APPLIED AND INDUSTRIAL MATHEMATICS M.S.

Degree: Master of Science
https://www.towson.edu/fcsm/departments/mathematics/grad/applied/

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The Master of Science program provides students with a broad knowledge in applied mathematics with an emphasis on areas with the highest demand in business and industry. Among the areas stressed in the program are mathematical modeling, numerical computations, operations research, financial mathematics and statistical analysis. Numerical, computational and algorithmic approaches to problem solving are stressed throughout the program. Graduates of the program will be qualified to work in such fields as operations research, stochastic modeling, financial data analysis and statistics, among many others. Graduates of the program will also be prepared for further work at the doctoral level.

The main objectives of the program are:

1. to prepare individuals to apply advanced mathematical skills to problems in areas of science, business and industry;
2. to develop the students’ abilities to integrate, in a meaningful way, the use of technology in their everyday professional practice;
3. to give educators an opportunity to satisfy their in-service requirements and simultaneously enhance their knowledge of technology and enrich their mathematical backgrounds;
4. to supply students with the mathematical competency necessary for advancement to a more professional role;
5. to educate students to solve problems, to work in teams and to communicate in an interdisciplinary setting;
6. to familiarize students with the recent advances in applied mathematics;
7. to prepare students for further graduate work at the doctoral level in applied mathematics; and
8. to enrich the academic culture by providing opportunities for interaction of mathematical and industrial research.

Both full-time and part-time students are encouraged to enroll in the program. Core courses are usually offered in the evening, for the convenience of part-time students.

Admission Requirements

- A baccalaureate degree in mathematics or a related field. The applicant’s undergraduate training must have included at least three terms of calculus, a course in linear algebra and one of the following: a course in differential equations or a course in probability. Students with any deficiency in their mathematical background may be admitted conditionally if they are willing to correct such deficiency.
- An undergraduate GPA of at least 3.00 for full admission, 2.75 for conditional admission, is required. All GPA calculations for admission are based upon the last 60 units of undergraduate and post-baccalaureate study.
- Students who received their degree outside the United States must provide official verification of their English competency by submitting an English assessment report of their IELTS, TOEFL or other Towson University-approved testing system. Students must meet the standards set by Towson University to be admitted into the program.

Degree Requirements

There are two concentrations from which to choose: Differential Equations/Optimization or Applied Statistics/Mathematical Finance.

A student may transfer up to two graduate-level mathematics courses taken at another institution, provided that the transfer is consistent with the graduate policy.

The program requires the completion of an applied full-year research project at a graduate level. There are three options listed below in order of priority to complete this requirement. The project can be:

1. An external applied project through a local industry or a government agency. Students choosing this option take MATH 791 and MATH 792, under the supervision of a faculty member from the Department of Mathematics.
2. With a faculty member in the Department of Mathematics on an applied graduate-level project. Students choosing this option take MATH 880 and MATH 881.
3. In the department’s Applied Mathematics Laboratory (AML). Typically, corporations and government agencies sponsor these projects. Students choosing this option take MATH 880 and MATH 881. Not all AML projects can be used for the internship purpose.

Students need to submit a project proposal to the graduate committee for approval. In particular, students working on AML projects must describe their roles and responsibilities as part of the team. Students on AML projects must take MATH 791 and MATH 792, under the supervision of a faculty member from the Department of Mathematics.

If the Graduate Program Committee believes that all attempts, based on the above options, to find an internship project for the student were not successful, the student can take two additional 600-level mathematics courses from the declared concentration and must pass both courses with a letter grade B+ or higher.

All graduate students are required to meet with the APIM graduate program director two and a half terms prior to their graduation (late April or late October, whichever applies) to discuss their choices for completing the internship requirement. Students will commit themselves to their choice by signing a form available from the director.

Students whose careers are in education may, with the approval of the department’s Graduate Program Committee, replace the industrial setting of the internship with an educational setting. This will typically entail the development of original course material stressing applied mathematics and using innovative teaching techniques.
The student is required to successfully complete at least 10 courses (a minimum of 30 units) as indicated below: At most, two 500-level classes will count towards the degree.

