference adaptive control for continuous and discrete-time deterministic systems. Topics include model-based methods for estimation and control, stability of nonlinear systems and adaptive laws. Applications of adaptive control in mechanical systems and manufacturing processes.

ME 785. Theory of Deformable Solids in Mechanical Engineering I. 3 credits, 3 contact hours.
Prerequisites: ME 616 or equivalent and ME 620. Measure of strain; strain tensor; stress tensor; equilibrium equations; constitutive relations; compatibility conditions; conditions for and formulation of three-dimensional problems; and the relationship of engineering theories for beams, plates, and shells to the equations of elasticity.

ME 786. Theory of Deformable Solids in Mechanical Engineering II. 3 credits, 3 contact hours.
Prerequisite: ME 785. Solutions for problems formulated in ME 785 eigenfunction solutions; operational methods; complex variables theory; three-dimensional problems; contact problems; wave propagation; and non-linear problems.

ME 790A. Doc Dissertation & Res. 1 credit, 1 contact hour.
Co-requisite: ME 791. Approval of the dissertation advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in mechanical engineering. For PhD students who have successfully defended their dissertation proposal. The student must register in ME 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members. Students enrolled in the PhD program before 2015 Fall must accumulate a minimum number of credits in Doctoral Dissertation Research and Pre-Doctoral Research (see graduate catalog for program-specific details; the same requirement may apply to joint PhD programs with other universities).

ME 791. Mechanical Engineering Colloquium. 0 credits, 1 contact hour.
Prerequisites: graduate standing and major in mechanical engineering. National and international experts in mechanical engineering discuss their recent research. Required of all students enrolled in mechanical engineering graduate degree programs. Students must register in this course for at least two semesters and attend at least four lectures in each semester. All doctoral students and students with assistantships must register in this course each semester and attend regularly.

ME 792B. Pre-Doctoral Research. 3 credits, 3 contact hours.
Co-requisite: ME 791. Approval of the dissertation advisor is required for registration. Preliminary experimental and/or theoretical investigation of a relevant topic in mechanical engineering. For students who have passed the qualifying examination but have not defended the dissertation proposal. Permission is needed of the academic advisor as well for students who have completed the required coursework but have not passed the qualifying examination.

ME 794. Graduate Seminar and Professional Presentations. 0 credits, 0 contact hours.
Regular attendance required of all students in the Mechanical Engineering PhD program. Each PhD student is required to make a 15 minute presentation on a topic related to the student's research with an additional 10 minutes to address audience questions. The seminar participants evaluate each speaker.

MECH 630. Theory Of Elasticity. 3 credits, 3 contact hours.
Prerequisite: differential equations. Theory of elasticity as basis for both advanced stress analysis and for a critical examination of elementary stress analysis.

MNE 601. Computerized Manufacturing Systems. 3 credits, 3 contact hours.
Development of automated manufacturing systems with applications including Industrial Robotics, Programmable Logic Controller, Lean Manufacturing and other artificial intelligence technologies. Laboratory experimentation using hardware and software necessary for various industrial robots & PLC systems in the automotive assemble; pharmaceutical and chemical industries are included.

MNE 602. Flexible and Computer Integrated Manufacturing. 3 credits, 3 contact hours.
Prerequisite: MNE 601. Flexible manufacturing systems are developed including Robotic applications, PLC & CNC programming as automated inspection and transportation systems. Laboratory experience with hardware and software needed for various industrial robots & other automated systems are included.

MNE 654. Design for Manufacturability. 3 credits, 3 contact hours.
Prerequisite: MNE 601 or instructor's approval. Methodologies used in the synthesis and analysis of product design to optimize manufacturability. The relationship of design to production processes, product material, material handling, quality costs, and CAD/CAM are presented. Emphasis is on both formed products and assembled products. Simulation and other design analysis tools are employed.

MNE 655. Concurrent Engineering. 3 credits, 3 contact hours.
Concurrent/simultaneous engineering methods and tools such as system analysis, system modelling and system integration, market oriented, integrated design for manufacturing, assembly, quality and maintenance, product design analysis, integrated product design and manufacturing innovation methods, QFD (Quality Function Deployment) ? applied to concurrent engineering, FMEA (Failure Mode and Effect Analysis), POKA-YOKE, KANZEI, waste reduction, quality circles, rapid prototyping of designed objects and various other advanced processing methods.

MNE 725. Independent Study. 3 credits, 3 contact hours.
Prerequisites: written permission from the director of manufacturing systems engineering programs, and courses prescribed by the supervising faculty member. Areas of study in manufacturing computer systems analysis and design in which one or more students may be interested, but that are not of sufficiently broad interest to warrant a regular course offering.

MNE 791. Seminar In Manufact Engr. 1 credit, 1 contact hour.
A series of invited speakers, primarily from industry, will discuss current manufacturing problems and methods. Attendance at these seminars is required for all students enrolled in the manufacturing systems engineering program.

