Operations Research with Engineering

Degrees Offered

- Master of Science in Operations Research with Engineering (Non-Thesis)
- Doctor of Philosophy in Operations Research with Engineering

Program Description

Operations Research (OR) involves mathematically modeling physical systems (both naturally occurring and man-made) with a view to determining a course of action for the system to either improve or optimize its functionality. Examples of such systems include, but are not limited to, manufacturing systems, chemical processes, socio-economic systems, mechanical systems (e.g., those that produce energy), and mining systems.

Program Requirements

Master of Science in Operations Research with Engineering (Non-Thesis)

Core Courses	18.0
ORWE courses not taken as core courses	12.0
Total	30.0

All Masters students are required to take a set of core courses (18 credits) that provides basic tools for the more advanced and specialized courses in the program as specified below.

MATH324	STATISTICAL MODELING	3.0
MATH530	INTRODUCTION TO STATISTICAL METHODS	3.0
ORWE586	LINEAR OPTIMIZATION	3.0
or ORWE585	NETWORK MODELS	
MATH438	STOCHASTIC MODELS	3.0
or MATH538	STOCHASTIC MODELS	
or EBGN526	STOCHASTIC MODELS IN MANAGEMENT SCIENCE	
ORWE587	NONLINEAR OPTIMIZATION	3.0
or ORWE588	INTEGER OPTIMIZATION	
MEGN502	ADVANCED ENGINEERING ANALYSIS	3.0
or CSCI406	ALGORITHMS	
or CEEN405	NUMERICAL METHODS FOR ENGINEERS	
or CEEN505	NUMERICAL METHODS FOR ENGINEERS	

The remaining 12 credits of coursework can be completed with any ORWE-labeled course not taken as core. Or, specialty tracks can be added in areas, for example, including: (i) operations research methodology; (ii) systems engineering; (iii) computer science; (iv) finance and economics; and (v) an existing engineering discipline that is reflected in a department name such as electrical, civil, environmental, or mining engineering.

Students who do not wish to specialize in a track mentioned in the table below and do not wish to complete 12 additional credits of ORWE-labeled coursework can "mix and match" from the ORWE coursework and coursework mentioned in the tables below in consultation with and approval from their academic advisers.

Examples of specialty tracks from various departments across campus are given below:

Energy Systems within Mechanical Engineering Track (12 credits from the course list below)

MEGN461	THERMODYNAMICS II	3.0
MEGN567	PRINCIPLES OF BUILDING SCIENCE	3.0
MEGN583/ AMFG501	ADDITIVE MANUFACTURING	3.0
MEGN570	ELECTROCHEMICAL SYSTEMS ENGINEERING	3.0
MEGN560	DESIGN AND SIMULATION OF THERMAL SYSTEMS	3.0

Additive Manufacturing Track (12 credits from the course list below)*

*Subject to approval by graduate council

AMFG511	DATA DRIVEN ADVANCED MANUFACTURING	3.0
MEGN583/ AMFG501	ADDITIVE MANUFACTURING	3.0
AMFG531	MATERIALS FOR ADDITIVE MANUFACTURING	3.0
AMFG421/521	DESIGN FOR ADDITIVE MANUFACTURING	3.0

Applied Mathematics and Statistics Track (12 credits from the course list below)

MATH500	LINEAR VECTOR SPACES	3.0
MATH532	SPATIAL STATISTICS	3.0
MATH536	ADVANCED STATISTICAL MODELING	3.0
MATH537/538	MULTIVARIATE ANALYSIS	3.0
MATH438/538	STOCHASTIC MODELS	3.0
MATH551	COMPUTATIONAL LINEAR ALGEBRA	3.0
EENG511	CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS	3.0

Economics Track (12 credits from the course list below)

EBGN509	MATHEMATICAL ECONOMICS	3.0
EBGN510	NATURAL RESOURCE ECONOMICS	3.0
EBGN530	ECONOMICS OF INTERNATIONAL ENERGY MARKETS	3.0
EBGN535	ECONOMICS OF METAL INDUSTRIES AND MARKETS	3.0
EBGN590	ECONOMETRICS I	3.0
EBGN645	COMPUTATIONAL ECONOMICS	3.0
CSCI555	GAME THEORY AND NETWORKS	3.0

Business Track (12 credits from the course list below)