1. at least four 600-level courses from a declared concentration
2. at least two 600-level courses from the other concentration
   NOTE: At most one of the courses in the degree requirement No. 2 above can be replaced with MATH 633, MATH 651, MATH 671, MATH 676 or MATH 685.
3. at least two elective courses at the 500 or 600 level
4. an internship project (MATH 791 & MATH 792) or applied graduate research project (MATH 880 & MATH 881) or alternative coursework approved by the Graduate Committee.

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Courses for all Concentrations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MATH 791 &amp; MATH 792</td>
<td>MASTERS INTERNSHIP I and MASTER'S INTERNSHIP II</td>
<td>6</td>
</tr>
<tr>
<td>OR MATH 880 &amp; MATH 881</td>
<td>APPLIED MATHEMATICS GRADUATE PROJECT I and APPLIED MATHEMATICS GRADUATE PROJECT II</td>
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<tr>
<td>OR 6 units of alternative coursework approved by the Graduate Committee</td>
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<tr>
<td>Concentration Coursework</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Other Concentration Coursework</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Electives</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>30</td>
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</tbody>
</table>

### Differential Equations/Optimization Concentration

Select at least 4 courses from declared concentration and 2 courses from the other concentration:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 635</td>
<td>APPLIED NUMERICAL ANALYSIS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 636</td>
<td>LINEAR AND NONLINEAR PROGRAMMING</td>
<td>3</td>
</tr>
<tr>
<td>MATH 637</td>
<td>ADVANCED TOPICS IN APPLIED OPERATIONS RESEARCH</td>
<td>3</td>
</tr>
<tr>
<td>MATH 673</td>
<td>INTEGRAL TRANSFORMS AND APPLICATIONS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 674</td>
<td>APPLIED PARTIAL DIFFERENTIAL EQUATIONS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 675</td>
<td>ASYMPTOTIC AND PERTURBATION ANALYSIS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 686</td>
<td>SPECIAL TOPICS IN DIFFERENTIAL EQUATIONS OR OPTIMIZATION</td>
<td>3</td>
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</table>

### Applied Statistics/Mathematical Finance Concentration

Select at least 4 courses from declared concentration and 2 courses from the other concentration:

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 632</td>
<td>COMPUTATIONAL STOCH-ASTIC MODELING</td>
<td>3</td>
</tr>
<tr>
<td>MATH 634</td>
<td>TIME SERIES ANALYSIS AND FORECASTING</td>
<td>3</td>
</tr>
<tr>
<td>MATH 638</td>
<td>APPLIED MULTIVARIATE STATISTICAL ANALYSIS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 639</td>
<td>LOSS MODELS</td>
<td>4</td>
</tr>
<tr>
<td>MATH 643</td>
<td>COMPUTATIONAL METHODS OF MATHEMATICAL FINANCE</td>
<td>3</td>
</tr>
<tr>
<td>MATH 644</td>
<td>MATHEMATICS OF FINANCIAL DERIVATIVES</td>
<td>3</td>
</tr>
<tr>
<td>MATH 687</td>
<td>SPECIAL TOPICS IN APPLIED STATISTICS OR MATHEMATICAL FINANCE</td>
<td>3</td>
</tr>
</tbody>
</table>