MTEN 610. Found of Materials Sci & Engr. 3 credits, 3 contact hours.
Prerequisite: Graduate standing. Core course for students in Material Science and Engineering. The effect of structure on the properties and behavior of engineering materials. Topics include atomic structure, bonding, crystallography, and defects in solids; properties of metals, semiconductors, ceramics, and polymers and their behavioral response to mechanical, chemical, optical, electrical, and magnetic stimuli.

MTEN 611. Diffusion & Solid State Kineti. 3 credits, 3 contact hours.
Prerequisite: MTSE 602. The atomic theory of diffusion and mathematical derivation of the diffusion equations. Diffusion phenomena in dilute alloys as well as in ionic and covalent solids are considered. High atom mobility effects at defect sites and surfaces are examined. Chemical kinetics and kinetics of phase transformations including nucleation, growth, and spinodal decomposition are discussed.

MTEN 612. Thermodynamics of Materials. 3 credits, 3 contact hours.
Prerequisite: Undergraduate thermodynamics. Core course for students in Material Science and Engineering. Review of first, second, and third laws of thermodynamics and their applications to materials. Stability criteria, simultaneous chemical reactions, binary and multicomponent solutions, phase diagrams, surfaces, adsorption phenomena, thermochemistry of homogeneous and heterogeneous reactions are covered.

MTEN 613. Characterization of Materials. 3 credits, 3 contact hours.
Prerequisites: Undergraduate classes covering physics, chemistry, thermodynamics, and heat and mass transfer, or permission of the instructor. The course is designed to introduce graduate students in chemical and materials engineering, and other engineering and science disciplines, to fundamentals and theory of different types of materials characterization tools. Methods and techniques necessary to understand and quantify diverse materials properties will be discussed. As important for many methods, basic principles of interaction of radiation and particle beams with matter will be studied. Topics include, but are not limited to: Diffraction methods; imaging via optical, scanning, transmission electron, scanning tunnelling, and field ion microscopy; microanalysis and spectroscopy, including energy dispersive, wavelength dispersive, Auger methods; secondary ion mass spectroscopy, X-ray photoelectron spectroscopy; materials preparation for analysis, including electron, ion growth, sputtering; thermal analysis: DTA, DSC; and depending on the availability and functionality of equipment, lab visits and demonstrations will be scheduled to the class to discuss some case studies.

MTEN 631. Data Science for Chemical and Materials Engineers. 3 credits, 3 contact hours.
Prerequisites: BS degree in Chemical, Mechanical, Electrical or Biomedical Engineering, or in Physics or Chemistry. This is a course for graduate level students in chemical engineering, materials engineering, pharmaceutical engineering, or a related discipline. The focus is on the use of data science techniques to solve problems in chemical engineering. We will first discuss the Python programming language and how it can be used to manipulate, clean, explore, and visualize scientific datasets using the pandas package. We will the cover statistics and probability as it applies to engineering problems; this includes conditional probability, probability distributions, hypothesis testing, and Bayesian inference. Basic supervised machine learning models will be introduced, including linear and logistic regression, decision trees and random forest, and support vector machines. Students will then learn different analytical techniques and how to combine all of these skills to solve engineering problems involving large amounts of data and make predictions. Finally, we will cover how to access data and create your own datasets; topics include databases (including relational databases such as SQL) and basic data mining and web scraping. Applications of these methods will be demonstrated in chemical engineering (e.g., optimization and controls, sensor analysis), materials engineering (e.g., structural databases and property selection), and pharmaceutical engineering (e.g., drug selection). Students will gain hands-on experience in implementing and utilizing these various methods through computational laboratory assignments and reports and a semester-long engineering design project.

MTEN 633. Machine Learning for Chemical and Materials Engineers. 3 credits, 3 contact hours.
Prerequisites: Undergraduate degree in either Chemical, Mechanical, Electrical or Biomedical Engineering, or in Physics or Chemistry. This course builds upon foundational knowledge in mathematical and statistical tools or data science and data visualization to learn and apply machine learning approaches for solving problems in Engineering with emphasis on applications in Chemical and Materials. As an engineering course, the emphasis is on case studies involving problem solving to augment mechanistic methods. It will include artificial intelligence (AI) topics such as machine learning and deep learning via methods such as classification, clustering, and neural networks (NNs), along with robust estimation including validation and error quantification. Class projects will concern case studies from a broad range of disciplines and applications to chemical and materials engineering problems.

MTEN 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in materials engineering. A written report must be submitted to the project advisor. The student cannot register in MTEN 700B more than once and the incomplete (I) grade is not allowed. Master’s students registering for the first time in Master’s Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

MTEN 701B. Masters Thesis. 3 credits, 3 contact hours.
Corequisites: CHE 791. Corequisite for full-time students: CHE 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in materials engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in MTEN 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

MTEN 701C. Master's Thesis. 6 credits, 6 contact hours.
Corequisites: CHE 791. Co-requisite for full-time students: CHE 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in materials engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (MTEN 701B course) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

MTEN 702. Selected Topics in Materials Science and Engineering. 3 credits, 3 contact hours.
Restrictions: Graduate standing. Topics of current interest in materials science and engineering.