ORWE559	SUPPLY CHAIN MANAGEMENT	3.0
EBGN560	DECISION ANALYTICS	3.0

EBGN571	MARKETING ANALYTICS	3.0
EBGN562	STRATEGIC DECISION MAKING	3.0

Computer Science Track (12 credits from the course list below)

CSCI542	SIMULATION	3.0
CSCI562	APPLIED ALGORITHMS AND DATA STRUCTURES	3.0
CSCI571	ARTIFICIAL INTELLIGENCE	3.0
CSCI575	ADVANCED MACHINE LEARNING	3.0
CSCI555	GAME THEORY AND NETWORKS	3.0

Civil Engineering - Geotechnics Track (12 credits from the course list below)

CEEN506	FINITE ELEMENT METHODS FOR ENGINEERS	3.0
CEEN510	ADVANCED SOIL MECHANICS	3.0
CEEN519	RISK ASSESSMENT IN GEOTECHNICAL ENGINEERING	3.0
CEEN511	UNSATURATED SOIL MECHANICS	3.0
CEEN512	SOIL BEHAVIOR	3.0
CEEN515	HILLSLOPE HYDROLOGY AND STABILITY	3.0

Civil Engineering-Structures Track (12 credits from the course list below)

CEEN506	FINITE ELEMENT METHODS FOR ENGINEERS	3.0
CEEN530	ADVANCED STRUCTURAL ANALYSIS	3.0
CEEN531	STRUCTURAL DYNAMICS	3.0
CEEN533	MATRIX STRUCTURAL ANALYSIS	3.0
CEEN543	CONCRETE BRIDGE DESIGN BASED ON THE AASHTO LRFD SPECIFICATIONS	3.0
CEEN545	STEEL BRIDGE DESIGN	3.0

Nuclear Engineering Track (12 credits from the course list below)

NUGN506	NUCLEAR FUEL CYCLE	3.0
NUGN510	INTRODUCTION TO NUCLEAR REACTOR PHYSICS	3.0
NUGN520	INTRODUCTION TO NUCLEAR REACTOR THERMAL-HYDRAULICS	3.0
NUGN580	NUCLEAR REACTOR LABORATORY	3.0
NUGN590	COMPUTATIONAL REACTOR PHYSICS	3.0
NUGN585/586	NUCLEAR REACTOR DESIGN I	2.0

Electrical Engineering-Antennas and Wireless Communications Track (12 credits from the course list below)

EENG525	ANTENNAS	3.0
EENG527	WIRELESS COMMUNICATIONS	3.0
EENG530	PASSIVE RF & MICROWAVE DEVICES	3.0
EENG526	ADVANCED ELECTROMAGNETICS	3.0
EENG528	COMPUTATIONAL ELECTROMAGNETICS	3.0

Electrical Engineering-Energy Systems and Power Electronics Track (12 credits from the course list below)

EENG570	ADVANCED HIGH POWER ELECTRONICS	3.0
EENG580	POWER DISTRIBUTION SYSTEMS ENGINEERING	3.0
EENG581	POWER SYSTEM OPERATION AND MANAGEMENT	3.0
EENG583	ADVANCED ELECTRICAL MACHINE DYNAMICS	3.0

Electrical Engineering-Information and Systems Sciences Track (12 credits from the course list below)

EENG509	SPARSE SIGNAL PROCESSING	3.0
EENG511	CONVEX OPTIMIZATION AND ITS ENGINEERING APPLICATIONS	3.0
EENG515	MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS	3.0
EENG517	THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS	3.0
EENG519	ESTIMATION THEORY AND KALMAN FILTERING	3.0
EENG527	WIRELESS COMMUNICATIONS	3.0
EENG589	DESIGN AND CONTROL OF WIND ENERGY SYSTEMS	3.0
MEGN544	ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL	3.0

Mining and Earth Systems Track (12 credits from the course list below)

MNGN502	GEOSPATIAL BIG DATA ANALYTICS	3.0
MNGN512	SURFACE MINE DESIGN	3.0
MNGN516	UNDERGROUND MINE DESIGN	3.0
MNGN536	OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY	3.0
MNGN539	ADVANCED MINING GEOSTATISTICS	3.0

Doctor of Philosophy in Operations Research with Engineering

The ORWE PhD allows students to complete an interdisciplinary doctoral degree in Operations Research with Engineering by taking courses and conducting research in eight departments/divisions: Applied Mathematics and Statistics, Electrical Engineering, Computer Sciences, Civil and Environmental Engineering, Economics & Business, Mining Engineering, Mechanical Engineering, and Metallurgical & Materials Engineering.