**NOTE:** All courses above have strictly enforced prerequisites.

### Electives

**Electives for Both Concentrations (at least two courses):**

<table>
<thead>
<tr>
<th>Code</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 531</td>
<td>PROBABILITY</td>
<td>4</td>
</tr>
<tr>
<td>MATH 532</td>
<td>MATHEMATICAL STATISTICS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 533</td>
<td>APPLIED REGRESSION AND TIME SERIES PREDICTIVE MODELING</td>
<td>4</td>
</tr>
<tr>
<td>MATH 535</td>
<td>NUMERICAL ANALYSIS I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 537</td>
<td>OPERATIONS RESEARCH</td>
<td>3</td>
</tr>
<tr>
<td>MATH 538</td>
<td>LONG-TERM ACTUARIAL MODELS I</td>
<td>3</td>
</tr>
<tr>
<td>MATH 563</td>
<td>LINEAR ALGEBRA</td>
<td>3</td>
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<tr>
<td>MATH 575</td>
<td>MATHEMATICAL MODELS</td>
<td>3</td>
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<tr>
<td>MATH 576</td>
<td>INTRODUCTORY REAL ANALYSIS</td>
<td>3</td>
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<tr>
<td>MATH 577</td>
<td>COMPLEX ANALYSIS</td>
<td>3</td>
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<tr>
<td>MATH 579</td>
<td>FOURIER ANALYSIS WITH APPLICATIONS</td>
<td>3</td>
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<tr>
<td>MATH 585</td>
<td>MATHEMATICAL FINANCE</td>
<td>3</td>
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<tr>
<td>MATH 586</td>
<td>RISK MANAGEMENT AND FINANCIAL ENGINEERING</td>
<td>3</td>
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<tr>
<td>MATH 633</td>
<td>QUEUING SYSTEMS</td>
<td>3</td>
</tr>
<tr>
<td>MATH 651</td>
<td>MATHEMATICS OF FUZZY LOGIC</td>
<td>3</td>
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<tr>
<td>MATH 671</td>
<td>CHAOTIC DYNAMICS AND FRACTAL GEOMETRY</td>
<td>3</td>
</tr>
<tr>
<td>MATH 676</td>
<td>INTRODUCTION TO MATHEMATICAL CONTROL THEORY</td>
<td>3</td>
</tr>
<tr>
<td>MATH 685</td>
<td>SPECIAL TOPICS IN APPLIED MATHEMATICS</td>
<td>3</td>
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</tbody>
</table>

1. Use applied mathematics techniques to model, analyze and solve real world problems.
2. Apply advanced mathematical skills to solve and model problems in areas of science, business, and industry.
3. Integrate the use of technology in their professional practices.
4. Apply and demonstrate research skills, writing skills, thinking skills, and problem solving skills.

### Courses

**MATH 501 HISTORY OF MATHEMATICS (3)**

Development of mathematics emphasizing mathematical concepts and contributions and individuals and societies. Prerequisites: MATH 263 or MATH 265, and MATH 274.

**MATH 527 READINGS IN MATHEMATICS EDUCATION FOR THE ELEMENTARY SCHOOL TEACHER (1-3)**

Directed study for the teacher of elementary school mathematics. Prerequisites: MATH 321 or MATH 323 and approval of instructor.

**MATH 531 PROBABILITY (4)**

Probability in sample spaces, discrete and continuous random variables, distribution theory, Tchebychev's theorem, central limit theorem, expected values and moments. Prerequisite: MATH 274.

**MATH 532 MATHEMATICAL STATISTICS (3)**

Sample theory and distributions, point estimation, confidence intervals, tests of hypothesis, regression, correlation and analysis of variance. Prerequisite: MATH 331 (531).
MATH 533 APPLIED REGRESSION AND TIME SERIES PREDICTIVE MODELING (4)
Simple and multiple regression models, least squares estimates, hypothesis testing, confidence intervals and prediction intervals, model building methods and diagnostic checking. Non-seasonal time series models: autoregressive, moving-average, autoregressive moving-average, and/or autoregressive integrated moving-average models, parameter estimation and forecasting. Minitab or a similar software is used for real data analysis. Prerequisite: MATH 265 or equivalent and MATH 332/ MATH 532 or equivalent.

MATH 535 NUMERICAL ANALYSIS I (3)
Error analysis, interpolation, numerical differentiation and integration, numerical solution of algebraic equations and of systems of algebraic equations. Prerequisites: MATH 265, MATH 274 and COSC 236.

MATH 537 OPERATIONS RESEARCH (3)
Introduction to linear, integer and nonlinear programming; the simplex method and interior point methods, duality and sensitivity analysis: formulation of optimizations models and applications to problems from industry. Prerequisites: MATH 211 or MATH 273 and MATH 265.