MTEN 711. Nanocomposite Materials. 3 credits, 3 contact hours.
Prerequisites: Core courses in MTSE, MTEN 611 and MTEN 613 or equivalent courses, or permission of the instructor. This course covers advanced aspects of nanocomposite materials formation, properties, characterization, and applications. Emerging materials and their synthesis techniques are discussed along with key issues in processing, as well as identification and characterization of properties as relevant to application areas. Examples include, Polymer-based and Polymer-filled Nanocomposites, Bio-Nanocomposites, Metal and Ceramic Nanocomposites, Nanocomposites for Energy and Electronics materials, etc.

MTEN 712. Nanomaterials. 3 credits, 3 contact hours.
New feature of the 700 level course will be hands-on small projects carried out by groups of two students in Professor Iqbal's laboratories during the second half of the semester. The projects will be selected from the topics covered in the course. A second feature will involve a lecture on a specialized nanomaterial topic given by an invited outside lecturer. This 3 credit interdisciplinary course is designed to teach and provide hands-on project experience to M.S. and Ph.D. graduate students in chemistry, physics/materials science, and chemical/biomedical/electrical engineering on the fundamentals, synthesis, characterization and applications of nanomaterials. 75% of the course will comprise of lectures-one or two of which will be given by invited outside lecturers. 25% of the course will involve small projects based on the syllabus and conducted in the research laboratories of the instructor.

MTEN 725. Independent Study I. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

MTEN 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for MTEN 726 if they have taken MTEN 725 in a prior semester. Students cannot register for this course with the same advisor as they had in MTEN 725.

MTEN 790A. Doct Dissertation & Res. 1 credit, 1 contact hour.
Corequisites: CHE 791. Co-requisite for full-time students: CHE 791. Approval of the dissertation advisor is required for registration. Experimental and theoretical investigation of a relevant topic in materials engineering. For PhD students who have successfully defended their dissertation proposal. The student must register in MTEN 790A every semester until successful dissertation defense. A written dissertation must be defended and approved by a committee of at least five members. Students enrolled in the PhD program before 2015 Fall must accumulate a minimum number of credits in Doctoral Dissertation Research and Pre-Doctoral Research (see graduate catalog for program-specific details; the same requirement may apply to joint PhD programs with other universities).

MTEN 792. Pre-Doctoral Research. 3 credits, 3 contact hours.
Co-requisite: CHE 791. For students admitted to the Doctor of Philosophy Program in Materials Science and Engineering with option in Engineering who have not yet passed Dissertation Proposal. Experimental or theoretical investigation of a topic in chemical engineering. Research is carried out under the supervision of designated chemical engineering faculty.

PHB 505. Principles of Pharm. Microbiology and Biochemistry. 3 credits, 3 contact hours.
Prerequisite: Graduate standing. This course covers major concepts of cell biology including cell physiology and structure, molecular biology, and genetics. Cellular chemistry, life cycles, and regulation are discussed as well as the fundamentals of biochemistry related to physical organic chemistry, including buffers, blood proteins, enzymes, carbohydrates, fats, and nucleic acids. This is a required course for PHB students with no or limited knowledge of biology.

PHB 590. Graduate Co-op Work Experience I. 3 credits, 3 contact hours.
Prerequisites: Permissions from Pharmaceutical Bioprocessing Graduate Advisor and Career Development Services. Cooperative education internship provides on-the-job reinforcement of the academic program by placement in major-related work situations at pharmaceutical companies or companies serving the pharmaceutical industry. Work assignment developed or approved by the co-op office and evaluated by the department. Cannot be used for degree credit.

PHB 591. Graduate Co-op Work Experience II. 3 credits, 0 contact hours.
Prerequisites: Permissions from Pharmaceutical Bioprocessing Graduate Advisor and Career Development Services. Same range of activities as in PHB 590. Cannot be used for degree credit.

PHB 592. Graduate Co-op Work Experience III. 3 credits, 3 contact hours.
Prerequisites: Permissions from Pharmaceutical Bioprocessing Graduate Advisor and Career Development Services. Same range of activities as in PHB 590 and PHB 591. Cannot be used for degree credit.

PHB 593. Graduate Co-op Work Experience IV. 0 credits, 3 contact hours.
Prerequisites: Permissions from Pharmaceutical Bioprocessing Graduate Advisor and Career Development Services. Same range of activities as in PHB 590, PHB 591 and PHB 592. Cannot be used for degree credit.

