Industrial and Systems Engineering

Chair
- Geb W. Thomas

Undergraduate major: industrial engineering (BSE)

Graduate degrees: MS in industrial engineering; PhD in industrial engineering

Faculty: https://engineering.uiowa.edu/people/ise-people
Website: https://engineering.uiowa.edu/ise

The Department of Industrial and Systems Engineering offers undergraduate and graduate degrees and research programs in industrial and systems engineering.

Industrial and systems engineering encompasses analysis, design, and implementation of systems through optimal use of resources—human, material, energy, information, and financial. Systems may range from small units to extremely large operations. The industrial engineer must be skilled in mathematics, physical sciences, management, and human relations; and understands and designs solutions for the complexities of manufacturing, computer systems, economics, optimization, human behavior, and systems analysis and design.

Programs

Undergraduate Program of Study

Major
- Major in Industrial Engineering (Bachelor of Science in Engineering)

Graduate Programs of Study

Majors
- Master of Science in Industrial Engineering
- Doctor of Philosophy in Industrial Engineering

Facilities

The following facilities and laboratories are operated by faculty in the Department of Industrial and Systems Engineering, and may employ undergraduate and graduate students. For information about laboratories affiliated with core courses coordinated by other College of Engineering departments, see those departmental catalog sections.

Additive Manufacturing-Integrated Product Realization Laboratory

Researchers at Additive Manufacturing-Integrated Product Realization Laboratory (AMPRL) focus on studying how material-forming processes that occur in nature can be utilized to enable next-generation additive manufacturing (AM) technologies. Current research includes the design and development of next-generation AM technologies, AM process modeling and optimization, and the advancement of novel applications of new AM technologies. The lab applies its technological developments in a diverse array of fields, including tissue engineering, sensing, energy harvesting, and robotics. The lab is furnished with state-of-the-art material preparation, processing, and characterization equipment, as well as several custom 3D printers invented and developed by the group.

Design for Manufacturing Laboratory

The Design for Manufacturing Laboratory provides students with experience in computer-aided design and computer-aided manufacturing (CAD/CAM) systems. It is equipped with 4-axis computer numerical control (CNC) mills (Haas and Tormach), CNC router (Techno-CNC), CNC metal lathe (Haas and Techno-CNC), drill press, plastic injection molder, thermoforming machine, band saw, disc sander, bench grinder, polishing wheel, hand drill, sandblasting cabinet, press, foot shear, and welding station. The lab has the latest software technology, including Pro/ENGINEER and Rhinoceros.

Driving Safety Research Institute

The Driving Safety Research Institute (DSRI) is home to the nation’s first and largest public simulator of its kind in the world. For the last 25 years, the University of Iowa has conducted advanced research and development in support of saving lives, improving quality of life, advancing technology, and improving the efficiency and productivity of the automotive and supporting industries. Most importantly, DSRI serves as a place where students can learn firsthand about how innovation occurs in science and engineering.

From drug research to automated vehicles, DSRI is dedicated to engaging in a broad, holistic approach. Faculty, staff, and students at DSRI collaborate with nearly all UI colleges in their automotive safety research. Human factors research at DSRI is funded by government agencies and industry leaders for the public and private sectors. DSRI supports undergraduate, graduate, and doctoral students in driving research studies. Many of these studies include the use of the DSRI miniSim, a portable, high performance driving simulator based on DSRI state-of-the-art driving simulation technology developed through decades of research. In-house workstations and computers equipped with software such as MATLAB, Visual Studio, R, and SAS are available to students with approved access to the facility.

Automated vehicle technology is revolutionizing transportation and mobility, unlike any other technology of the past several decades. Vehicles, and their underlying technologies, are changing at a rapid pace. Many of the advanced driver assistance technologies and vehicle safety systems have been in research and development programs at the UI. The UI specializes in driver performance and behavior and how to optimally design the user interface of such systems. As vehicles become increasingly automated, the College of Engineering is leading a number of advanced research projects in automated and connected vehicles, funded by government and industry. Together with industry partners, the automated vehicles division is being built with a broad range of capabilities. These vehicles will be used to collect data for research programs funded through industry and government contracts.

