Department of Computational Modeling and Simulation Engineering

Web Site: http://www.odu.edu/cmsv
1300 Engineering and Computational Sciences Building
757-683-3720
Yuzhong Shen, Chair
Yuzhong Shen, Graduate Program Director

Department Description
The CMSE Department offers an undergraduate four-year degree program leading to the Bachelor of Science in Modeling and Simulation Engineering (BS-M&SE). The department also offers programs of graduate study leading to the degrees Master of Engineering, Master of Science, Doctor of Engineering, and Doctor of Philosophy with a major in Modeling and Simulation. The department's academic programs are coupled with a strong department research program conducted jointly with researchers from the Virginia Modeling, Analysis and Simulation Center (VMASC). Research activities range from investigation of fundamental modeling and simulation methods and technologies to applications of modeling and simulation in the domains of medicine and health care, transportation, education and gaming, science and engineering, homeland security and defense, and business enterprise decision support.

Special Facilities:
The CMSE Department is located on the first floor of the E. V. Williams Engineering and Computational Sciences Building on the Old Dominion University Norfolk Campus. In addition to the department and faculty offices, this facility also houses several instructional and research laboratories, a virtual reality theater, and a four-walled C.A.V.E. (Cave Automatic Virtual Environment).

Undergraduate Projects and Research Laboratory
The Undergraduate Projects and Research Laboratory, is mainly used for facilitating modeling and simulation projects-based instruction in both lower and upper division undergraduate levels. This also involves courses in the major with a significant laboratory component. The Laboratory can accommodate 24 students with laptop computers and provide 5 workstations for undergraduate labs and research. Each workstation contains a high performance computer and collaboration spaces. The lab also contains a Polycom Teleconference system to support distance learning. The lab is equipped with 3 digital projectors to support teaching.

Medical Simulations Laboratory
The Medical Simulations Laboratory is mainly used to support teaching and research activities related to medical simulations for planning, training, education, analysis and visualization. It contains 15 high performance PC workstations, 4 haptic devices, three 3D scanners, two 3D printers, 4 reach-in displays, 3 LCD TVs, 6 Oculus Rift headsets, 2 HTC Vive headsets, and 2 Microsoft Hololens. The laboratory is also equipped with a large selection of software such as Autodesk Maya, Google SketchUp, Microsoft XNA Game Studio, Unity Game Engine, and ArcGIS.

Applied M&S Research Laboratory
The Applied M&S Research Laboratory is the third laboratory area. This graduate research laboratory contains PC workstations and spaces for 10 graduate students and also supports faculty/VMASC collaborative research activities. Several research topics are conducted in this laboratory including high performance computing, cyber security, simulation architectures, transportation systems, military M&S, digital manufacturing, and enterprise decision support. Visualization of these is also a significant part of these areas.

Collaborative Autonomous Systems Laboratory
The Collaborative Autonomous Systems Laboratory supports instructional and multidisciplinary research activities related to autonomous systems. This forth laboratory area is shared with the mechanical and aerospace department. CMSE maintains 4 PC workstations and 10 various types of robotic systems. The lab contains an area dedicated to cyber security research as related to collaborative autonomous systems.

The CAVE (CAVE Automated Virtual Environment)
The CAVE (Cave Automated Virtual Environment) Virtual Reality laboratory area contains several 3D visualization systems. The CAVE is a high-resolution projection-screen virtual reality system. The screens are arranged in a 10 foot cube with computer-generated images projected on three walls and a floor. The CAVE lab also contains a 3 meter Vision Dome projection system and an Immersa-Desk virtual reality display. Two 3D printers are also placed in the CAVE Lab.

Associated Centers:
A significant resource to the department is the Virginia Modeling, Analysis and Simulation Center located adjacent to the University's Tri-Cities Higher Education Center in Suffolk, Virginia. VMASC occupies a two-story, 60,000 square foot building designed to support state-of-the-art research in modeling, simulation and visualization. Some of the center's facilities are used in the department's educational programs; in addition, VMASC researchers teach courses and mentor students in the department's academic programs.

List of Degrees and Certificates
- Master of Science, Engineering - Modeling and Simulation
- Doctor of Engineering - Modeling and Simulation
- Doctor of Philosophy, Engineering - Modeling and Simulation
- Graduate Certificate in Modeling and Simulation Engineering
- Advanced Engineering Certificate in Cyber Systems Security

Master of Science, Engineering - Modeling and Simulation
The master's degree in modeling and simulation (M&S) emphasizes a strong, common subject core while providing the student with the flexibility to design a plan of study to meet each individual's study objectives and needs. The purpose of the program's subject core is to provide a common academic foundation for all simulation students. Thus, all students in this program will have grounding in the same methods, principles, and philosophy of simulation. This provides the mechanisms for the simulationist to work across disciplines and domains while maintaining a common frame of reference for communication, technical specialization, and advanced study and research. The Master of Science (MS) in Modeling and Simulation offers two options: Thesis Option and Course Option. The Thesis Option requires six hours of thesis credit and 24 hours of course credit and it is directed primarily at full-time students who are preparing for a career in advanced M&S research and/or academic positions. The Course Option requires 30 hours of course credit and it is focused on developing the practical skills and knowledge needed to solve problems requiring applications of modeling and simulation. The Course Option is further divided into two tracks: Development Track and Application Track. The Development Track is programming intensive and prepares students for advanced simulation development, while the Application Track focuses on the usage of existing simulation tools.

