INSTITUTION:  Michigan Technological University, Houghton, MI

EXECUTIVE OFFICER:  Dr. Richard Koubek, President

PREVIOUS COMMISSION ACTION AND SOURCES:  An interim report is required by 7/31/2018 on student learning outcomes, assessment, and program review.

This interim report derives from the Team Report of the institution’s 2015 Assurance Review and should address the following:

Student learning outcomes assessment
- Clear differentiation of expected learning outcomes for undergraduate and graduate programs. (Core Component 3A and 4B)
- Develop a comprehensive assessment program for graduate programs across all delivery modes. (Core Component 4B)
- Report of graduate learning outcomes data including demonstration of use of the data for continuous program improvement. (Core Component 3A)

Program review
- Create a review process for departments, and undergraduate and graduate programs not holding programmatic accreditation. The process should include a review schedule and involve external reviewers. (Core Component 4A)
- Report preliminary findings based on the data collected and analyzed for the initial department(s) and program(s) on the program review schedule and demonstrate the use of the data for continuous improvement. (Core Component 4A)
- Report graduate program persistence, attrition and completion data. (Core Component 4C)

REPORT PRESENTATION AND QUALITY: The Michigan Technological University interim report is organized effectively around the two primary areas—student learning outcomes and program review—identified as concerns in the Team Report of the institution’s 2015 Assurance Review. The University’s report is clearly written and supported by extensive appendices that include a range of documents pertaining to learning outcomes and program review. Indications are that the interim report is comprehensive and candid.
The University Senate of Michigan Technological University

Proposal XX-18
(Voting Units: Academic)

Proposal for New Graduate Degree

“Masters in Engineering Management (MEM)”

Introduction The School of Business and Economics currently offers a Master’s in Business Administration graduate degree that does not include an opportunity for students to specialize in a technical domain. The School of Business and Economics proposes a new graduate degree program: Masters in Engineering Management (MEM). We propose a technical/business (hybrid) degree program that focuses on the managerial knowledge, skills, and abilities critical for operations management success within technical industries.

1. October 23, 2018

2. Contact

Soonkwan Hong
Associate Professor of Marketing
School of Business and Economics
shong2@mtu.edu

3. Approval

(Not applicable)

4. General description and Characteristics

This program will be reviewed and accredited by AACSB (Association to Advance Collegiate Schools of Business). Additionally, the program director will work with the Graduate School to perform annual program reporting of quality characteristics.

The recent success of the B.S. in Engineering Management (undergraduate enrollment growth to 80 students from its introduction in 2013) and the support from various departments at the College of Engineering and College of Sciences and Arts encourages the school to offer this degree program at the master’s level. Given the large engineering and science population at Michigan Tech, the program would be of great necessity and appeal to the University community. The intent of this degree is to build on the technical foundation provided in the
undergraduate curriculum, adding the business acumen to increase the graduate’s future career trajectory. The most significant difference between the MEM and the MBA degree programs is in the addition of a significant number of technical courses (both approved and electives), as compared to a more general management curriculum for the MBA degree. The MEM should be considered a specialized graduate degree.

The university strategic plan also underscores the significance of developing interdisciplinary degrees as well as research endeavors. Stakeholders, including but not limited to alumni, members of various boards, and industry leaders, also echo that such a program will add value to the University as well as the School of Business and Economics (SBE). The program will provide opportunities for our engineering graduates to learn how to evaluate and manage innovation and technology in harmony with current business practices.

Student performance will be assessed using accepted learning objectives (AACSB approved) and rubrics developed by the SBE faculty. Each business core course will be assessed on a regular schedule. The current learning objectives are:

**Goal 1: Decision Making**

Objective 1a: Identify key problems, risks and opportunities in complex business scenarios.

Criterion
1) Students can identify key problems in complex business scenarios.
2) Students can identify key risks in complex business scenarios.
3) Students can identify key opportunities in complex business scenarios.