Graphical Representation of Knowledge Lab (GROK)

The GROK Lab develops technologies to help scientists and doctors improve their understanding and control of complex systems such as robots, distributed sensor networks, and augmented-reality systems. The lab designs and builds software, electronic circuits, and mechanical devices that create or modify complex systems and that extend scientists’ understanding of how to make these systems perform their intended tasks better.

The lab has a variety of software development platforms and manufacturing tools, including computer numerical control (CNC) machines and supplies for casting and molding, as well as a suite of equipment for circuit design, testing, and assembly. The GROK lab has developed technologies used by NASA to control robots exploring South America and Mars. Its most recent projects have focused on using distributed wireless sensor networks to monitor factory-related health hazards and on developing surgical simulators to better train orthopedic surgeons.
Human Analytics Laboratory
The Human Analytics Laboratory (HAL) investigates human behavioral operations in complex systems with the developmental foci of human factors metrology, behavioral data analytics, and operations management. The HAL lab seeks the discovery and application of knowledge of human behavior to improve systems, learning, operations, and performance.

Information and Cognitive Systems Research Group
Research in the Information and Cognitive Systems Research Group focuses on the design and analysis of cognitive work and information systems in real-world domains. The current emphasis is on cognitive work in health care systems.

The research group conducts studies in usability testing, process mapping, cognitive walkthroughs, dynamic systems simulation, and interface design, prototyping, and evaluation. The research facility houses state-of-the-art qualitative field data collection equipment and data analysis tools, programming tools for dynamic systems simulations, and design, prototyping, and usability testing hardware and software tools for interface and display design. The facility also employs data modeling tools and diagramming tools.

Intelligent Systems Laboratory
The Intelligent Systems Laboratory conducts research in data science and computational intelligence leading to applications in manufacturing, energy, service industry, and health care. The current project focuses on smart manufacturing, digital industry, cloud and edge modeling, service manufacturing, and autonomous systems. Many of the intelligent manufacturing concepts pursued globally have originated in the laboratory. The pioneering research has been marked with the publication of the textbook "Intelligent Manufacturing Systems" (Prentice Hall) and the Journal of Intelligent Manufacturing.

Laboratory for IoT-Enabled Data Analytics and System Informatics
The lab utilizes high-performance computing workstations to model uncertainty quantifications and complex variable relationships. The aim is to develop engineering-guided statistical techniques to facilitate the interpretability, real-time monitoring, and root cause analysis of complex systems. The lab focuses on developing and applying data analytics tools to various promising areas including advanced manufacturing systems, driver simulation and monitoring systems, and water and hydrology modeling systems. The research in the group requires algorithm development, hardware design, theoretic analysis, and simulation and emulation.

Operator Performance Laboratory
The Operator Performance Laboratory (OPL) is a flight test organization at the University of Iowa. The lab specializes in civil and military flight testing and assessment of technologies in operational contexts, such as flight in degraded visual environments and GPS-denied environments. Quantification of data link and sensor performance for manned and unmanned aircraft in such an operational context is an area of focus. OPL develops, tests, and evaluates helmet-mounted displays (HMDs), synthetic vision systems, live virtual constructive (LVC) training systems, physiological-based workload measurement systems, pilot spatial orientation enhancement systems, and embedded flight simulation capabilities.

Unmanned aircraft operations include test flights supporting commercial unmanned aircraft systems (UAS) autonomy, 5th- and 6th-generation manned-unmanned teaming (MUMT) concepts, and the extension of LVC toward MUMT. The OPL team developed the Cognitive Assessment Tool Set (CATS), which is able to accurately quantify human cognitive workload using a flight-approved sensor package. CATS has been used in many flight tests as the data collection and analysis tool for pilot behavior in real-world flight environments. OPL pioneered the development and testing of LVC technology that blends ground-based battlespace simulations with airborne testbeds equipped with radar and weapons simulators that can employ simulated ordnance for effect in distributed simulation environments. This capability has been demonstrated many times, including at the Interservice/Industry Training Simulation Education Conference. In 2004, the OPL team developed and tested a synthetic vision system that was subsequently commercialized by Dynon Avionics under the brand name Skyview. This system has sold over 10,000 units and is flying in thousands of aircraft.