MATH 538 LONG-TERM ACTUARIAL MODELS I (3)
Theory and applications of long-term actuarial mathematics in the area of life insurance, annuities and pensions. Topics include survival models, life table, present value random variables for contingent insurance and annuities, future loss random variables, actuarial equivalence principle and other principles for pricing life insurance and annuity contracts, benefit reserves. Prerequisites: MATH 331, MATH 312.

MATH 539 BIOSTATISTICS II (3)
Probability and random variables, estimation and hypothesis testing, nonparametric methods, categorical data analysis, multiple regression, analysis of variance, and design techniques for epidemiological study. Minitab or a similar software will be used for data analysis. Prerequisites: Math 237 Elementary Biostatistics or equivalent and Math 273 Calculus I or equivalent.

MATH 542 SHORT-TERM ACTUARIAL MODELS (4)
Covers part of the syllabus of the Short-Term Actuarial Mathematics exam offered by Society of Actuaries. Topics including severity models, frequency models, aggregate models, risk measures, construction and selection of parametric models, insurance and reinsurance coverages, and pricing and reserving for short-time insurance coverages. Prerequisites: MATH 390 or Exam P, and MATH 332 or equivalent.

MATH 548 ADVANCED ACTUARIAL MODELS (3)
Benefit reserves for traditional life insurances and annuities; multiple state models and multiple life functions, premiums and reserves based on these models; multiple decrement models and probabilities; models for cash flow of basic universal life insurance. Prerequisite: MATH 538.

MATH 551 GRAPH THEORY (3)
Statistical process control including principles of control charts, control charts for attributes and variables and special control charts; methods for quality improvement. Acceptance sampling including single, double, multiple and sequential attribute sampling and acceptance sampling by variable. Prerequisite: One course in elementary statistics.

MATH 557 DIFFERENTIAL GEOMETRY (3)
Curvatures of curves and surfaces in E3, geodesics, invariants, mappings and special surfaces. Prerequisites: MATH 275 Calculus III and MATH 265 Eled. Linear Algebra.

MATH 553 LINEAR ALGEBRA (3)
Vector spaces over arbitrary fields, linear transformations, eigenvalues, eigenvectors, inner products, bilinear forms, direct sum decompositions and the Jordanian form. Prerequisites: MATH 265 and MATH 267.

MATH 555 THEORY OF NUMBERS (3)
Topics include congruences, polynomial congruences, primitive roots, residues, and multiplicative functions. Prerequisite: Math 369.

MATH 556 ALGEBRAIC STRUCTURES (3)
Topics include groups, solvability and insolvability of polynomials, principal ideal, Euclidean, and unique factorization domains. Prerequisite: Math 369.

MATH 557 FOURIER ANALYSIS WITH APPLICATIONS (3)

MATH 575 MATHEMATICAL MODELS (3)
Consideration of some mathematical problems in sociology, psychology, economics, management science and ecology, and developing appropriate mathematical models and techniques to solve them.

MATH 585 MATHEMATICAL FINANCE (3)
Mathematical theory, computation and practical application of derivatives in managing financial risk. Parity and option relationships, binomial option pricing, the Black-Scholes equation and formula, option Greeks, market-making and delta-hedging, exotic options, lognormal distribution, Brownian motion and ITO's lemma, interest rate models. Computer laboratory activities throughout. Prerequisite: MATH 331.

MATH 586 RISK MANAGEMENT AND FINANCIAL ENGINEERING (3)
Mean-variance portfolio theory, asset pricing models, market efficiency and behavioral finance, investment risk and project analysis, capital structures, Cash flow engineering, Monte Carlo methods, statistical analysis of simulated data, risk measures, framework for fixed income engineering, portfolio management, change of measures and Girsanov Theorem and tools for volatility engineering. Computer laboratory activities throughout. Prerequisite: MATH 485 or MATH 585 or equivalent.
MATH 602 CULTURAL AND PHILOSOPHICAL BACKGROUND OF MATHEMATICS (3)
Meanings and origins of mathematical concepts, schools of philosophical thought, cultural and ethnomathematical context of mathematics, philosophy and purpose of mathematics education, current issues in mathematics and mathematics education, role of the mathematics teacher in current debates. Prerequisite: Admission to master’s in Mathematics Education program.