Objective 1b: Evaluate multiple alternatives to make appropriate executive-level recommendations.

Criterion
1) Students consider multiple alternatives when making recommendations.
2) Students make appropriate recommendations.
3) Students’ recommendations are executive-level.

**Goal 2: Managerial Competences**

Objective 2a: Generate unique and differentiated alternatives to offer business solutions under uncertainty.

Criterion
1) Students suggest alternatives that are unique.
2) Students suggest alternatives that are differentiated from competitors.
Objective 2b: Recommend appropriate technologies in business solutions.

Criterion
1) Students suggest technologies that are appropriate.
2) Students suggest technologies that integrate with business solutions.

Objective 2c: Demonstrate ethical leadership by influencing globally aware, socially and environmentally responsible behaviors.

Criterion
1) Students demonstrate globally aware leadership behaviors.
2) Students demonstrate socially responsible leadership behaviors.
3) Students demonstrate environmentally responsible leadership behaviors.

**Goal 3: Professional Communication**

Objective 3a: Written communication is logical, concise, and comprehensive.

Criterion
1) Written communication has a logically flow from premises to conclusions.
2) Written communications are concise, minimizing repetition and extraneous information.
3) Written communications are comprehensive, without gaps of missing information.

Objective 3b: Oral presentation is persuasive and audience-tailored.

Criterion
1) Student presentations are persuasive.
2) Student presentations are tailored to their audiences.

**Goal 4: Disciplinary Knowledge**

Objective 4a: Demonstrate knowledge necessary for a MEM graduate.

Criterion
1) Student have acquired disciplinary knowledge in finance.
2) Student have acquired disciplinary knowledge in accounting.
3) Student have acquired disciplinary knowledge in operations management and project management.
4) Student have acquired disciplinary knowledge in technology and innovation domains.

The program will only use existing and regularly offered courses. The SBE expects the list to evolve as new courses are developed across campus.
It will be a course-based master’s program; therefore, the designation of Masters in Engineering Management is appropriate.

The SBE Graduate Programs Committee started the curriculum identification process by determining the requisite skills and knowledge necessary for a MEM graduate. From that abstract, high-level view, specific courses were identified that contain the content that aligns with the profile from an academic perspective. Based on this process, five courses were identified as requirements for all students in the MEM. These courses span the accounting, finance, operations, project management and management of technology and innovation domains.

Students will also have the flexibility to enroll in more business courses or technical courses via a set of focused electives. The program director will advise MEM students to encourage a coherent combination of electives suited to a particular domain.

Finally, a set of technical electives will augment the anticipated strong STEM background of the target student population. The proposed program balances business knowledge with an expansion of technical competency of students from various undergraduate backgrounds in engineering and science, which is not readily possible with the current Tech MBA® program. The SBE Dean and SBE Associate Dean met with Department Chairs and the College of Engineering Associate Deans from various units across campus over the summer to obtain feedback on the MEM proposal. These representatives provided guidance on courses to include (and to delete) based on relevance to the intended expertise of MEM graduates and course availability. Again, the program director will advise MEM students to encourage a coherent combination of technical electives suited to a particular domain.

5. Title of the program: Masters in Engineering Management (MEM)

6. Rationale

(a) We are creating this specialized graduate degree for the following reasons:

i. To give students the opportunity to pursue a career requiring a foundation in both engineering and business. The curriculum enables students to enhance their technical depth with technical electives while adding vital management competency and awareness.

ii. To introduce technical graduates (e.g. engineering undergraduates) to a subset of current business principles and processes while learning to better assess the commercial ramifications of their technical design decisions. Their engineering skill set is augmented with essential business expertise, including knowledge of organizational behavior, cost management, and leadership skills. Thereby, future graduates of the MEM program are prepared to manage people, lead scientific or engineering operations, head
complex technical projects, or pursue entrepreneurial endeavors within a high-technology context. We anticipate graduates will secure better entry level jobs employing their technical skills. We also expect graduates to rapidly transition into upper level management positions employing their business skills.

iii. To aid students with technical majors in broadening and diversifying career opportunities that were previously unavailable to purely technical graduates. Discussions with alumni clearly reflect regret at the missed opportunity to study business earlier in their careers. With business credentials on their resumes, engineering graduates will differentiate themselves from their peer group.