PHB 610. Biotechnology-Biopharmaceutical, Processes and Products. 3 credits, 3 contact hours.
Prerequisites: PHB 505, if required and PHEN 601. This course covers biological processes used in the pharmaceutical and biotechnology industry to obtain pharmaceutical products, including biochemical processes for antibiotic production and peptide extraction, and biopharmaceutical process to obtain recombinant proteins, monoclonal antibodies, cytokines, hormone and blood products, therapeutic enzymes, antibodies, vaccines, and nucleic acid therapeutics.

PHB 615. Bioseparation Processes. 3 credits, 3 contact hours.
Prerequisites: If required, PHEN 500, PHEN 501, PHEN 502 and PHB 505 and PHEN 601. This course covers the principles, methods and unit operations for the separation and recovery of biologically obtained molecules and especially proteins. Also studied here is the relationship between the chemistry of biological molecules and efficient separation and preservation of biological activity, with special emphasis on separation of biomolecules.

PHB 630. Pharmaceutical Bioprocess Engineering. 3 credits, 3 contact hours.
Prerequisites: If required, PHEN 500, PHEN 501, PHEN 502 and PHB 505; PHEN 601. This course covers the principles and methods to develop and operate bioprocess engineering systems, with emphasis on pharmaceutical bioprocessing and the use of chemical engineering principles to obtain products of therapeutic values. Topics include cell line selection, cell growth kinetics, substrate utilization, product formation, transport phenomena in biosystems, and bioreactors.

PHB 698. Special Topics in Pharmaceutical Bioprocessing I. 3 credits, 3 contact hours.
Prerequisites: Graduate standing and permission of the instructor. Topics of current interest in Pharmaceutical Bioprocessing.

PHB 699. Special Topics in Pharmaceutical Bioprocessing II. 3 credits, 3 contact hours.
Prerequisites: Graduate standing and permission of the instructor. Topics of current interest in Pharmaceutical Bioprocessing.

PHB 701B. Master's Thesis. 3 credits, 3 contact hours.
Prerequisites: Matriculation in the MS program in PHB and approval of PHB Program Advisor. Original research under the guidance of a Thesis Advisor. A written thesis must be approved by a three-member Thesis Committee including the primary advisor and at least one member of the CBPE faculty. A student must continue to register for at least 3 credits per semester until at least 6 credits have been completed and a written thesis is approved. Only a total of 6 credits will count toward the degree.

PHB 701C. Master's Thesis. 6 credits, 0 contact hours.
Prerequisites: Matriculation in the MS program in PHB and approval of PHB Program Advisor. Original research under the guidance of a Thesis Advisor. A written thesis must be approved by a three-member Thesis Committee including the primary advisor and at least one member of the CBPE faculty. A student must continue to register for at least 3 credits per semester until at least 6 credits have been completed and a written thesis is approved. Only a total of 6 credits will count toward the degree.

PHB 725. Independent Study I. 3 credits, 3 contact hours.
Prerequisites: Permission from the Program Advisor in PhB (not the Thesis Advisor), as well as completion of courses prescribed by a supervising faculty member (who cannot be the student's Thesis Advisor). This special course covers areas of study in which one or more students may be interested, but which is not of sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once with the same supervising faculty member.

PHB 726. Independent Study II. 3 credits, 3 contact hours.
Prerequisites: Permission from the Program Advisor in PhB (not the Thesis Advisor), as well as completion of courses prescribed by a supervising faculty member (who cannot be the student's Thesis Advisor). This special course covers areas of study in which one or more students may be interested, but which is not of sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once with the same supervising faculty member.

PHB 791. Graduate Seminar. 0 credits, 0 contact hours.
Prerequisite: Graduate standing. Required, when offered, of all PHB graduate students receiving departmental or research-based awards. The student must register each semester until completion of the degree, if the Graduate Seminar is offered. Outside speakers and department members present their research for general discussion.

PHEN 500. Pharmaceutical Engineering Fundamentals I. 3 credits, 3 contact hours.
Prerequisite: undergraduate calculus. This is a required bridge course for those students who are admitted to the Pharmaceutical Engineering MS program without an undergraduate engineering degree. This course is not counted toward degree credit related to the Pharmaceutical Engineering MS program. The course covers the fundamentals of calculus, differential equations, probability and statistics, and finance business mathematics applied to pharmaceutical engineering problems and illustrated through pharmaceutical engineering examples.

PHEN 501. Pharmaceutical Engineering Fundamentals II. 3 credits, 3 contact hours.
Prerequisite: If needed, PHEN 500 (which can also be taken concurrently with this course), as well as an undergraduate course in physical chemistry. This course is a required bridge course for those students who are admitted to the Pharmaceutical Engineering MS program without an undergraduate engineering degree or with an engineering background that did not include the topics covered in this course. The course is not counted toward degree credit related to the Pharmaceutical Engineering MS program. The course covers the fundamentals of pharmaceutical engineering calculations related to material and energy balances applied to pharmaceutical facilities and systems; estimation of thermophysical properties, phase and reaction equilibrium; and chemical kinetics and basic reactor design.