OPL has performed many flight test projects on its fleet of aircraft, exceeding a total 2,400 flight hours of developmental test and evaluation and operational test and evaluation data collection. OPL has 10 instrumented research aircraft. These include two L-29 fighter jet trainers, two MI-2 twin-turbine helicopters, one A-36 Bonanza, one Cessna 172, three TBM 3M UAS (62lbs), and one Vaper 55 (55 lbs). The OPL L-29s are the only tactical jet research aircraft that are equipped with the F-35 HMD. The OPL MI-2 is a one-of-a-kind sensor platform with a conformal HMD using full-color symbology showing threats and obstacles acquired by its suite of onboard sensors. Each OPL aircraft also is a flight simulator. Additionally, the OPL has a Boeing 737-800 full flight deck simulator, an unmanned aerial vehicle (UAV) ground control station simulator, a fast jet simulator, and deployable command and control (C2) bus as well as a C2 high mobility multipurpose wheeled vehicle for use as a forward command node in rugged terrain. OPL has an extensive telemetry infrastructure that is deployable. OPL’s flight support system also is deployable using mobile tool control, spares, jigs, and jacks, among other means.

Courses

Industrial and Systems Engineering Courses

ISE:1000 First-Year Seminar 0-1 s.h.
Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities). Requirements: first- or second-semester standing.

ISE:2000 Industrial Engineering Sophomore Seminar 0 s.h.
Curriculum and profession; ethics and professionalism in classroom and workplace. Requirements: sophomore or transfer standing in engineering.

ISE:2360 Design for Manufacturing 3 s.h.
Fundamentals of design, engineering graphics, and manufacturing processing; computer graphics using Pro/ENGINEER for CAD and CAM; typical industrial processes, including casting, welding, machining, forming; laboratory exercises and projects. Corequisites: ENGR:2720.

ISE:2500 Engineering Economy 3 s.h.
Basic concepts of engineering economy; time value of money, cash flow equivalence, depreciation, tax considerations, continuous cash flows, cost accounting overview; main analysis techniques—present worth, uniform annual cost, rate of return, benefit/cost ratio, replacement and break-even analysis. Corequisites: STAT:2020.

ISE:3000 Professional Seminar: Industrial Engineering 0 s.h.
Professional aspects of industrial engineering presented through lectures and discussions by guest speakers, field trips, films, panel discussions. Requirements: junior standing.
ISE:3300 Manufacturing Systems 3 s.h.
Manufacturing and logistics systems, supply chain management, MRP/ERP systems, lean manufacturing, concurrent engineering, value stream mapping and six sigma. Offered spring semesters. Prerequisites: ISE:2360 and ISE:3700.

ISE:3350 Process Engineering 3 s.h.
Methodologies, algorithms, and tools for processing modeling, analysis, and reengineering; modeling issues in product and component design, product and process modularity, quality, reliability, and agility. Prerequisites: ISE:3700.

ISE:3400 Human Factors 3 s.h.
Design of human-machine systems; development of optimum work environments by applying principles of behavioral science and basic knowledge of human capacities and limits. Offered fall semesters. Prerequisites: PSY:1001.

ISE:3450 Ergonomics 3 s.h.
Ergonomic design of jobs and products in an industrial and consumer market setting; principles of good design, examples of poor design; consequences of poor job and product design; principles of work sampling, usability studies, performance rating, sizing and planning of workstations, hand tool design, ergonomic design in transportation; related group project.

ISE:3500 Information Systems Design 3 s.h.
Structure and design of computer-based information systems; concepts of information systems, decision-making; computer hardware, software, data structures; methods for determining system requirements; designing, implementing, evaluating, managing information systems; applied projects. Prerequisites: ENGR:1300.

ISE:3600 Quality Control 3 s.h.
Basic techniques of statistical quality control; application of control charts for process control variables; design of inspection plans and industrial experimentation; modern management aspects of quality assurance systems. Offered fall semesters. Prerequisites: STAT:2020 or BAIS:9100 or (STAT:3101 and STAT:3200). Same as CEE:3142, STAT:3200.

ISE:3610 Stochastic Modeling 3 s.h.

ISE:3660 Data Analytics with R 3 s.h.
Basics of data analytics and data mining; how to implement a variety of popular data mining methods in R to tackle business and engineering problems; focus on process of turning raw data into intelligent decisions and algorithms commonly used to build predictive models and find relevant patterns in data. Prerequisites: STAT:2020.