(b) In addition, the MEM program will contribute to the SBE’s vision to produce tech-savvy business graduates and business-savvy tech graduates. The MEM program takes advantage of a business school embedded in a technological university. While the Bureau of Labor Statistics does not track Engineering Management as a separate category, the related job title of Industrial Engineers can provide relevant information. According to the Bureau of Labor Statistics, this career field is growing faster than the national average (10% growth rate) over the next decade. Furthermore, the number of jobs in this field is very large compared to other engineering fields. We anticipate strong career placement for MEM graduates.

7. Discussion of related programs within the institution and at other institutions

The Tech MBA® program currently offered by the School of Business and Economics will be the backbone of the proposed program where engineering and science students are exposed to business aspects of engineering, technology, and innovation.

By definition, a MBA degree provides broad coverage across the spectrum of business disciplines. An MBA is widely considered to be a generalized graduate program with equal representation of the primary core functions (and theoretical foundations) applied in most business schools. The MBA is more attractive for a career that requires overall business knowledge. Indeed, our prior Tech MBA® program required 12 business courses, whereas the MEM degree requires only a portion of the Tech MBA® courses.

By definition, a M.S. degree is a focused, deeper and more precise degree program. In this case, the MEM is focused on technical knowledge and abilities combined with the primary business content required for expertise in management of operations within technical industries. Indeed, students will be able to extend their technical education through graduate courses in the various engineering and science departments. This degree requires a strong background in a technical domain through the electives selected. Students will be encouraged to select courses that present a logical connection, appealing to recruiters in a well-defined
industry or area. Graduates will more likely remain in supervisory levels within a technical unit as a career choice. Again, the proposed program balances business knowledge with the technical competency of students from various undergraduate backgrounds in engineering and science, which is not readily possible with the current Tech MBA® program.

Other institutions in the State of Michigan (Lawrence Technological University - Master of Engineering Management, University Detroit Mercy - Master of Science in Technical Management, University Michigan Dearborn – Master of Science in Engineering Management, Western Michigan University - Master of Science in Engineering Management, Wayne State University – Master of Science in Engineering Management, and Eastern Michigan University - Master of Science in Engineering Management) offer programs which are quite engineering-centric, and generally lack core business components. Michigan State University also offers a Master of Science program in Operations and Engineering Management, but the curriculum is primarily business courses.

The proposed program will be hosted in the School of Business and Economics with a focus on providing students with a unique opportunity to further develop their skill sets in their respective engineering and science fields as well as expand required knowledge in business, innovation, and technology management.

8. Projected enrollment

The enrollment is projected to be 20 students in the first year, with a gradually increasing enrollment of +5% each year until the program plateaus with an estimated 40 students annually admitted.

The proposed program is a 30-credit course-based degree.

**Business Requirements (15 credits)**
1. BA 5300: Financial Reporting & Control
2. BA 5400: Financial Risk Management & Decision Making (Prereq: BA 5300)
3. BA 5610: Operations Management
4. MGT 4600: Management of Technology and Innovation
5. ENG/OSM 4300: Project Management
   OR BA5650 Project Management

**Focused Electives (6 credits)**
1. BA 5200: Information Systems Management & Data Analysis
2. BA 5700: Managing Behavior in Organizations
3. BA 5800: Marketing, Technology & Globalization
4. CEE 5350: Life Cycle Engineering
5. MEEM 4650: Quality Engineering OR
   OSM 4650: Six Sigma Fundamentals OR
MEEM 5650: Advanced Quality Engineering
6 MGT 3800: Entrepreneurship

Prerequisites
MA 3710: Engineering Statistics (or any other stats course)
(CEE 3710 Stats for Civil Engineering)