MATH 621 SEMINAR IN TEACHING ELEMENTARY/MIDDLE SCHOOL MATHEMATICS (3)
Analysis of pedagogical methods and materials in elementary and middle school mathematics instruction and assessment. Mathematics topics include, but are not limited to, those taught in grades 1 – 8. Prerequisites: MATH 204, MATH 205, and MATH 251, or their equivalents.

MATH 622 SEMINAR IN TEACHING ADVANCED PLACEMENT CALCULUS (3)
Discussion and analysis of materials, pedagogy, and technology for the teaching of Advanced Placement Calculus in high schools. Prerequisites: Admitted into the MS program in Mathematics Education or the consent of the instructor.

MATH 624 EUCLIDEAN AND NON-EUCLIDEAN GEOMETRY THROUGH AN INQUIRY APPROACH (3)
An exploration and comparison of the geometry of Euclidean and Non-Euclidean surfaces, including spherical geometry. Problem solving, problem posing, and the use of physical and technological models will be integrated throughout. Prerequisite: admission to the Mathematics Education M.S. program.

MATH 625 SEMINAR IN MATHEMATICS EDUCATION FOR SECONDARY SCHOOL TEACHERS (3)
Investigations of recent curricula and research, pedagogy, materials, technology and assessment techniques for middle and high school teachers of mathematics. Prerequisite: MATH 423 or equivalent.

MATH 626 TECHNOLOGY IN SCHOOL MATHEMATICS TEACHING AND LEARNING (3)
History and use of technology in teaching mathematics in grades 6 through 12. Students will use scientific and graphing calculators, computers and other devices such as the Calculator-Based Laboratory (CBL) to solve problems found in secondary mathematics curriculum and apply this knowledge in the teaching of mathematical concepts. Software such as Mathematica, MathCad and Geometer’s Sketchpad will be studied and students will write lessons using one of these software packages. The use of the Internet and other technological resources to teach mathematics will also be studied. Prerequisite: Admission to the graduate program.

MATH 627 CURRICULUM ISSUES IN SECONDARY SCHOOL MATHEMATICS (3)
Analyze secondary school mathematics curriculum development from a historical perspective and discuss past influences on current methodology. Distinguish current curriculum trends and design alternatives. Evaluate contemporary curriculum by assessing an existing text or program. Create a selected mathematics unit. Prerequisite: Math 625.

MATH 628 REAL ANALYSIS FOR TEACHERS (3)
Principles underlying calculus, including topics in real analysis such as completeness for the reals, limits, continuity, differentiation/integration, sequences and series. Emphasis on mathematical theory and the pedagogy of teaching functions. Precalculus and calculus in the secondary school. Prerequisites: Admission to the master’s program in Mathematics Education (or approval of department), MATH 273 and MATH 274 or equivalent.

MATH 629 UNDERSTANDING AND USING MATHEMATICS EDUCATION RESEARCH (3)
Introduction to the theory and methodology of mathematics education research, including quantitative and qualitative designs. Students will gain experience in reading and interpreting mathematics education research, with a specific focus on applying research findings to classroom practice. Prerequisite: admission to the Mathematics Education M.S. program.

MATH 630 STATISTICS-AN INTEGRATED APPROACH (4)
Theory and practices of basic statistical analysis and inference with emphasis on analyzing and solving real problems using statistics. Descriptive statistics, introduction to probability, sampling distributions, estimation, hypotheses testing, regression, correlation, nonparametric techniques and analysis of variance, and computer programming incorporated throughout. Prior knowledge of programming is not necessary. Prerequisite: MATH 274 (not open to students who have completed MATH 332).

MATH 631 TOPICS IN PROBABILITY (3)
Review of basic probability theory, types of convergence and limit theorems, elementary stochastic processes. Markov chains, birth and death processes. Gaussian processes. Examples from engineering, physical and social sciences, management and statistics. Prerequisite: MATH 331.