The program's subject core consists of:
1. an overview of modeling and simulation;
2. an in-depth exploration of specific simulation methodological approaches;
3. simulation system modeling principles and techniques;
4. an introduction to computer visualization and visual simulation; and,
5. principles of stochastic analysis.

Most courses are offered in distance learning format. They are delivered to Old Dominion University's higher education centers and are available synchronously using video teleconferencing software.

**Master of Science Admission Requirements**

The Master’s Degree in Modeling and Simulation is designed for students having bachelor’s degrees in Engineering, Science or Mathematics, although students from other educational backgrounds may apply with appropriate leveling courses. Prerequisites for admission include: mathematics – two courses in differential and integral calculus and one course in calculus-based probability and statistics; and computer science – algorithmic problem solving using a high-level object-oriented programming language such as C++.

A minimum GPA of 2.80 overall and a minimum GPA of 3.0 in the undergraduate major are required. Students with notable deficiencies may be considered for provisional admission and will be required to complete prerequisite course requirements in addition to the graduate degree requirements. Job experience and training may be considered in evaluating prerequisite requirements.

Applicants should plan to submit a completed application form, transcripts from all colleges and universities attended, GRE scores (verbal, quantitative, and analytical writing - required of MS applicants for the thesis option only), a resume and personal statement of objectives, two letters of recommendation from former university instructors or current employer (recommendation letters are required of MS applicants for the thesis option only), and TOEFL scores if an international applicant.

Potential prerequisite courses for the master’s degrees in modeling and simulation include the following:

1. Introductory differential and integral calculus equivalent to MATH 211 (Calculus I) and MATH 212 (Calculus II).
2. Calculus-based probability and statistics; this material is available for graduate credit in PSYC 727. Undergraduate courses STAT 330 or ENMA 420 will also meet the prerequisite requirement.
3. Computer science fundamentals including an object-oriented programming language such as C++, algorithmic problem solving, and data structures.

**Master of Science Degree Requirements**

The Master of Science program requires 12 hours of course credit in modeling and simulation foundation courses. These foundation courses include:

- MSIM 741 Principles of Visualization 3
- MSIM 551 Analysis for Modeling and Simulation 3
- or MSIM 751 Advanced Analysis for Modeling and Simulation

Advanced Modeling Course (see list below) 3

Advanced Simulation Course (see list below) 3

**Advanced Modeling Course Examples (3 credits)**

- MSIM 607 Machine Learning I
- MSIM 660 System Architecture and Modeling
- MSIM 702 Systemic Decision Making
- MSIM 730 Simulation Formalisms
- MSIM 772 Modeling Global Events
- MSIM 774 Transportation Network Flow Models

Other courses with graduate program director's approval.

**Advanced Simulation Course Examples (3 credits)**

- MSIM 711 Finite Element Analysis
- MSIM 722 Cluster Parallel Computing

The remaining course credits (12 credits for the thesis option and 18 credits for the course option) are elective course credits. These courses are selected to achieve one or more program objectives or themes and must be approved by the student’s advisor and/or graduate program director. Elective courses outside the CMSE Department must be approved by the graduate program director. The thesis option concludes with 6 credit hours of thesis credit (MSIM 699) and a thesis defense and the course option concludes with a comprehensive exam. Students must also complete the Responsible Conduct of Research for Engineers training online.

Certain students will need to take pre-requisite leveling courses that will count towards the 12 credit hour elective course requirement. These courses are: MSIM 510 Model Engineering; MSIM 541 Computer Graphics and Visualization; MSIM 602 Simulation Fundamentals; and, MSIM 603 Simulation Design. The Course Option Application Track only requires MSIM 510 Model Engineering and MSIM 602 Simulation Fundamentals as leveling courses.

The MS Course Option is also offered online via the Blackboard Academic Suite and WebEx that provides online lectures, homework submissions, examinations, discussion boards, wikis, video/audio collaboration sessions and grading. Students having access to reliable high speed internet service can connect and participate in engaging discussion and distributed asynchronous learning with the instructor and other students. All course materials are distributed and collected electronically. Students located in the Hampton Roads region may utilize live courses to fulfill the elective course requirement with approval from the CMSE graduate program director.