Technical Electives* (9 credits)

Civil & Environmental Engineering
1 CEE 5710: Modeling and Simulation Applications
2 CEE 5404: Transportation Planning
3 CEE 5417: Transportation Design
4 CEE 5501: Environmental Process Engineering
5 CEE 5730: Probabilistic Analysis and Reliability
6 CEE 5760: Optimization Methods in Civil/Env. Engineering
7 EC 3400: Economic Decision Analysis

Chemical Engineering
1 CM 3310: Process Control
2 CM 5100: Applied Mathematics for Chemical Engineering
3 CM 5300: Advanced Transport Phenomena
4 CM 5400: Advanced Reactive Systems Analysis
5 EC 3400: Economic Decision Analysis

Computer Science
1 CS 3712 Software Quality Assurance
2 CS 4712 Data Mining
3 CS 5471 Computer Security
4 CS 5841 Machine Learning
5 EC 3400: Economic Decision Analysis

Electrical & Computer Engineering
1 EE 3261: Control Systems
2 EE 5300: Mathematical & Computational Methods in Engineering
3 EE 5451: Cyber Risk Assessment Critical Inference
4 EE 5500: Probability and Stochastic Processes
5 EE 5511: Information Theory
6 EE 5521: Detection Estimation
7 EE 5821: Computational Intelligence
8 EE 5230: Power Systems Operations
Mechanical Engineering
1 MEEM 3600: Introduction to Manufacturing
2 MEEM 5680: Optimization I
3 EC 3400: Economic Decision Analysis

Courses may be double-counted by MTU undergraduate students who follow the Accelerated track

* This list of technical electives is just an example; other courses are open for consideration. Students will need to satisfy the course prerequisites in selection of their technical electives.

10. New course descriptions

There will be no new course added for the program.

11. Model schedule (Business courses only)

<table>
<thead>
<tr>
<th>Business requirements</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MGT 4600: Management of Technology and Innovation</td>
<td>BA 5610: Operations Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OSM 4300: Project Management</td>
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<tr>
<td>Focused electives</td>
<td>Focused Elective 1</td>
<td>Focused Elective 2</td>
</tr>
<tr>
<td></td>
<td>Technical Elective 1</td>
<td>Technical Elective 3</td>
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<tr>
<td></td>
<td>Technical Elective 2</td>
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</tbody>
</table>

See the MTU course catalog for the semesters the different focused and technical electives are offered.

12. Library and other learning sources
The library and other learning resources will be identical to those for current students.

13. Faculty resumes

14. Description of available/needed equipment

No new or specific equipment needed for the program.

15. Program costs

The proposed program leverages the Tech MBA® program and other courses currently offered by engineering and science programs. Therefore, no specific additional cost will be incurred from the program.

16. Space

No new space is needed.

17. Accreditation requirement

Michigan Tech is accredited by the Higher Learning Commission (HLC) (https://www.mtu.edu/provost/accreditation/hlcommission/). Individual programs may, in addition, seek and receive professional accreditation (https://www.mtu.edu/provost/accreditation/professional/).

This program will be reviewed and accredited by AACSB (Association to Advance Collegiate Schools of Business).

18. Program specific policies, regulations, and rules

(Not applicable)

http://www.admin.mtu.edu/usenate/policies/p108-1-1.htm

Graduate Certificate
Safety and Security of Autonomous Cyber-Physical Systems

1. Proposal Date: 13 November 2018

2. Proposer Contacts and Departments:

William Predebon (wwpredeb@mtu.edu), Chair, Mechanical Engineering-Engineering Mechanics

Daniel Fuhrmann (fuhrmann@mtu.edu), Chair, Electrical and Computer Engineering

Steven Goldsmith (sygoldsm@mtu.edu), Research Professor and Instructor, Mechanical Engineering-Engineering Mechanics, Electrical and Computer Engineering