MATH 632 COMPUTATIONAL STOCHASTIC MODELING (3)

MATH 633 QUEUING SYSTEMS (3)
Characterization and analysis of basic queuing systems, both single-server and multiple-server. The M/G/1 and G/M/m queuing systems. Multiserver with queuing, multiserver queuing rules, priority queues. Networks of queues: response time, routing, flow and congestion control. Manufacturing systems: capacity/inventory investment and scheduling. Prerequisites: MATH 331, MATH 531, or consent of chairperson.

MATH 634 TIME SERIES ANALYSIS AND FORECASTING (3)
An introduction to statistical models for time series analysis and forecasting. Topics include time series decompositions, exponential smoothing, dynamic regression, spectral analysis and filtering. A variety of models will be discussed including the Holt, Holt-Winters, ARMA, ARIMA, SARIMA, and state-space models. Prerequisites: MATH 265 and MATH 332, or MATH 532, or consent of department chair.
MATH 635 APPLIED NUMERICAL ANALYSIS (3)

MATH 636 LINEAR AND NONLINEAR PROGRAMMING (3)
Formulations and model building in linear programming. The simplex method and its variants: duality theory, sensitivity analysis, polynomial time algorithms, multiobjective optimization models and algorithms. Prerequisite: MATH 265, MATH 275 and graduate standing, or consent of chairperson.

MATH 637 ADVANCED TOPICS IN APPLIED OPERATIONS RESEARCH (3)
Dynamic programming, formulation of deterministic decision-process problems, analytic and computational methods of solution, application to problems of equipment replacement, resource allocation, scheduling, search and routing. Brief introduction to decision making under risk and uncertainty. Prerequisites: MATH 275 and MATH 331, or MATH 531, or consent of chairperson.

MATH 638 APPLIED MULTIVARIATE STATISTICAL ANALYSIS (3)
A brief review of vector and matrix algebra and an introduction to applications of multivariate statistical methods. Multivariate normal distribution and its properties, inference for mean vector of a multivariate normal distribution, and simultaneous inference for components of the mean vector. Principle components, factor analysis, and discrimination & classifications. The course introduces many applications of the topics related to real world problems in the fields of engineering, sciences, and business. Minitab or a similar software is used for real data analysis. Prerequisites: MATH 531 or equivalent, MATH 533 or equivalent, MATH 265 or equivalent.

MATH 639 LOSS MODELS (4)
Severity models, frequency models, aggregate models, survival models, construction of parametric models, and credibility models. Prerequisites: MATH 532, or equivalent.

MATH 641 ENTERPRISE RISK MANAGEMENT (3)
Covers part of the syllabus of the Enterprise Risk Management exam offered by Society of Actuaries. Serves as an introduction to Enterprise Risk Management. It will define and categorize different types of risks an entity faces, and define an ERM framework. Ways to measure and quantify the risk, such as (principle based) Economic Capital, Value at Risk (VaR), and stress scenarios will be analyzed and compared. The course will conclude with applications of these methods in a case study of an insurance company and recent regulatory developments. Prerequisite: Pass Exam P or MATH 331 / MATH 531.

MATH 643 COMPUTATIONAL METHODS OF MATHEMATICAL FINANCE (3)
Computation techniques involving tree method, finite difference scheme, Monte Carlo simulation, term structure fitting and modeling, financial derivative pricing, the Greeks of options, Capital Asset Pricing Model, Value-at-Risk calculation. Software package such as Mathematica or Excel will be used. Prerequisites: MATH 585, or equivalent.

MATH 644 MATHEMATICS OF FINANCIAL DERIVATIVES (3)
Modern pricing theory for financial derivatives, stochastic differential equations, Ito formula, martingales, Girsanov Theorem, Feynman-Kac PDE, term structure, Interest-Rate models and derivatives, optimal stopping and American options. Prerequisites: MATH 585, or equivalent.