**Doctor of Engineering - Modeling and Simulation**

The D. Eng. in Modeling and Simulation program focuses on developing the advanced skills and knowledge to enable the graduate to conduct and lead advanced technical M&S projects in an engineering environment. It affords engineering practitioners the opportunity to achieve advanced graduate education beyond the master’s degree.

For complete information on admission requirements and core degree requirements, please refer to the Doctor of Engineering program information at: http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/#doctorofengineeringprogram

The program of study for the D.Eng. in M&S program is developed with the approval of the graduate program director and the student’s advisor. The program shall include a minimum of 18 credits of professional course work (http://catalog.odu.edu/graduate/frankbattencollegeofengineeringandtechnology/#doctorofengineeringprogram). The course ENGN 812 Engineering Leadership is cross-listed with the course ENMA 880 Leadership for Engineering Managers and ENGN 612 Analysis of Organizational Systems is cross-listed with ENMA 601 Analysis of Organizational Systems. Other professional courses can be substituted by other courses approved by the Graduate Program Director if these professional courses are not available.

The D.Eng. also requires 18 credits of technical core course work beyond the master’s degree distributed as follows:

**Technical Core Courses**

- Advanced Simulation Course from the list below
- MSIM 830 Simulation Formalisms
- MSIM 842 Synthetic Environments

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Department of Computational Modeling and Simulation Engineering
Applicants are expected to have the following foundation knowledge:

2. Computer science fundaments including an object-oriented programming language such as C++, algorithmic problem solving, and data structures.

Other courses with graduate program director's approval.

No more than three credits from course work satisfying foundation knowledge requirements may be included in the program of study for technical elective credit. At least three-fifths of the non-project coursework must be at the 800-level.

Certain students entering the program will be required to complete additional pre-requisite leveling courses. These courses are: MSIM 510 Model Engineering; MSIM 541 Computer Graphics and Visualization; MSIM 602 Simulation Fundamentals; and MSIM 603 Simulation Design.

For graduation, students must complete the requirements for their final project and the Responsible Conduct of Research for Engineers training online.

**Doctor of Philosophy, Engineering - Modeling and Simulation**

The Ph.D. in Modeling and Simulation program focuses on developing the necessary skills and knowledge to enable the graduate to conduct and evaluate independent, original research in an area of modeling and simulation. The goal of the program is to prepare students for careers in teaching and research at academic institutions, as well as the conduct of leadership of research and development in public and private organizations.

**Doctor of Philosophy Admission Requirements**

Admission to the Ph.D. in M&S program is made in accordance with Old Dominion University and Batten College of Engineering and Technology requirements for doctoral programs as specified in this Catalog. Specific requirements for the modeling and simulation degree include the following:

1. Completion of a master’s degree in an appropriate and closely related field is expected. However, students who have completed 24 credits of graduate courses in an appropriate field from an accredited institution may apply.
2. A minimum GPA in graduate course work of 3.50 (out of 4.0) is required of most students. A student with a GPA greater than 3.25 and with evidence of a high level of professional capability in the field of modeling and simulation may be eligible for admission to the program upon submission of a petition to the graduate program director.
3. Recent scores (typically, not more than five years old) on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.
4. Three letters of recommendation (typically at least two of which are from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are required.
5. The applicant must submit a statement of purpose, goals, and objectives related to the program and a resume.

Applicants are expected to have the following foundation knowledge:

2. Computer science fundamentals including an object-oriented programming language such as C++, algorithmic problem solving, and data structures.

3. Knowledge of the content of the foundation courses required in the Modeling and Simulation Master’s Program.

**Doctor of Philosophy Degree Requirements**

The Ph.D. in modeling and simulation is offered in accordance with the general requirements for doctoral degrees as specified in the Requirements for Graduate Degrees Section of this Catalog. Specific program of study requirements for the concentration in modeling and simulation include the following:

1. Completion of a minimum of 24 credits of course work beyond the master’s degree; and a minimum of 24 credits of dissertation research.
2. Successful completion of a written diagnostic examination before completion of nine credits of advanced course work.
3. Successful completion of a written and oral qualifying (candidacy) examination near the completion of the course work.
4. Successful presentation of a dissertation research proposal at the beginning of the dissertation research.
5. The successful completion and public defense of a dissertation representing independent, original research worthy of publication in a peer-reviewed scholarly journal.

The program of study for the Ph.D. in M&S program is developed with the approval of the graduate program director and the student’s advisor. The program shall include a minimum of 24 credit hours of course work beyond the master’s degree distributed as follows.