3. Sponsor Department Approvals: Attached at end of document

4. General Description and Characteristics of Program

The Departments of Mechanical Engineering-Engineering Mechanics and Electrical and Computer Engineering propose the establishment of the interdisciplinary Graduate Certificate in Safety and Security of Autonomous Cyber-Physical Systems. Students completing this certificate will demonstrate competencies in the hierarchical design, control, and integration of technologies into cyber-physical components and systems including modern networked and autonomous mobile systems for land, air, and water. While the certificate focus includes autonomous vehicles, the knowledge can be applied to other cyber-physical systems such as robots, manufacturing, and infrastructure. The competencies include threat analysis and vulnerability assessment, risk analysis for cyber-safety issues, systems engineering for safety and security, redundancy, fault-tolerance for modern mobility platforms, and the design and analysis of novel strategies for meeting emerging vehicle and other cyber-physical safety and security threats.

The certificate will be available to degree-seeking students enrolled in the Graduate School at Michigan Technological University, as well as non-degree seeking students employed in industry and at federal facilities and laboratories. Students enrolling in this certificate program must have an undergraduate degree in Mechanical Engineering, Electrical Engineering, or in a closely-related field that is primarily based on physical engineered systems. The certificate will be offered to on-campus students and online students. This certificate requires a minimum total of 15 credits.

Students must earn a grade of B or higher in each of the courses counting toward the certificate. A maximum of 6 credits is allowed in courses at the 4000-level.

The Director of Graduate Studies in each of the ME-EM and ECE departments will oversee the certificate program and acceptance for students in their departments, or most closely aligned with their departments.

Catalog Description - The Graduate Certificate in Safety and Security of Autonomous Cyber-Physical Systems provides knowledge of cyber-physical safety and security strategies arising from modern, advanced system control networks and interconnected system complexes. Students accepted into this certificate program should have a working understanding of mobile system components, control systems design and modeling, and computer networking.
5. Rationale

In January 2016, Forbes magazine reported that more than 209,000 cybersecurity jobs were unfilled in the US alone. The shortfall of qualified cybersecurity engineers in the automotive area alone is further exacerbated by the need for deep knowledge of the embedded control and communications components of physical systems (including acceleration, braking, steering, stability, speed control, collision avoidance) that are physically integrated with the computers, software, sensors, and actuators that make up an autonomous system. Based upon discussions with a GM cybersecurity manager, other recent industry partners' input on new and emerging technologies in the automotive industry, and associated new job functions and hiring requirements, it is critical that students and incumbent engineers develop high-level skills targeted to meet the growing need for engineers to incorporate cyber-safety and security into the design of advanced components, controls, and communications among subsystems of autonomous cyber-physical systems of all types.

This certificate will also address safety and security of autonomous mobile platforms beyond automotive. Various recent press releases state:

- **Michigan Tech has a 64-year history of R&D in unstructured environments with the Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, MI coupled with years of testing and development at the Keweenaw Research Center.** TARDEC conducts R&D in a number of laboratories including: Crew Station Systems Integration Laboratory, Robotic Systems Integration Laboratory, Ground Vehicle Simulation Laboratory, High Performance Computing Laboratory, Next Generation Software Laboratory, Center for Ground Vehicle Development and Integration, and the Ground Vehicle Power and Systems Engineering Laboratory.

- **Michigan Technological University received $2.8 million from the US Department of Energy (DOE) to develop next-generation control systems for light-duty hybrid electric vehicles.** Michigan Tech is one of three Michigan recipients of a total of $8.5 million in new grants from DOE’s Advanced Research Projects Agency-Energy (ARPA-E). One project, titled “Connected and Automated Control for Vehicle Dynamics and Powertrain Operation on a Light-Duty Multi-Mode Plug-in Hybrid Electric Vehicle”, will integrate advanced controls with connected and automated vehicle functions, enabling eco-routing and vehicle cooperative driving.