PHEN 502. Pharmaceutical Engineering Fundamentals III. 3 credits, 3 contact hours.
Prerequisite:If needed, PHEN 500 and PHEN 501, as well as undergraduate course in physical chemistry. This is a required bridge course for those students who are admitted to the Pharmaceutical Engineering MS program without an undergraduate engineering degree or with an engineering background that did not include the topics covered in this course. The course is not counted toward degree credit related to the Pharmaceutical Engineering MS program. The course covers the fundamentals of fluid mechanics, heat transfer, mass transfer and the design of unit operations involving these principles.

PHEN 590. Graduate Co-op Work Experience I. 1 credit, 1 contact hour.
Prerequisite: permission from Pharmaceutical Engineering Program Advisor and Division of Career Development Services. Cooperative education internship provides on-the-job reinforcement of the academic program by placement in major-related work situations at pharmaceutical companies or companies serving the pharmaceutical industry. Work assignment developed or approved by the co-op office and evaluated by the department. Cannot be used for degree credit.

PHEN 591. Graduate Co-op Work Experience II. 1 credit, 1 contact hour.
Prerequisite: permission from Pharmaceutical Engineering Program Advisor and Division of Career Development Services. Same range of activities as in PHEN 590.

PHEN 592. Graduate Co-op Work Experience III. 1 credit, 1 contact hour.
Prerequisite: permission from Pharmaceutical Engineering Program Advisor and Division of Career Development Services. Same range of activities as in PHEN 590 and PHEN 591.

PHEN 593. Graduate Co-op Work Experience IV. 0 credits, 0 contact hours.
Prerequisites: One immediately prior 3-credit registration for graduate co-op work experience with the same employer. Requires approval of departmental co-op advisor and the Division of Career Development Services. Must have accompanying registration in a minimum of 3 credits of course work.

PHEN 601. Principles of Pharmaceutical Engineering. 3 credits, 3 contact hours.
This course provides an overview of the pharmaceutical industry, including basic information about drug discovery and development, FDA requirements and approval processes, drug dosage forms, and the role of key operational units in drug manufacturing processes. This course enables the students to: understand the role of the pharmaceutical industry in the global market and its implications; learn the fundamentals of the drug development cycle and the investment required to bring a drug to market; learn the most important drug manufacturing processes and the key elements of dosage formulation.

PHEN 602. Pharmaceutical Facility Design. 3 credits, 3 contact hours.
Prerequisite: PHEN 601, PHEN 603; undergraduate courses in differential equations and fluid flow or completion of bridge program for students who are required to take it. This course provides instruction in design of state-of-the art pharmaceutical facilities for both manufacturing and R&D, by identifying key functional requirements and design concepts necessary to pharmaceutical processes. Interdisciplinary training will be provided in appropriate areas of facility design.

PHEN 603. Pharmaceutical Unit Operations: Processing of Liquid and Dispersed Phase Systems. 3 credits, 3 contact hours.
This course examines methodologies, both applied and fundamental, to analyze and scale up manufacturing pharmaceutical processes involving liquid and dispersed-phase systems, such as liquid and multiphase mixing, sterilization and sanitation, lyophilization, filtration, centrifugation and others. The emphasis is primarily on the engineering aspects of the parmaceutical processes examined in the course.

PHEN 604. Validation and Regulatory Issues in the Pharmaceutical Industry. 3 credits, 3 contact hours.
This course is focused on the development of a working knowledge of the Federal Code of Regulations and its impact on the pharmaceutical and allied industries. The history of the Federal Government's regulation of the pharmaceutical industry is studied. Also covered is the industry's response and the methodologies it uses to comply with these regulations.

PHEN 605. Pharmaceutical Packaging Technology. 3 credits, 3 contact hours.
Prerequisite: PHEN 601, PHEN 603, and completion of the bridge program for students who are required to take it. This course focuses on developing a working knowledge of the machinery and unit operations used in transferring a drug substance in the bulk final form to a finished product ready for sale to the consuming public. Packaging of both liquid and solid forms in various types of delivery containers such as vials/ampoules, blister packs, individual packets, bottles, pouches and syringes is examined. The cleaning, sterilization and scaling/capping required for each dosage form is discussed, as well as freeze-drying, tableting capsule filling, and form/fill/seal, and proper labeling of final drug forms.

PHEN 606. Pharmaceutical Unit Operations: Solids Processing. 3 credits, 3 contact hours.
This course examines methodologies, both applied and fundamental, to analyze and scale up manufacturing pharmaceutical processes involving solids processing, such as solids characterization, blending, milling, granulation, tableting, coating, and others. The emphasis is primarily on the engineering aspects of the pharmaceutical processes examined in the course.