**Common Core**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSIM 510</td>
<td>Model Engineering</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 541</td>
<td>Computer Graphics and Visualization</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 602</td>
<td>Simulation Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 603</td>
<td>Simulation Design</td>
<td>3</td>
</tr>
<tr>
<td>Total Hours</td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

**Electives** - Minimum of 12 credits of elective courses that provide a basis for dissertation research. No more than six credits from course work satisfying foundation knowledge requirements may be included in the program of study for elective credit. At least three-fifths (15 credits) of non-dissertation course work must be at the 800-level. Elective courses outside the MSVE Department must be approved by the graduate program director.

Certain students entering the program will be required to complete additional pre-requisite leveling courses. These courses are: MSIM 510 Model Engineering; MSIM 541 Computer Graphics and Visualization; MSIM 602 Simulation Fundamentals; and MSIM 603 Simulation Design.

For graduation, students must successfully defend their dissertation and complete the Responsible Conduct of Research for Engineers training online.

**Graduate Certificate in Modeling and Simulation Engineering**

The Graduate Certificate in Modeling and Simulation Engineering is designed for those who meet the admission requirements of the modeling and simulation master's program and wish to broaden their knowledge of modeling and simulation related principles and practices without pursuing a graduate degree. This is a 12 credit hour non-degree program offered by the Department of Computational Modeling & Simulation Engineering. The
certificate program is open to both degree-seeking and non-degree-seeking graduate students. Certain courses taken for the certificate program may later be applied to the master’s degree in modeling and simulation.

Graduate Certificate Admission Requirements
Students should have either an undergraduate degree from a regionally accredited institution and should have a mathematical background through calculus, along with a calculus based probability and statistics course. Students should submit a graduate non-degree application through the Office of Admissions, and then submit a departmental application with copies of unofficial transcripts from all previous coursework to the CMSE Department. Departmental applications are available online on the CMSE Department’s website – https://www.odu.edu/cmse (https://www.odu.edu/cmse/) - and should be sent to:

Academic Advisor and Program Manager
CMSE Department
Old Dominion University
1300 Engineering and Computational Sciences Building
Norfolk, VA 23529

Graduate Certificate Course Requirements
The Graduate Certificate in Modeling and Simulation Engineering requires the completion of 12 credit hours at the graduate level. The course requirements are:

Select three courses from the following:  

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSIM 601</td>
<td>Introduction to Modeling and Simulation</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 602</td>
<td>Simulation Fundamentals</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 510</td>
<td>Model Engineering</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 603</td>
<td>Simulation Design</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 541</td>
<td>Computer Graphics and Visualization</td>
<td>3</td>
</tr>
<tr>
<td>MSIM 551</td>
<td>Analysis for Modeling and Simulation</td>
<td>3</td>
</tr>
</tbody>
</table>

MSIM Elective *  

* A graduate level elective approved by the Graduate Program Director. This elective may be an MSIM course or from another discipline outside of modeling and simulation. It is possible that this course may be outside of the discipline of modeling and simulation, but approved because it complements the field of modeling and simulation and the student's interests.

An overall GPA of 3.0 or better is required to earn the graduate certificate in modeling and simulation engineering.

Advanced Engineering Certificate in Cyber Systems Security
The certificate program aims to provide a thorough understanding the cyber security threats faced by the stand-alone computer systems, networked systems, IT infrastructure, and cyber physical systems having embedded computer systems operated by individuals, small businesses and large enterprises along with the knowledge required to defend against these threats. The course will enable participants to learn state of the art techniques necessary for analyzing cyber security risks, preventing, detecting and recovering from cyber attacks through class room instructions and hands-on lab work. The program uniquely accommodates students from engineering, math and sciences as well as practicing engineers and managers. The course will make use of ODU’s multidisciplinary strengths in the fields of Cyber Systems, Computer Engineering, Software Engineering and Modeling and Simulation. This program is designed both as a complement for students working on graduate degrees and for those personnel working on information and cyber systems used in industry, small businesses, healthcare, government, military and home land security. It is anticipated that students will complete the program in 2 semesters (full time enrollment) or 2 years (part-time enrollment or working to complement an existing graduate program).

Certificate Program Admission Requirements
All applicants admitted to the certificate program must have earned a baccalaureate degree in engineering, mathematics, science, or a related STEM field from a regionally-accredited institution or an equivalent degree from a foreign institution. Those whose native language is not English must submit a minimum score of 230 on the computer-based TOEFL or 80 on the TOEFL iBT.

Certificate Program Curriculum Requirements
The Graduate Certificate in Cyber Security requires completion of 12 credit hours of graduate coursework, consisting of two core courses and two elective courses from the course list below.