- **The American Center for Mobility’s self-driving research site in Ypsilanti, Michigan, has established a new partnership with 15 Michigan universities, including Michigan Tech.** The partnership will lead to training, courses, recruitment, internships, co-ops and work-study programs. The article was featured in First Bell, a daily science and engineering newsletter published by the American Society for Engineering Education (ASEE). In addition, Michigan Tech is one of three Michigan universities whose students have been invited to participate in a three-year autonomous vehicle competition sponsored by General Motors and the Society of Automotive Engineers (SAE).

- **Michigan Technological University’s Great Lakes Research Center was the site for the unveiling of the Marine Autonomy Research Site (MARS)—the first freshwater testbed of its kind in the world.** Among the coalition’s partner organizations is the Great Lakes-St. Lawrence Governors and Premierses, chaired by Governor Rick Snyder. The group’s Executive Director David Naftzger said, “Shipping will look different in 25 years. Largely because of the work done here.”
Michigan Tech is in discussions to become a partner of the Institute on Public Policy and Law in Autonomy at Syracuse University.

Michigan Tech has received encouragement from automotive industry OEMs, such as General Motors and Ford, for this curriculum development and for the past creation of several new courses in this area. Michigan Tech should offer recognition to students who complete a set of focused courses to give them a credential indicating their knowledge in this rapidly emerging field. Of special importance is the need to provide engineers and practitioners with coursework that emphasizes cyber-physical safety and security as a systems-engineering function, without the need for a traditional computer science background required by traditional cybersecurity courses. The cyber-physical courses account for background material that is suitable for mechanical and electrical engineers with automotive and other backgrounds. The focus of this certificate is on the physical hardware, the embedded controllers within that hardware, and the systems integration and communications among the subsystems to help ensure safety and security of massive and energetic systems operating autonomously including cars, trucks, military vehicles, ships, robots, manufacturing systems, and infrastructure.

This program will complement the existing Graduate Certificate in Automotive Systems and Controls, but this new program will focus on cyber-safety and security aspects and their impact on autonomous vehicles and other systems. This graduate certificate is already in demand: discussions with Army TARDEC, the above-mentioned OEMs, Michigan Automotive Defense and Cyber Awareness Team (MADCAT), and Tier 1 organizations (including Delphi, FEV, and Continental) have been positive and encouraging. Indeed, one Tier 1 manager of an autonomous driving unit has enrolled for courses in anticipation of this certificate becoming realized.

The Graduate Certificate in Safety and Security of Autonomous Cyber-Physical Systems will enable students to:

1) Apply modern cyber-safety and security analysis engineering principles to autonomous vehicles and a variety of systems involving onboard control networks, advanced automation, and collaborative vehicle and machine collectives;

2) Improve interdisciplinary skills in the analysis of complex systems with safety and security requirements; and

3) Communicate clearly with peers and management on established and emerging cyber-safety and security issues.

Students who complete this certificate will be able to demonstrate that they understand the cyber-safety and security issues for vehicles and interconnected systems, can apply that understanding to analyze and synthesize safe and secure cyber-physical systems, and effectively work at the intersection of cybersecurity and safety of autonomous systems.

6. Related Programs:

There are currently NO courses devoted to automotive cybersecurity and safety at any institutions of higher learning at this writing. Training in the form of 1-3 day industrial courses is available through the Society of Automotive Engineers, Vector Consulting Services, MIRA (Horiba MIRA – Kyoto, Japan), and a few other automotive suppliers. There are a variety of short courses held at various automotive cybersecurity conferences and summits covering general and special topics, such as the SANS Institute Automotive Cybersecurity Summit held in May, 2018. However, on
July 29, 2018 Gov. Rick Snyder announced a new program for Michigan high schools. “Masters of Mobility: Cyber Security on the Road” will provide in-depth training for Michigan high school teachers as well as resources and materials that will teach students to program, hack and learn to defend against cyber-attacks.