MATH 650 PATTERNS IN MATHEMATICAL DESIGNS (3)
A geometrical bridge between science and art covering topics such as the systems of proportion in mathematics, art, architecture, and in nature; the golden mean, Fibonacci series, Archimedes and logarithmic spirals, growth and similarity in nature; graphs and maps on the Euclidean plane and on a sphere, on a torus, and map coloring; periodic and non-periodic tilings, duality and the modules of semi regular tilings; polyhedra and platonic solids and their duality and combinatorial and space-filling properties. Prerequisite: Admission to the Master's Program in Mathematics Education or approval of the department.

MATH 651 MATHEMATICS OF FUZZY LOGIC (3)
Basic concepts of fuzzy logic, fuzzy sets, fuzzy uncertainty, fuzzy relations, comparing fuzzy logic with first-order predicate logic, algebra of fuzzy logic, approximate reasoning, rule-based systems. Description of linguistic data using fuzzy sets. Applications: rule-based expert systems, decision making, pattern recognition, control theory, optimization. Prerequisite: Graduate standing or consent of chairperson.

MATH 653 TOPICS IN GEOMETRY (3)
Axiomatic development of Euclidean, elliptic and hyperbolic geometries; the study of the analytic plane, the sphere and the Poincare model as models for these axiomatic systems. Not open to students who have had MATH 353. Prerequisites: MATH 274 and MATH 467 (or MATH 568).

MATH 667 ALGEBRA OF SYMMETRIES (3)
Complex integers, permutation groups, properties of abstract groups of plane transformations and matrix representations of transformations. Culminates in developing the 17 groups of symmetries of the Euclidean plane. No credit toward the master's in Applied and Industrial Mathematics. Prerequisite: Admission to the Master of Science in Mathematics Education Program or approval of the department.

MATH 671 CHAOTIC DYNAMICS AND FRACTAL GEOMETRY (3)
Introduction to the classical theory of linear systems and the modern theory of nonlinear and chaotic systems. Modeling of discrete and continuous time systems. Bifurcation theory, symbolic dynamics, fractals and complex dynamics, Julia sets and the Mandelbrot set. Mathematica or an equivalent software package will be used. Prerequisites: MATH 265 and MATH 275, and graduate standing or consent of chairperson.

MATH 673 INTEGRAL TRANSFORMS AND APPLICATIONS (3)
Integral transforms and their applications: Fourier, Laplace, Hankel, Mellin, and z-transforms and their applications for solving ordinary differential equations, partial differential equations, integral equations, and difference equations arising from physics, engineering and sciences. Prerequisites: MATH 374, (or MATH 574) and MATH 379 (or MATH 579); and MATH 475 (or MATH 577); or consent of chairperson.

MATH 674 APPLIED PARTIAL DIFFERENTIAL EQUATIONS (3)
Discussions of the typical partial differential equations of applied mathematical physics: Heat equations. Wave equations, Beam equations, Laplace equations. Separation of variables, variation of parameters and Fourier transform for initial and boundary value problems, Calculus of variation and Ritz-Galerkin's numerical method. Prerequisite: MATH 374 (or MATH 574), MATH 379 (or MATH 579), or consent of chairperson.

MATH 675 ASYMPTOTIC AND PERTURBATION ANALYSIS (3)
Asymptotic series and asymptotic methods for approximating solutions to linear and nonlinear ordinary differential equations. Asymptotic expansion of integrals; Watson's Lemma. Perturbation series; regular and singular perturbation theory. Boundary layer theory for ordinary differential equations. Prerequisites: MATH 374/ MATH 574 or equivalent and MATH 475/ MATH 577 or equivalent.
MATH 676 INTRODUCTION TO MATHEMATICAL CONTROL THEORY (3)
Problems and specific models of mathematical control theory.
Elements of classical control theory: controllability, observability, stability, stabilizability and realization theory for linear and nonlinear systems. Optimal control Maximum Principle and the existence of optimal strategies. Prerequisites: MATH 265 and MATH 374/MATH 574.