PHEN 612. Pharmaceutical Reaction Engineering. 3 credits, 3 contact hours.
Prerequisite: PHEN 601, PHEN 603; undergraduate courses in differential equations and chemical engineering kinetics, or completion of bridge program for students who are required to take it. This course examines a variety of reactions and reactors typically encountered in the pharmaceutical industry, including single/multiphase systems (e.g., crystallization), chemical synthesis, enzymatic, bio-reactions (fermentation), and others. The course then focuses on quantitative pharmaceutical reactor design and scale-up issues.

PHEN 614. Pharmaceutical Separation Processes. 3 credits, 3 contact hours.
This course covers separation processes in general and pharmaceutical separations in particular. Specific processes to be studied include distillation, extraction, crystallization, adsorption, ion exchange, chromatography, moving bed processes, electrophoresis, freeze drying, microfiltration/ultrafiltration, reverse osmosis, and pervaporation.

PHEN 618. Principles of Pharmacokinetics and Drug Delivery. 3 credits, 3 contact hours.
The course covers the basic principles of pharmacokinetics, including drug transport, parenteral and enteral routes of drug administration, and factors affecting drug absorption, distribution, metabolism, and excretion. Mathematical pharmacokinetic models and drug delivery processes are also presented and quantitatively studied.

PHEN 698. Special Topics in Pharmaceutical Engineering I. 3 credits, 3 contact hours.
Prerequisite: graduate standing and permission of the instructor. Topics of current interest in pharmaceutical engineering.

PHEN 699. Special Topics in Pharmaceutical Engineering II. 3 credits, 3 contact hours.
Prerequisite: graduate standing and permission of the instructor. Topics of current interest in pharmaceutical engineering.

PHEN 700B. Master's Project. 3 credits, 3 contact hours.
Approval of the project advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in the student's academic program. A written report must be submitted to the project advisor. The student cannot register in 700B more than once and the incomplete (I) grade is not allowed.

PHEN 701B. Master's Thesis. 3 credits, 3 contact hours.
Corequisite for full-time students: PHEN 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in pharmaceutical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student is expected to defend the thesis upon accrual of six thesis credits. Additional registration in PHEN 701B, beyond six credits, is required every semester until successful thesis defense (six credits count toward degree requirements and time limits apply). Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

PHEN 701C. Master'S Thesis. 6 credits, 3 contact hours.
Corequisite for full-time students: PHEN 791. Approval of the thesis advisor is required for registration. Experimental and/or theoretical investigation of a relevant topic in pharmaceutical engineering that can lead to a quality publication. A written thesis must be defended and approved by a committee of at least three faculty members. The student must continue registering for three thesis credits (PHEN 701B course) each semester until successful thesis defense (six credits count toward degree requirements and time limits apply).

PHEN 702. Selected Topics in Pharmaceutical Engineering. 3 credits, 3 contact hours.
Prerequisite: graduate standing and permission of the instructor. Topics of current interest in pharmaceutical engineering.

PHEN 725. Independent Study. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once.

PHEN 726. Independent Study II. 3 credits, 3 contact hours.
Approvals of the academic advisor and course instructor are required for registration. Students working on their PhD dissertation or MS thesis cannot normally register for this course with their respective dissertation/thesis advisor. This special course covers areas of study in which one or more students may be interested but there is not sufficiently broad interest to warrant a regular course offering. Students may not register for this course more than once. Students should only register for PHEN 726 if they have taken PHEN 725 in a prior semester. Students cannot register for this course with the same advisor as they had in PHEN 725.

PHEN 791. Graduate Seminar. 0 credits, 0 contact hours.
Required, when offered, of all pharmaceutical engineering graduate students receiving departmental or research-based awards. The student must register each semester until completion of the degree, if the Graduate Seminar is offered. Outside speakers and department members present their research for general discussion.

TRAN 552. Geometric Design of Transportation Facilities. 3 credits, 3 contact hours.
Prerequisite: CE 350 or equivalent. Design principles and criteria related to highways and railroads resulting from requirements of safety, vehicle performance, driver behavior, topography, traffic, design, speed, and levels of service. Elements of the horizontal and vertical alignments and facility cross-section, and their coordination in the design. Computer-aided design procedures including COGO, CADAM, Digital Terrain Modeling. Same as CE 552.

TRAN 553. Design and Construction of Asphalt Pavements. 3 credits, 3 contact hours.
Importance of designing asphalt pavements. Topics include the origin of crude, refining crude, types of asphalts, desired properties of asphalt cement, specification and tests for asphalt cement, aggregates for asphalt mixtures, aggregate analysis, gradation and blending, hot-mix asphalt (HMA) mix design, manufacture of HMA and HMA-paving, hot and cold recycling. Same as CE 553.

TRAN 592. Graduate Co-op Work Experience. 1 credit, 1 contact hour.
Prerequisites: permission from Transportation Program and Division of Career Development Services. Work assignments and projects are developed by the co-op office in consultation with the transportation program. Work assignments are related to student's major and are evaluated by Transportation Program faculty coordinators. Credits for this course may not be used to fulfill any transportation degree requirements.