The proposed certificate has a strong focus on the intersection of cybersecurity with components, safety, vehicle and system controls, advanced operator assistance systems, vehicle and system communications (V2X), and autonomous operation to meet emerging industry needs. The certificate is aligned with the established *Graduate Certificate in Automotive Systems and Controls*, but is unique with respect to its focus on safety threats introduced by the cybersecurity issues of advanced automation, operator functions, and the interconnection of autonomous vehicles and systems for land, air, and water as well as in other applications in robotics, manufacturing, and infrastructure. The proposed certificate curriculum is also aligned with the new Master of Science in Cybersecurity offered by the Computer Science Department, but the proposed certificate is accessible to students in engineering, without a traditional CS background that does not address the dynamics and control of engineered physical systems.

7. Projected Enrollments:

Based upon historical enrollment of the two core courses shown in Table 1, and the expanded electives for this proposed certificate, it is estimated that the steady state student enrollment for the certificate will be 15-20 students.

<table>
<thead>
<tr>
<th>Semester Course</th>
<th>Fall 2014</th>
<th>Spring 2015</th>
<th>Fall 2015</th>
<th>Spring 2016</th>
<th>Fall 2016</th>
<th>Spring 2017</th>
<th>Fall 2017</th>
<th>Spring 2018</th>
<th>Fall 2018</th>
</tr>
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<tbody>
<tr>
<td>CSICS</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>22</td>
<td>*</td>
<td>29</td>
<td>*</td>
<td>37</td>
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<tr>
<td>CSAS I</td>
<td>*</td>
<td>3</td>
<td>*</td>
<td>*</td>
<td>19</td>
<td>*</td>
<td>21</td>
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</table>

Table 1. Historical enrollments for the certificate core courses CSICS = MEEM 5300/EE 5455 Cybersecurity of Industrial Control Systems, CSAS I = MEEM 5310/EE 5310 Cybersecurity of Automotive Systems I.

8. Scheduling Plans:

No change in the regular scheduling of the existing courses is anticipated. The Departments delivering the courses have agreed to fit them into their regular scheduling plans. All of the courses are now regularly offered.

9. Curriculum Design:

In accordance with Senate policy, the requirements for the *Graduate Certificate in Safety and Security of Autonomous Cyber-Physical Systems* are a minimum 15 credits of coursework, including the required 9 credits of core courses and 6 credits of approved electives. A grade of B or higher is required in all applicable courses and there is a maximum of 6 credits at 4000-level.
Required Coursework (Core) 6 credits – both of the following:

- MEEM 5300 / EE 5455 Cybersecurity of Industrial Controls (3)
- MEEM 5310 / EE 5310 Cybersecurity of Automotive Systems I (3)

Required Coursework (Primary Focus) 3 credits - one of the following:

- EE 5365 In-Vehicle Communications Networks (3)
- EE 5367 Vehicular Communications Networks (3)
- MEEM / EE 5750 Distributed Embedded Control Systems (3)
- MEEM / EE 5811 Automotive Systems (3)
- EE / MEEM 5812 Automotive Control Systems (3)
- MEEM 6320 / ECE 6320 Cybersecurity of Automotive Systems II (3)

Elective Coursework - 6 Credits

- CS 4471 Computer Security (3)
- MEEM 4730 Dynamic Systems Simulation (3)
- EE 5365 In-Vehicle Communications Networks (3)
- EE 5367 Vehicular Communications Networks (3)
- MEEM 5430 Human Factors – Transportation (3)
- CS 5472 Advanced Topics in Computer Security (3)
- MEEM / EE 5750 Distributed Embedded Control Systems (3)
- MEEM / EE 5811 Automotive Systems (3)
- EE / MEEM 5812 Automotive Control Systems (3)
- EE 5821 Computational Intelligence (3)
- EE 5841 Machine Learning (3)
- MEEM 6320 / EE 6320 Cybersecurity of Automotive Systems II (3)

10. Course Descriptions: No new courses, all are currently offered

Core and Primary Focus

MEEM 5300 / EE 5455 Cybersecurity of Industrial Controls (3) on campus & online
Steven Goldsmith (ME-EM/ECE)