MATH 677 ADVANCED MATHEMATICAL MODELING (3)
Development of appropriate stochastic as well as deterministic models to solve applied mathematical problems in the fields of physics, engineering, and the social sciences. Topics include optimization models, dynamic models, probability models and Monte Carlo simulation. Mathematica or a similar software package will be used. Prerequisites: MATH 331 or MATH 531, and MATH 379 or MATH 579, or consent of chairperson.

MATH 680 SPECIAL TOPICS IN MATHEMATICS EDUCATION (3)
Topics will be chosen focusing on pedagogy, educational theories, curriculum, research, policy, or other issues of mathematics education. Content will be determined to complement graduate course offerings in mathematics education. May be repeated for a total of 9 units provided a different topic is taken each time. Prerequisite: program admission.

MATH 681 SPECIAL TOPICS IN MATHEMATICS FOR TEACHERS (3)
Topics will be chosen from a mathematical field related to, or extending, the K-12 school mathematics curriculum. Content will be determined to complement graduate course offerings in mathematics education. May be repeated for a total of 9 units provided a different topic is taken each time. Prerequisite: program admission.

MATH 684 SPECIAL TOPICS IN MATHEMATICS AND STATISTICS (3)
Topics will be chosen in mathematics or statistics. Course content will be determined so as to complement course offerings in mathematics and statistics. Course may be repeated for a maximum of 8 units. Prerequisite: will vary depending on topic.

MATH 685 SPECIAL TOPICS IN APPLIED MATHEMATICS (3)
Topics will be chosen in a mathematical field not directly related to differential equations/optimization or applied statistics/mathematical finance. Course content will be determined to complement the existing course offerings. Prerequisite: will vary depending on topic.

MATH 686 SPECIAL TOPICS IN DIFFERENTIAL EQUATIONS OR OPTIMIZATION (3)
Topics will be chosen in a mathematical field related to differential equations or optimization. Course content will be determined to complement the existing course offerings in the differential equations/optimization track. Prerequisite: will vary depending on topic.

MATH 687 SPECIAL TOPICS IN APPLIED STATISTICS OR MATHEMATICAL FINANCE (3)
Topics will be chosen in a mathematical field related to statistics or mathematical finance. Course content will be determined to complement the existing course offerings in the applied statistics/mathematical finance track. Prerequisite: will vary depending on topic.

MATH 695 INDEPENDENT STUDY IN MATHEMATICS (1-3)
Directed independent study in selected areas of graduate level mathematics. Prerequisite: Permission of instructor and graduate adviser.

MATH 791 MASTERS INTERNSHIP I (3)
An original investigation of a problem to be pursued in cooperation with a local industry or business under the direction of an industry supervisor and a member of the mathematics faculty. Prerequisites: Completion of at least 15 units toward the M.S. degree in Applied and Industrial Mathematics and consent of chairperson.

MATH 792 MASTER'S INTERNSHIP II (3)
An original investigation of a problem to be pursued in cooperation with a local industry or business under the direction of an industry supervisor and a member of the mathematics faculty. Prerequisites: Completion of at least 15 units toward the M.S. degree in Applied and Industrial Mathematics and consent of chairperson.

MATH 880 APPLIED MATHEMATICS GRADUATE PROJECT I (3)
An internal applied mathematics graduate project based on mutual research interests of a graduate student in the APIM program and a faculty advisor will be investigated. The advisor will guide the student throughout different phases of solving the applied mathematics problem. Prerequisites: permit required, APIM graduate students only.

MATH 881 APPLIED MATHEMATICS GRADUATE PROJECT II (3)
An internal applied mathematics graduate project based on mutual research interests of a graduate student in the APIM program and a faculty advisor will be investigated. The advisor will guide the student throughout different phases of solving the applied mathematics problem. Permit required, only APIM graduate students.

MATH 885 APPLIED MATHEMATICS GRADUATE PROJECT CONTINUUM (1)
Students who cannot complete Math 880-881 in two semesters will then register for Math 885, one unit, in the next semester. Except in special circumstances, Math 885 cannot be repeated. Prerequisites: Consent of the instructor.