ISE:3700 Operations Research 3 s.h.
Operations research models and applications; emphasis on deterministic model (linear programming, duality). Offered fall semesters. Prerequisites: MATH:2550. Corequisites: STAT:2020.

ISE:3750 Digital Systems Simulation 3 s.h.
Simulation modeling and analysis; emphasis on construction of models, interpretation of modeling results; input and output analysis; hands-on usage of ARENA simulation software, manufacturing, health care, and service. Offered spring semesters. Prerequisites: ISE:3610 and ISE:3700.

ISE:3760 Applied Linear Regression 3 s.h.
Regression analysis with focus on applications; model formulation, checking, and selection; interpretation and presentation of analysis results; simple and multiple linear regression; logistic regression; ANOVA; polynomial regression; tree models; bootstrapping; hands-on data analysis with computer software. Prerequisites: STAT:2020 or STAT:2010 or STAT:3120. Same as DATA:3200, IGPI:3200, STAT:3200.

Independent projects in industrial engineering for undergraduate students, including laboratory study, an engineering design project, analysis and simulation of an engineering system, computer software development, CAD/CAM applications, or research.

ISE:4116 Manufacturing Processes Simulations and Automation 3 s.h.
Material processing, metal cutting theories, forming, micro/nano fabrication, programmable logic controller, computer numerical controllers, discrete control system, DC and AC servo motors. Command generation. Prerequisites: ME:2300 or ISE:2360. Same as ME:4116.

ISE:4172 Big Data Analytics 3 s.h.
Principles of data mining and machine learning in context of big data; basic data mining principles and methods—pattern discovery, clustering, ordering, analysis of different types of data (sets and sequences); machine learning topics including supervised and unsupervised learning, tuning model complexity, dimensionality reduction, nonparametric methods, comparing and combining algorithms; applications of these methods; development of analytical techniques to cope with challenging and real "big data" problems; introduction to MapReduce, Hadoop, and GPU computing tools (CUDA and OpenCL). Prerequisites: STAT:2020 or BAIS:9100. Requirements: basic programming skills in C, C++, Java, or Python; knowledge of Matlab, Octave, or R; and knowledge of a word processor. Recommendations: ISE:3760 and CS:4400 and CS:3330 and MATH:2550.

ISE:4175 Safety Engineering 3 s.h.
Systems safety principles and methods, occupational safety, product safety and liability, accident investigation and prevention methods and analysis, hazard analysis, and standards and regulations.

ISE:4600 Industrial Engineering Design Project 1-4 s.h.
Projects involving product and related operational system design in an industrial or service organization; associated entrepreneurial or intrapreneurial planning. Corequisites: ISE:2500 and ISE:3300 and ISE:3350 and ISE:3400 and ISE:3450 and ISE:3500 and ISE:3600 and ISE:3750, if not taken as prerequisites. Requirements: completion of all ISE coursework.

ISE:4620 Design of Experiments for Quality Improvement 3 s.h.
Development of skills necessary to efficiently and effectively design and analyze experiments for quality improvement; topics include experiment planning, design, and statistical analysis of the results; experimentation is beneficial in all phases of industrial processes including new product design, process development, and manufacturing process improvement; students develop successful experiments that can lead to reduced development lead time, enhanced process performance, and improved product quality. Prerequisites: STAT:2020. Requirements: junior (third year) standing.
ISE:4900 Introduction to Six Sigma 3 s.h.
Six Sigma techniques for the DMAIC cycle (Define, Measure, Analyze, Improve, Control); what is needed for data collection (process inputs and outputs, measurement tools), conduct analysis (hypothesis testing, process capability studies), and conduct process improvement studies (design of experiments, response surface methodology); overview of Six Sigma, process and project management skills; application of the DMAIC model to a real-life improvement projection (a "learn-by-doing" approach). Prerequisites: ISE:3600.

ISE:5000 Graduate Seminar: Industrial Engineering 1 s.h.
Recent advances and research in industrial engineering presented by guest lecturers, faculty, students. Requirements: graduate standing.

ISE:5310 Advanced Computational Design and Manufacturing 3 s.h.
Provides understanding and practical experience in application of computational techniques to solve design and manufacturing problems; introduction to underlying concepts behind 3D geometry representations, algorithms, and underlying mathematical foundations essential to solving a wide variety of problems in computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE); hands-on computational skills working on team-based course projects. Requirements: knowledge of basic C/C++ programming concepts.