Specialty Requirements

Doctoral students develop a customized curriculum to fit their needs. The degree requires a minimum of 72 graduate credits that includes coursework and a thesis. Coursework is valid for nine years towards a PhD degree; any exceptions must be approved by the Director of the ORWE program and by the student's adviser.

Credit requirements

Core Courses	24.0
Area of Specialization Courses	12.0
Any Combination of Specialization Courses or Research	12.0
Research Credits	24.0
Total Semester Hrs	**72.0**

Research Credits

Students must complete at least 24.0 research credits. The student's faculty adviser and the doctoral thesis committee must approve the student's program of study and the topic for the thesis.

Qualifying Examination Process and Thesis Proposal

Upon completion of the appropriate core coursework, students must pass Qualifying Exams I (written, over four courses) and II (oral, consisting of a report and research presentation) to become a candidate for the PhD, ORWE specialty. Qualifying Exam I is generally taken no later than three semesters after entry into the PhD program, and Qualifying Exam II follows no more than two semesters after having passed Qualifying Exam I. The proposal defense should be completed within ten months of passing Qualifying Exam II.

Transfer Credits

Students may transfer up to 24.0 credits of graduate-level coursework from other institutions toward the PhD degree subject to the restriction that those courses must not have been used as credit toward a Bachelor's degree. The student must have achieved a grade of B or better in all graduate transfer courses and the transfer must be approved by the student's doctoral thesis committee and the Director of the ORWE program.

Although most doctoral students will only be allowed to transfer up to 24 credits, with approval from the student's doctoral committee, exceptions may be made to allow students who have earned a specialized thesis-based master's degree in operations research or other closely related field from another university to transfer up to 36 credits in recognition of the degree. Students should consult with their academic advisors and ORWE director for details.

Unsatisfactory Progress

In addition to the institutional guidelines for unsatisfactory progress as described elsewhere in this bulletin: Unsatisfactory progress will be assigned to any full-time student who does not pass the following prerequisite and core courses in the first three semesters of study:

CSCI262	DATA STRUCTURES	3.0
ORWE586	LINEAR OPTIMIZATION	3.0
CSCI406	ALGORITHMS	3.0
EBGN526	STOCHASTIC MODELS IN MANAGEMENT SCIENCE	3.0

Unsatisfactory progress will also be assigned to any students who do not complete requirements as specified in their admission letters. Any exceptions to the stipulations for unsatisfactory progress must be approved by the ORwE committee. Part-time students develop an approved course plan with their advisor.

Prerequisites

Students must complete the following undergraduate prerequisite courses with a grade of B or better:

CSCI261	PROGRAMMING CONCEPTS	3.0
CSCI262	DATA STRUCTURES	3.0

Required Course Curriculum

All PhD students are required to take a set of core courses that provides basic tools for the more advanced and specialized courses in the program.

Core Courses		
CSCI406	ALGORITHMS	3.0
MEGN502	ADVANCED ENGINEERING ANALYSIS	3.0
ORWE586	LINEAR OPTIMIZATION	3.0
MATH530	INTRODUCTION TO STATISTICAL METHODS	3.0
MATH438	STOCHASTIC MODELS	3.0
ORWE585	NETWORK MODELS	3.0
ORWE588	INTEGER OPTIMIZATION	3.0
ORWE587	NONLINEAR OPTIMIZATION	3.0
Total Semester Hrs		**24.0**

Students are required to take four courses from the following list:

Area of Specialization Courses		
CSCI555	GAME THEORY AND NETWORKS	3.0
CSCI562	APPLIED ALGORITHMS AND DATA STRUCTURES	3.0
EBGN509	MATHEMATICAL ECONOMICS	3.0
EBGN528	INDUSTRIAL SYSTEMS SIMULATION	3.0
or MATH542	SIMULATION	
or CSCI542	SIMULATION	
EBGN560	DECISION ANALYTICS	3.0
EBGN575	ADVANCED MINING AND ENERGY ASSET VALUATION	3.0
EENG517	THEORY AND DESIGN OF ADVANCED CONTROL SYSTEMS	3.0
MATH531	THEORY OF LINEAR MODELS	3.0
MATH532	SPATIAL STATISTICS	3.0
MATH537	MULTIVARIATE ANALYSIS	3.0
MATH582	STATISTICS PRACTICUM	3.0
MEGN592	RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN	3.0
MNGN536	OPERATIONS RESEARCH TECHNIQUES IN THE MINERAL INDUSTRY	3.0
MNGN538	GEOSTATISTICAL ORE RESERVE ESTIMATION	3.0
ORWE688	ADVANCED INTEGER OPTIMIZATION	3.0
ORWE686	ADVANCED LINEAR OPTIMIZATION	3.0
5XX/6XX	Special Topics (Requires approval of the advisor and OrwE program director)	3.0