Required Core Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSIM 570</td>
<td>Foundations of Cyber Security</td>
<td>3</td>
</tr>
<tr>
<td>MSIM/ENMA 670</td>
<td>Cyber Systems Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

Electives (Select two of the following):

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 516</td>
<td>Cyber Defense Fundamentals</td>
<td></td>
</tr>
<tr>
<td>ECE 519</td>
<td>Cyber Physical System Security</td>
<td></td>
</tr>
<tr>
<td>MSIM 673</td>
<td>Threat Modeling and Risk Analysis</td>
<td></td>
</tr>
<tr>
<td>MSIM 773</td>
<td>Networked System Security</td>
<td></td>
</tr>
</tbody>
</table>

Total Hours 12

MODELING AND SIMULATION Courses

MSIM 506. Introduction to Distributed Simulation. 3 Credits.

An introduction to distributed simulation. Topics include motivation for using distributed simulation, distributed simulation architectures, time management issues, and distributed simulation approaches. Current standards for distributed simulation are presented.

MSIM 508. Introduction to Game Development. 3 Credits.

Requires an understanding of physics and either CS 361 or MSIM 331.

An introductory course focused on game development theory and modern practices with emphasis on educational game development. Topics include game architecture, computer graphics theory, user interaction, audio, high level shading language, animation, physics, and artificial intelligence. The developed games can run on a variety of computer, mobile, and gaming platforms.

MSIM 510. Model Engineering. 3 Credits.

The goal of this course is to develop understanding of the various modeling paradigms appropriate for capturing system behavior and conducting digital computer simulation of many types of systems. The techniques and concepts discussed typically include UML, concept graphs, Bayesian nets, Markov models, Petri nets, system dynamics, Bond graphs, etc. Students will report on a particular technique and team to implement a chosen system model. (cross-listed with ECE 510).

MSIM 511. Networked System Security. 3 Credits.

Course presents an overview of theory, techniques and protocols that are used to ensure that networks are able to defend themselves and the end-systems that use networks for data and information communication. Course will also discuss industry-standard network security protocols at application, socket, transport, network, VPN, and link layers, popular network security tools, security, performance modeling and quantification and network penetration testing. Discussion will be based on development of system level models and simulations of networked systems. Cross-listed with ECE 511.

MSIM 516. Cyber Defense Fundamentals. 3 Credits.

This course focuses on cybersecurity theory, information protection and assurance, and computer systems and networks security. The objectives are to understand the basic security models and concepts, learn fundamental knowledge and tools for building, analyzing, and attacking modern security systems, and gain hands-on experience in cryptographic algorithms, security fundamental principles, and Internet security protocol and standards. Cross-listed with ECE 516.
MSIM 510. Cyber Physical Systems Security. 3 Credits.
Cyber Physical Systems (CPS) integrate computing, networking, and physical processes. The objectives of this course are to learn the basic concepts, technologies and applications of CPS, understand the fundamental security challenges and national security impact, and gain hands-on experience in CPS infrastructures, critical vulnerabilities, and practical countermeasures. Cross-listed with ECE 519.

MSIM 520. Introduction to Artificial Intelligence. 3 Credits.
Introduction to concepts, principles, challenges, and research in major areas of artificial intelligence. Areas of discussion include: natural language and vision processing, machine learning, machine logic and reasoning, robotics, expert and mundane systems. Laboratory work required. Prerequisite: Instructor approval.

MSIM 540. Game Physics Modeling and Simulation. 3 Credits.
This introductory class will provide the student with a basic understanding of the mathematical foundations and algorithmic concepts needed to become competent at implementing game physics engines. We will emphasize the mathematical foundations that apply to many areas of simulation, which subsumes the mathematics of game physics, such as linear algebra emphasizing vectors and matrices, as well as introductory vector calculus. This class will also exploit open-source C++ software implemented by the author of the textbook. Prerequisites: CS 250.

MSIM 541. Computer Graphics and Visualization. 3 Credits.
The course provides a practical treatment of computer graphics and visualization with emphasis on modeling and simulation applications. It covers computer graphics fundamentals, visualization principles, and software architecture for visualization in modeling and simulation. Pre- or corequisites: CS 250 and MSIM 603.

MSIM 551. Analysis for Modeling and Simulation. 3 Credits.
An introduction to analysis techniques appropriate to the conduct of modeling and simulation studies. Topics include input modeling, random number generation, output analysis, variance reduction techniques, and experimental design. In addition, techniques for verification & validation are introduced. Course concepts are applied to real systems and data. Prerequisites: STAT 330.

MSIM 562. Introduction to Medical Image Analysis. 3 Credits.
Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Cross-listed with ECE 462/ECE 562.

MSIM 563. Design and Modeling of Autonomous Robotic Systems. 3 Credits.
Course focuses on autonomous robotics systems with emphasis on using modeling and simulation (M&S) for system level design and testing. Fundamental concepts and algorithms associated with autonomous robotic systems are discussed. Course topics include: robotic control, architectures, and sensors as well as more advanced concepts such as error propagation, localization, mapping and autonomy. Strategies that leverage M&S to accelerate the development and testing of sophisticated autonomous robotic algorithms for individual or teams of robots are covered. Pre- or corequisite: CS 150.