ISE:5420 Automated Vehicle Systems 3 s.h.
Overview of vehicle technologies (HAV) and advanced driver assistance systems (ADAS) including a historical perspective, testing, policy and regulation, algorithm design, and human factors. Recommendations: ISE:3400.

ISE:5460 User Experience Design 3 s.h.
Introduction to user experience (UX) research and design fundamentals; UX design as a critical first step in user research, designing products and services for users (e.g., digital, physical, hybrid), and validating products and services; UX theory, methods, and design; examination of user research techniques to facilitate UX design; UX design to achieve user engagement when using products and services; how demand for UX professionals has increased; lectures, readings, hands-on UX design activities, and UX design project.

ISE:5520 Renewable Energy 3 s.h.
Introduction to different sources of renewable energy generation including wind, solar, fuel cells, and bioenergy; design of energy solutions for different stand-alone applications (i.e., factories, data centers, hospitals) and system-wide solutions powering transportation systems, cities, or states; application-specific topics such as energy storage, control of energy generators, operations and maintenance, performance optimization, equipment health monitoring, predictive engineering, and integration of renewable energy with a grid.

ISE:5620 Design of Experiments 3 s.h.
Principles and methods of statistical design of experiments for product and process improvement; students develop skills necessary for planning, analysis, and optimization of experimental data, which can be applied across various fields of research including engineering, medicine, and the physical sciences. Prerequisites: STAT:2020.

ISE:5650 Mechatronics Engineering for Smart Device Design 3 s.h.
Introduction to basic mechatronics system components and design principles using mechatronics to meet functionality requirements of products, processes, and systems; lab-oriented assignments and team-based projects presented with innovative case studies in diverse application domains; labs require students to use a micro-controller kit to finish hardware development assignments; for students who plan to have a career in areas such as product development, robotics, design and manufacturing automation, technology management and innovations. Prerequisites: ENGR:2120 and ISE:2360.

ISE:5730 Digital Industry 3 s.h.
Modeling methodologies, analysis, and optimization of digital enterprise models; autonomous building of models from data stores; introduction to different application-as-a-service models embedded in edge, fog, and cloud architectures and solutions; science of process modeling and analysis illustrated with case studies. Prerequisites: ISE:3700.

ISE:5740 Design and Analysis of Computer Experiments 3 s.h.
Introduction to basic concepts of computer experiments; differences between computer and physical experiments; three technical contents including parametric and nonparametric prediction/inference models for computer experiments, space filling design for computer experiments, and criterion-based experiment design. Requirements: coding capability in at least one popular software (e.g., R, MATLAB, Python). Recommendations: STAT:4540, BAIS:9100 or MBA:8150, ISE:6790, or coding capability in R, MATLAB, or Python.

ISE:5995 Contemporary Topics in Industrial Engineering arr.
New topics or areas of study not offered in other industrial engineering courses; topics based on faculty/student interest.

Individual projects for industrial engineering graduate students; laboratory study, engineering design, analysis and simulation of an engineering system, computer software development, research. Requirements: graduate standing.

Experimental and/or analytical investigation of an approved topic for partial fulfillment of requirements for MS with thesis in industrial engineering. Requirements: graduate standing.

ISE:6211 Human Factors in Healthcare Systems 3 s.h.
Solving human factors problems in health care work systems; cognitive systems engineering, interface design, health care productivity, patient safety; specific research including decision-making, information transfer, and communication; discrete event and dynamic systems simulation modeling; human computer interaction; health information technology/systems; usability; business models of organizational, technical, and social elements of health care systems.

ISE:6220 Cognitive Engineering 3 s.h.
Cognitive engineering principles; decision-making and judgment; distributed cognition; cognitive work; human system interaction; cognitive work analysis; situated action and ecological models; mental models and representation; cognitive engineering methods and applications.

ISE:6300 Innovation Science and Studies 3 s.h.
Innovative typology and sources, classical innovation models, measuring innovation, innovation discovery from data, evolutionary computation in innovation, innovation life cycle.

ISE:6350 Computational Intelligence 3 s.h.
Concepts, models, algorithms, and tools for development of intelligent systems; data mining, expert systems, neural networks for engineering, medical and systems applications. Same as NURS:6900.