TRAN 602. Geographic Information Systems. 3 credits, 3 contact hours.
Prerequisite: course or working knowledge of CADD or permission of instructor. Geographical/Land Information System (GIS/LIS) is a computerized system capable of storing, manipulating and using spatial data describing location and significant properties of the earth's surface. GIS is an interdisciplinary technology used for studying and managing land uses, land resource assessment, environmental monitoring and hazard/toxic waste control, etc. Introduces emerging technology and its applications. Same as CE 602.

TRAN 603. Introduction to Urban Transportation Planning. 3 credits, 3 contact hours.
Urban travel patterns and trends; community and land activity related to transportation study techniques including survey methods, network analysis, assignment and distribution techniques. Case studies of statewide and urban areas are examined. Same as CE 603.

TRAN 608. Behavioral Issues in Transportation Studies. 3 credits, 3 contact hours.
Behavioral science concepts and principles such as perception, learning, motivation, and information processing as they relate to: transportation, consumer use of mass transit, automobiles, ridesharing and intelligent transportation systems. Same as HRM 608.

TRAN 610. Transportation Economics. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in economics. Principles of engineering economy. Cost of highway and public transportation facilities. Economic comparisons and evaluations. Financing approaches, tax allocation theory. Programming highway and public transit improvements. Same as IE 610.

TRAN 615. Traffic Studies and Capacity. 3 credits, 3 contact hours.
Prerequisite: elementary probability and statistics. Presentation of the characteristics of the traffic stream, road users, and of vehicles, and a review of traffic flow relationships. Students are exposed to the principal methodologies followed by transportation practices to perform volume, speed, travel time, delay, accident, parking, pedestrian, transit and goods movement studies. Presentation of the principal methodologies used to perform transportation facility capacity analyses for: basic freeway sections, weaving areas, ramps and ramp junctions, multi-lane and two lane roadways, signalized and unsignalized intersections. Students get hands on experience using highway capacity software (HCS) and SIDRA. Same as CE 660.

TRAN 625. Public Transportation Operations and Technology. 3 credits, 3 contact hours.
Prerequisite: graduate standing in civil or industrial engineering or instructor approval. Presentation of the technological and engineering aspects of public transportation systems. Historical development of public transportation technologies. Vehicle and right-of-way characteristics, capacity and operating strategies. Public transportation system performance. Advanced public transportation systems. Same as CE 625.

TRAN 640. Distribution Logistics. 3 credits, 3 contact hours.
Prerequisite: EM 602 or TRAN 650 or equivalent. Distribution logistics emphasizing systems engineering techniques used to optimize corporate profit and customer service: transportation modes; inventory policies; warehousing and order processing; and the best logistics gross margin. Same as EM 640.

TRAN 643. Transportation Finance. 3 credits, 3 contact hours.
Prerequisite: undergraduate course in economics. Balance sheets and income statements. Asset and liability management, sources and costs of debt and equity financing. Financial performance measures in the private sector (airlines, railroads, trucking and bus companies). Financing issues associated with the public sector (highways and mass transit). Equity and efficiency in pricing. Subsidy allocation formulae. Innovative financing schemes in the public sector. Same as IE 643.

TRAN 650. Urban Systems Engineering. 3 credits, 3 contact hours.
Prerequisite: computer programming background. Identifies the various urban problems subject to engineering analysis, and modern techniques for their solution, including inductive and deductive mathematical methods, mathematical modeling and simulation, and decision making under uncertainty. Same as CE 650.

TRAN 653. Traffic Safety. 3 credits, 3 contact hours.
Prerequisite: TRAN 615 or equivalent. System behavioral principles are applied to safety aspects of highway operation and design, and improvements of existing facilities. Solutions are evaluated on the basis of cost effectiveness. Same as CE 653.

TRAN 655. Land Use Planning. 3 credits, 3 contact hours.
Spatial relations of human behavior patterns to land use; methods of employment and population studies are evaluated; location and spatial requirements as related to land use plans; and concepts of urban renewal and recreational planning are investigated by case studies. Same as CE 655 and MIP 655.

TRAN 659. Flexible and Rigid Pavements. 3 credits, 3 contact hours.
Prerequisite: CE 341 or equivalent. Types of rigid (Portland cement) and flexible (bituminous pavements). Properties of materials, including mineral aggregates. Design methods as functions of traffic load and expected life. Importance and consequences of construction methods. Maintenance and rehabilitation of deteriorated pavements. Same as CE 659.

TRAN 700B. Master'S Project. 3 credits, 3 contact hours.
Master's students registering for the first time in Master's Project must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

TRAN 701B. Master's Thesis. 3 credits, 3 contact hours.
Prerequisite: written approval of thesis advisor. A comprehensive project, usually in the form of substantial study and analysis, a functional design project or control-operations systems study. Master's students registering for the first time in Master's Thesis must take simultaneously the INTD 799 (Responsible Conduct of Research) course.