MSIM 570. Foundations of Cyber Security. 3 Credits.
Course provides an overview of theory, tools and practice of cyber security and information assurance through prevention, detection and modeling of cyber attacks and recovery from such attacks. Techniques for security modeling, attack modeling, risk analysis and cost-benefit analysis are described to manage the security of cyber systems. Fundamental principles of cyber security and their applications for protecting software and information assets of individual computers and large networked systems are explored. Anatomy of some sample attacks designed to compromise confidentiality, integrity and availability of cyber systems are discussed. Pre- or corequisites: MSIM 510 or permission of the instructor.

MSIM 574. Transportation Data Analytics. 3 Credits.
This course presents the basic techniques for transportation data analytics. It will discuss statistical modeling, prominent algorithms, and visualization approaches to analyze both small- and large-scale data sets generated from transportation systems. Practices of using different data for various real-world traffic/transportation applications and decision making will also be discussed. Prerequisites: Basic probability and statistics (e.g., STAT 330); any programming language such as C, Python or Java is beneficial but not required.

MSIM 580. System Architecture and Modeling. 3 Credits.
Students will learn the essential aspects of the system architecture paradigm through environment and analysis of multiple architecture frameworks and enterprise engineering, such as IDEFO, TOGAF, DODAF and OPM. Emphasis on system modeling and enterprise engineering. (Cross listed with ENMA 660).

MSIM 601. Introduction to Modeling and Simulation. 3 Credits.
An introduction to the modeling and simulation discipline. Introduction to discrete event simulation (DES) including simulation methodology, input data modeling, output data analysis, and an overview of DES tools. Introduction to continuous simulation (CS) including simulation methodology, differential equation models, numerical solution techniques, and an overview of CS tools. Prerequisites: graduate standing; undergraduate preparation in calculus and probability & statistics; and computer literacy.

MSIM 687. Cooperative Education. 1-3 Credits.
Available for pass/fail grading only. Student participation for credit based on academic relevance of the work experience, criteria, and evaluation procedures as formally determined by the program and the Cooperative Education/Career Development Services program prior to the semester in which the work experience is to take place.
MSIM 668. Internship. 1-3 Credits.
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career-related experience. Prerequisites: Approval by department and Career Development Services.

MSIM 669. Practicum. 1-3 Credits.
Academic requirements will be established by the graduate program director and will vary with the amount of credit desired. Allows students an opportunity to gain short-duration career related experience. Student is usually employed--this is an additional project beyond the duties of the student’s employment.

MSIM 670. Cyber Systems Engineering. 3 Credits.
This course provides an overview of functioning of cyber systems including how a computer interacts with the outside world. The composition of critical infrastructure and functioning of different engineered systems that form critical infrastructure are discussed. Mutual dependence and interactions between cyber systems and other engineered systems and the resulting security risks are also explored. (Cross-listed with ENMA 670.)

MSIM 673. Threat Modeling and Risk Analysis. 3 Credits.
This course discusses how to develop cyber threat models using attack graphs/trees, STRIDE, Universal Modeling Language (UML), attack graphs/trees and common of risk analysis tools. Course also discusses the need for quantitative security analysis and formal validation of security models and basic principles of formal model validation. (Cross-listed with ENMA 673.)

MSIM 695. Topics in Modeling and Simulation. 3 Credits.
Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 697. Independent Study in Modeling and Simulation. 3 Credits.
Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of instructor or graduate program director.

MSIM 699. Thesis. 1-6 Credits.
Research leading to the Master of Science thesis. Prerequisites: permission of instructor and graduate program director.

MSIM 702. Systemic Decision Making. 3 Credits.
As machine age problems have given way to systems age messes, the underlying complexity associated with understanding these situations has increased exponentially. Accordingly, the methods we use to address these situations must evolve as well. This course will introduce students to a method for thinking holistically about problems and messes conceptually founded in systems theory. This paradigm, known as systemic thinking, will be contrasted with traditional systematic thinking, and practical guidelines for the deployment of a systemic thinking approach will be provided. This paradigm will increase the student's ability to make rational decisions in complex environments. (Cross-listed with ENMA 702/ENMA 802.)

MSIM 703. Optimization Methods. 3 Credits.
Covers advanced methods in Operations Research and Optimization. Focus will be on developing models and their applications in different domains including manufacturing and service. Modern optimization tools will be used to implement models for case studies, projects and research papers. The knowledge of programming and spreadsheets is expected. Contact instructor for more details. (Cross-listed with ENMA 703.)

MSIM 711. Finite Element Analysis. 3 Credits.
The purpose of the course is to provide an understanding of the finite element method (FEM) as derived from an integral formulation perspective. The course will demonstrate the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. Prerequisites: permission of the instructor.