ISE:6380 Deep Learning 3 s.h.
Basic principles of deep neural networks for various engineering applications; skill sets to design and implement deep learning algorithm for engineering applications; essential topics of deep learning for its practical use and exploring diverse methods and architectures for different types of applications.

ISE:6410 Research Methods in Human Factors Engineering 3 s.h.
Logic and methods for research and for analysis and evaluation of complex human-machine systems; advanced techniques for enhancement of human interaction with advanced information technology; emphasis on cognitive task analysis techniques for innovative design, understanding of how technology affects safety, performance, user acceptance.
ISE:6420 Human/Computer Interaction 3 s.h.
Development of projects using human factors principles in the design of computer interfaces.

ISE:6450 Human Factors in Aviation 3 s.h.
Measuring, modeling, and optimizing human visual performance; display design for optimal legibility, research in visibility, legibility, conspicuity, and camouflage; visibility model development.

ISE:6460 The Design of Virtual Environments 3 s.h.
Development of techniques for designing and creating three-dimensional representations of information for simulation, scientific visualization, and engineering; emphasis on human factors issues, software.

ISE:6480 Unmanned Aircraft Systems 3 s.h.
Applications and research in unmanned aircraft systems (UAS) with focus on engineering aspects; new era of aviation and how UAS are fast emerging as a disruptive technology in aviation; applications ranging from film production, photography, precision agriculture, remote sensing, and infrastructure inspections to military applications; problem space of UAS from a variety of angles including engineering controls design, data links, UAS types, human factors, regulatory aspects.

ISE:6600 Linear Programming 3 s.h.
Mathematical programming models; linear and integer programming, transportation models, large-scale linear programming, network flow models, convex separable programming. Requirements: calculus and linear algebra. Same as BAIS:6600, IGPE:6600.

ISE:6650 Human Analytics and Behavioral Operations 3 s.h.
Introduction to several quantitative applications related to determining workforce size, skills-sets, and multifunctionality in service and manufacturing systems, based on measurable quality and productivity performance at the intersection of human factors engineering and production planning; modeling and solving problems in a context of speed and accuracy trade-off; models include learning, forgetting, teamwork, fatigue, procrastination, and individual difference measures.

ISE:6760 Pattern Recognition for Financial Data 3 s.h.
Modeling and harvesting useful information and patterns for financial data; topics include basic concepts of financial data, financial data visualization, modeling and forecasting of financial time series, seasonal models, volatility models, value at risk, principal component analysis, and factor models.

ISE:6780 Financial Engineering and Optimization 3 s.h.
Quantitative methods of modeling various financial instruments (i.e., stocks, options, futures) and tools for measurement and control of risks inherent to financial markets; fundamentals of interest rates; options and futures contract valuation, including weather and energy derivatives; risk management and portfolio optimization; emphasis on modeling and solution techniques based on optimization and simulation approaches traditional to industrial engineering and operations research. Recommendations: basic knowledge of probability and statistics, numerical methods, and optimization.

ISE:6790 Advanced Data Analytics and Informatics 3 s.h.
Advanced analytics techniques (i.e., linear mixed effects model, Gaussian process model, Bayesian analytics); team project on selected data analytics topics from Kaggle using real industrial data for performance demonstration; emphasis on understanding methodology and technology applications; application of each analytics technique on various industrial data context. Recommendations: STAT:4540 or MBA:8150; working knowledge of important discrete and continuous distributions, joint distributions, linear regression, random process, hypotheses testing, and analysis of variance; and programming capability in any language (e.g., Matlab, R, Python).

ISE:6810 Advanced Topics on Additive Manufacturing 3 s.h.
Review of critical challenges facing 3D printing; emphasis on techniques and practical experience in developing novel additive manufacturing processes and applications; topics include 3D content creation and preparation, CAD systems for additive manufacturing, additive manufacturing processes, fabrication speed and improvements, rapid tooling and indirective processes.

ISE:7998 Special Topics in Industrial Engineering 3 s.h.
ISE:7999 Research: Industrial Engineering PhD Dissertation 3 s.h.
Experimental and/or analytical investigation of an approved topic for partial fulfillment of requirements for PhD in industrial engineering.