TRAN 701C. Master'S Thesis. 6 credits, 3 contact hours.
Prerequisite: written approval of thesis advisor. A comprehensive project, usually in the form of substantial study and analysis, a functional design project or control-operations systems study.

TRAN 702. Topics In Transportation. 3 credits, 3 contact hours.
Prerequisite: advisor's approval. Topics of special or current interest.

TRAN 705. Mass Transportation Systems. 3 credits, 3 contact hours.
Prerequisite: TRAN 610 or IE 610. Investigation of bus, rapid transit, commuter railroad, and airplane transportation systems. Existing equipment, economics, capacity, and terminal characteristics are discussed, as well as new systems and concepts. Long- and short-range transportation systems are compared. Same as CE 705.

TRAN 720. Discrete Choice Modeling for Travel Demand Forecasting. 3 credits, 3 contact hours.
Prerequisite: TRAN 610 or equivalent. Discrete choice modeling describes a class of theoretical and analytical models essential for most advanced planning and forecasting efforts in transportation analysis. Includes logit, multi-nominal, and probit models. Develops theoretical and analytical skills needed to design, estimate and apply both revealed and stated preference models to appropriate travel demand forecasting problems.

TRAN 725. Independent Study. 3 credits, 3 contact hours.

TRAN 726. Independent Study II. 3 credits, 3 contact hours.

TRAN 752. Traffic Control. 3 credits, 3 contact hours.
Traffic laws and ordinances; regulatory measures; traffic control devices; markings, signs and signals; timing of isolated signals; timing and coordination of arterial signal systems; operational controls; flow, speed, parking; principles of transportation system management/ administration; highway lighting; and state-of-the-art surveillance and detection devices and techniques. Hands-on experience with TRAF/NETSIM and FREESIM. Same as CE 752.

TRAN 753. Airport Design and Planning. 3 credits, 3 contact hours.
Prerequisites or corequisites: TRAN 610 or EM 693 and TRAN 615. Planning of individual airports and statewide airport systems. Functional design of air and landside facilities. Orientation, number and length of runways. Concepts of airport capacity. Passenger and freight terminal facility requirements. Airport access systems. FAA operating requirements. Financial, safety and security issues. Same as CE 753 and IE 753.

TRAN 754. Port Design and Planning. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or EM 693 and TRAN 615. Functional design of the water and landsides for general cargo, liquid and dry bulk, and container operations. Yard and storage systems. Port capacity in an intermodal network. Economic, regulatory, and environmental issues. Same as CE 754 and IE 754.

TRAN 755. Intelligent Transportation Systems. 3 credits, 3 contact hours.
Prerequisite: TRAN 752. Techniques used to improve the safety, efficiency and control of surface transportation systems. Emphasis on technological and operational issues of these systems and using them for incident detection and for traffic management through route and mode diversion.

TRAN 760. Urban Trans Networks. 3 credits, 3 contact hours.
Prerequisites: elementary probability and statistics and TRAN 650 or equivalent. Provides analytical techniques for the analysis of transportation problems in an urban environment. Principal components include applications of models for the analysis of transportation problems, advanced static, dynamic, and stochastic traffic assignment procedures and transportation network design exact and heuristic solution algorithms. Offers hands-on experience with existing software in traffic assignment and transportation network design.

TRAN 765. Multi-modal Freight Transportation Systems Analysis. 3 credits, 3 contact hours.
Prerequisites: TRAN 610 or equivalent and TRAN 650 or EM 602 or equivalent. Quantitative methods for the analysis and planning of freight transportation services. The supply-performance-demand paradigm for freight transportation systems. Cost and performance as determined by system design and operations. Relationship of traffic and revenue to service levels and pricing. Optimal service design and redesign for transportation enterprises and operations planning. Fleet and facility investment planning. Applications to various modes. Same as EM 765 and CE 765.

TRAN 790A. Doctoral Dissertation. 1 credit, 1 contact hour.
Corequisite: TRAN 791. Required of all candidates for the Doctor of Philosophy in Transportation. A minimum of 36 credits is required. Students may register for 6 to 15 credits of dissertation per semester. If 36 credits are achieved prior to completion of the doctoral dissertation and research, students must register for 3 credits per semester.

TRAN 791. Doctoral Seminar. 0 credits, 1 contact hour.
Corequisite: TRAN 790. A seminar in which faculty, students, and invited speakers will present summaries of advanced topics in transportation. Students and faculty will discuss research procedures, dissertation organization, and content. Students engaged in research will present their own problems and research progress for discussion and criticism.

TRAN 792. Pre-Doctoral Research. 0 credits, 0 contact hours.
Prerequisite: Permission of program director. For students admitted to the Doctor of Philosophy Program in Transportation who have not yet passed the qualifying examination. Research is carried out under the supervision of a faculty member in the program. Up to 6 credits may be applied toward the required dissertation credits for the program.

TRAN 792B. Pre-Doctoral Research. 3 credits, 3 contact hours.