MSIM 715. High Performance Computing and Simulations. 3 Credits.
Introduction to modern high performance computing platforms including top supercomputers and accelerators. Discussion of parallel architectures, performance, programming models, and software development issues. Case studies of scientific and engineering simulations will be explored. Students will have an opportunity to work on parallelization of problems from their research areas. Project presentations are required.

MSIM 722. Cluster Parallel Computing. 3 Credits.
This course provides detailed numerical step-by-step procedures to exploit parallel and sparse computation under MPI (Message Passing Interface) computer environments. Large-scale engineering/science applications are emphasized. Simultaneous linear equations are discussed.

MSIM 725. Principles of Combat Modeling and Simulation. 3 Credits.

MSIM 730. Simulation Formalisms. 3 Credits.
The focus of the course is on identification and investigation of mathematical and logical structures that form the foundation for computational simulation. Topics include: foundations of simulation theory in logic, discrete mathematics, and computability; simulation formalisms, including DEVS; interoperability protocols; and computational complexity.

MSIM 741. Principles of Visualization. 3 Credits.
Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

MSIM 742. Synthetic Environments. 3 Credits.
The course covers the theory and techniques for building effective and efficient synthetic environments for modeling and simulation applications. Topics include physics, artificial intelligence, virtual reality, and advanced modeling and rendering. The emphasis is on producing visually realistic synthetic environments based on effective approximations of physics and other related principles. Prerequisites: MSIM 541 or equivalent.

MSIM 751. Advanced Analysis for Modeling and Simulation. 3 Credits.
An introduction to stochastic dependence and Bayesian analysis techniques for conducting modeling and simulation studies. Topics include: measures of dependence, common multivariate distributions, sampling from multivariate distributions, elementary time series models and Bayesian statistics. Prerequisites: MSIM 451 or MSIM 551.

MSIM 762. Applied Medical Image Analysis. 3 Credits.
Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MRI/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

MSIM 772. Modeling Global Events. 3 Credits.
Modeling Global Events introduces modeling and simulation as a tool for expanding our understanding of events that have shaped the global environment of the 21st century. Students will review real-world case studies and then analyze these case studies via system dynamics, agent-based, social network, and game theory modeling paradigms. This course is designed to develop empirical research skills, conceptual modeling expertise, and model construction. Students will understand how to analyze, verify, and validate a model.
MSIM 773. Networked System Security. 3 Credits.
Course presents an overview of theory, techniques and protocols that are used to ensure that networks are able to defend themselves and the end-systems that use networks for data and information communication. Modeling of threats to networked systems, attack modeling with attack trees/graphs, cyber physical systems survivability to attacks, and behavior modeling of malware are explored. Network simulation/emulation using tools such as Scalable Simulation Framework (SSFNet), OPNET, or NS3 are examined. Application of industry-standard security protocols, such as, Secure Socket Layer (SSL), Transport Layer Security (TLS), IP-Security (IPSec), Public Key Infrastructure (PKI), WEP, WPA, etc. for engineering the security of networked systems will also be discussed.

MSIM 774. Transportation Network Flow Models. 3 Credits.
This course provides a rigorous introduction to transportation network modeling, with special emphasis on network equilibrium problems. Topics include: elementary graph theory, shortest path problem nonlinear optimization, optimization of univariate functions, deterministic and stochastic user equilibrium. (Cross-listed with CEE 774 and MSIM 774).

MSIM 775. Transportation Network Algorithms. 3 Credits.
Fundamental models and algorithms in optimization, stochastic modeling and parallel computing will be discussed and illustrated with transportation applications. (Cross-listed with CEE 775 and CEE 875).

MSIM 776. Simulation Modeling in Transportation Networks. 3 Credits.
Principles of simulation modeling, microscopic, mesoscopic, and macroscopic traffic simulation models. Course explores diver behavior in networks, calibration and validation of traffic simulation models, and use of traffic simulation software.

MSIM 780. Machine Learning II. 3 Credits.
Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principle component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. (Cross-listed with ECE 780 and ECE 880). Prerequisite: MSIM 607 or equivalent.

MSIM 795. Topics in Modeling and Simulation. 3 Credits.
Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 797. Independent Study in Modeling and Simulation. 3 Credits.
Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of instructor or graduate program director.

MSIM 802. Systemic Decision Making. 3 Credits.
As machine age problems have given way to systems age messes, the underlying complexity associated with understanding these situations has increased exponentially. Accordingly, the methods we use to address these situations must evolve as well. This course will introduce students to a method for thinking holistically about problems and messes conceptually founded in systems theory. This paradigm, known as systemic thinking, will be contrasted with traditional systematic thinking, and practical guidelines for the deployment of a systemic thinking approach will be provided. This paradigm will increase the student's ability to make rational decisions in complex environments. (Cross listed with ENMA 702/ENMA 802).