Mines' Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program may double count up to six credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with "B-" or better, not be substitutes for required coursework, and meet all other University, Department, and Program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

Courses

ORWE481. OPTIMIZATION MODELS IN MANUFACTURING. 3.0 Semester Hrs.
We address the mathematical formulation and solution of optimization models relevant in manufacturing operations. The types of deterministic optimization models examined include: (i) network models; (ii) linear programs; (iii) integer programs; and, (iv) nonlinear programs. Application areas include scheduling, blending, design, equipment replacement, logistics and transportation, among other topics. Students learn not only how to mathematically formulate the models, but also how to solve them with a state-of-the-art modeling language (AMPL) and appropriate solver (e.g., CPLEX or Minos). Algorithms for each problem class will be briefly discussed.

ORWE559. SUPPLY CHAIN MANAGEMENT. 3.0 Semester Hrs.
(II) Due to the continuous improvement of information technology, shorter life cycle of products, rapid global expansion, and growing strategic relationships, supply chain management has become a critical asset in today?s organizations to stay competitive. The supply chain includes all product, service and information flow from raw material suppliers to end customers. This course focuses on the fundamental concepts and strategies in supply chain management such as inventory management and risk pooling strategies, distribution strategies, make-to-order/make-to-stock supply chains, supplier relationships and strategic partnerships. It introduces quantitative tools to model, optimize and analyze various decisions in supply chains as well as real-world supply chain cases to analyze the challenges and solutions. 3 hours lecture; 3 semester hours.

ORWE585. NETWORK MODELS. 3.0 Semester Hrs.
(I) We examine network flow models that arise in manufacturing, energy, mining, transportation and logistics: minimum cost flow models in transportation, shortest path problems in assigning inspection effort on a manufacturing line, and maximum flow models to allocate machine-hours to jobs. We also discuss an algorithm or two applicable to each problem class. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. 3 hours lecture; 3 semester hours.

ORWE586. LINEAR OPTIMIZATION. 3.0 Semester Hrs.
(I) We address the formulation of linear programming models, linear programs in two dimensions, standard form, the Simplex method, duality theory, complementary slackness conditions, sensitivity analysis, and multi-objective programming. Applications of linear programming models include, but are not limited to, the areas of manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

ORWE587. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.
(I) This course addresses both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world engineering problems in areas such as manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with an algorithm such as MINOS) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

ORWE588. INTEGER OPTIMIZATION. 3.0 Semester Hrs.
(I) This course addresses the formulation of integer programming models, the branch-and-bound algorithm, total unimodularity and the ease with which these models are solved, and then suggest methods to increase tractability, including cuts, strong formulations, and decomposition techniques, e.g., Lagrangian relaxation, Benders decomposition. Applications include manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. 3 hours lecture; 3 semester hours.

ORWE686. ADVANCED LINEAR OPTIMIZATION. 3.0 Semester Hrs.
(II) As an advanced course in optimization, we expand upon topics in linear programming: advanced formulation, the dual simplex method, the interior point method, algorithmic tuning for linear programs (including numerical stability considerations), column generation, and Dantzig-Wolfe decomposition. Time permitting, dynamic programming is introduced. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Offered every other year. Prerequisite: MEGN586. 3 hours lecture; 3 semester hours.

ORWE688. ADVANCED INTEGER OPTIMIZATION. 3.0 Semester Hrs.
(II) As an advanced course in optimization, we expand upon topics in integer programming: advanced formulation, strong integer programming formulations (e.g., symmetry elimination, variable elimination, persistence), in-depth mixed integer programming cuts, rounding heuristics, constraint programming, and decompositions. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Prerequisite: MEGN588. 3 hours lecture; 3 semester hours. Offered every other year.

Program Director

Alexandra Newman, Professor, Mechanical Engineering