MSIM 803. Optimization Methods. 3 Credits.
Covers advanced methods in Operations Research and Optimization. Focus will be on developing models and their applications in different domains including manufacturing and service. Modern optimization tools will be used to implement models for case studies, projects and research papers. The knowledge of programming and spreadsheets is expected. Contact instructor for more details. (Cross-listed with ENMA 803).

MSIM 811. Finite Element Analysis. 3 Credits.
The purpose of the course is to provide an understanding of the finite element method (FEM) as derived from an integral formulation perspective. The course will demonstrate the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. Prerequisites: permission of the instructor.

MSIM 815. High Performance Computing and Simulations. 3 Credits.
Introduction to modern high performance computing platforms including top supercomputers and accelerators. Discussion of parallel architectures, performance, programming models, and software development issues. Case studies of scientific and engineering simulations will be explored. Students will have an opportunity to work on parallelization of problems from their research areas. Project presentations are required.

MSIM 822. Cluster Parallel Computing. 3 Credits.
This course provides detailed numerical step-by-step procedures to exploit parallel and sparse computation under MPI (Message Passing Interface) computer environments. Large-scale engineering/science applications are emphasized. Simultaneous linear equations are discussed.

MSIM 825. Principles of Combat Modeling and Simulation. 3 Credits.

MSIM 830. Simulation Formalisms. 3 Credits.
The focus of the course is on identification and investigation of mathematical and logical structures that form the foundation for computational simulation. Topics include: foundations of simulation theory in logic, discrete mathematics, and computability; simulation formalisms, including DEV'S; interoperability protocols; and computational complexity.

MSIM 841. Principles of Visualization. 3 Credits.
Well-designed graphical media capitalizes on human facilities for processing visual information and thereby improves comprehension, memory, inference, and decision making. This course teaches techniques and algorithms for creating effective visualizations based on principles and techniques from graphic design, visual art, perceptual psychology and cognitive science. Both users and developers of visualization tools and systems will benefit from this course.

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Course presents an overview of theory, techniques and protocols that are used to ensure that networks are able to defend themselves and the end-systems that use networks for data and information communication. Modeling of threats to networked systems, attack modeling with attack trees/graphs, cyber physical systems survivability to attacks, and behavior modeling of malware are explored. Network simulation/emulation using tools such as Scalable Simulation Framework (SSFNet), OPNET, or NS3 are examined. Application of industry-standard security protocols, such as, Secure Socket Layer (SSL), Transport Layer Security (TLS), IP-Security (IPSec), Public Key Infrastructure (PKI), WEP, WPA, etc. for engineering the security of networked systems will also be discussed.

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MSIM 875. Transportation Network Algorithms. 3 Credits.
Fundamental models and algorithms in optimization, stochastic modeling and parallel computing will be discussed and illustrated with transportation applications. (Cross-listed with CEE 775 and CEE 875).

MSIM 876. Simulation Modeling in Transportation Networks. 3 Credits.
Principles of simulation modeling, microscopic, mesoscopic, and macroscopic traffic simulation models. Course explores driver behavior in networks, calibration and validation of traffic simulation models, and use of traffic simulation software.

MSIM 880. Machine Learning II. 3 Credits.
Advanced topics in machine learning and pattern recognition systems. Data reduction techniques including principal component analysis, independent component analysis and manifold learning. Introduction to sparse coding and deep learning for data representation and feature extraction. (Cross-listed with ECE 780 and ECE 880). Prerequisite: MSIM 607 or equivalent.

MSIM 892. Doctor of Engineering Project. 1-9 Credits.
Directed individual study applying advanced level technical knowledge to identify, formulate and solve a complex, novel problem in Modeling and Simulation.

MSIM 895. Topics in Modeling and Simulation. 3 Credits.
Special topics of interest with emphasis placed on recent developments in modeling and simulation.

MSIM 897. Independent Study in Modeling and Simulation. 1-3 Credits.
Individual study selected by the student. Supervised and approved by a faculty member with the approval of the graduate program director. Prerequisites: permission of the instructor or graduate program director.

MSIM 898. Research in Modeling and Simulation. 1-12 Credits.
Supervised research prior to passing Ph.D. candidacy exam. Prerequisites: permission of the instructor and graduate program director.

MSIM 899. Dissertation. 1-12 Credits.
Directed research for the doctoral dissertation. Prerequisites: permission of the instructor and graduate program director.

MSIM 998. Master's Graduate Credit. 1 Credit.
This course is a pass/fail course for master's students in their final semester. It may be taken to fulfill the registration requirement necessary for graduation. All master's students are required to be registered for at least one graduate credit hour in the semester of their graduation.

MSIM 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.