General introduction to cybersecurity of industrial control systems and critical infrastructures. Topics include NIST and DHS publications, threat analysis, vulnerability analysis, red teaming, intrusion detection systems, industrial networks, industrial malware, and selected case studies.
MEEM 5310 / EE 5310 Cybersecurity of Automotive Systems I (3) on campus & online
Steven Goldsmith (ME-EM/ECE)

This course provides an understanding of modern automotive control and communications systems from a cyber safety and security perspective. Topics include: V2X communications, vehicle attack surfaces and vulnerabilities, in-vehicle networks, threat analysis and vulnerabilities, security mechanisms and architectures, security requirements analysis, hardware security modules, and standards (SAE J3061, Auto-ISAC, NHTSA).

EE5365 In-vehicle Communications Network (3) on campus
Aurenice Oliveira (ECE)

Course focuses on in-vehicle system domains and their requirements, and in-vehicle communication bus Controller Area Network (CAN) and its related physical layers standards. It also covers other buses such as LIN, FlexRay, MOST, Ethernet, as well as introduction to V2V and V21.

EE 5367 Vehicular Networking (3) on campus
Aurenice Oliveira (ECE)

Theories/principles, technologies, standards and applications of vehicular ad-hoc networks (VANET), as well as design considerations and main challenges to implement inter-vehicular communication networks. Topics include vehicle mobility modeling, physical layer considerations, routing protocols, and data security. Requires Linux OS, Python or C++.

MEEM / EE 5750 Distributed Embedded Control Systems (3) on campus
Bo Chen (ME-EM/ECE)

This course introduces embedded control system design using a model-based approach. Course topics include model-based embedded control system design, discrete-event control, sensors, actuators, electronic control unit, digital controller design, and communication protocols. Prior knowledge of hybrid electric vehicles is highly recommended.

MEEM / EE 5811 Automotive Systems (3) on campus & online
Jeff Naber (ME-EM)

Automotive systems for light duty vehicles are examined from the perspectives of requirements, design, technical, and economic analysis for advanced mobility needs. This course links the content for the automotive systems graduate certificate in controls, powertrain, vehicle dynamics, connected and autonomous vehicles.

EE / MEEM 5812 Automotive Control Systems (3) on campus & online
Jeff Burl (ECE)

Introduction to automotive control systems. Modeling and control methods are presented for: air-fuel ratio, transient fuel, spark timing, idle speed, transmission, cruise speed, anti-lock brakes, traction, active suspension systems, and hybrid electric vehicles, Advanced control methodologies are introduced for appropriate applications.
MEEM 6320 / EE 6320 Cybersecurity of Automotive Systems II (3) on campus & online
Steven Goldsmith (ME-EM/ECE)

This course covers advanced topics in cybersecurity of automotive systems. Some topics include communications security for V2X systems, vulnerabilities in cooperative vehicle infrastructures (CVI) such as intersection collision avoidance systems and platooning, threat analysis for CVI, and security issues introduced by autonomous driving systems operating at SAE J3016 Autonomy Levels 3, 4 and 5.

Electives

CS 4471 Computer Security (3) on campus
Bo Chen (CS)

Development and administration of secure software systems. Topics include principles of software development, practical cryptography, program security, operating system security, database security and administration, legal and ethical issues.

ECE 4723 Network Security (3) on campus
Christopher (Kit) Cischke (ECE)

Learn fundamentals of cryptography and its applications to network security. Understand network security threats, security services, and countermeasures. Acquire background knowledge on well-known network security protocols. Address open research issues in network security.

MEEM 4730 Dynamic System Simulation (3) on campus & online
Gordon Parker (ME-EM)

Methods for simulating dynamic systems described by ordinary differential equations using numerical integration are developed. Quantifying simulation errors for both batch and real-time, control system applications is covered along with numerical optimization strategies for model validation. MATLAB and Simulink are used to illustrate key concepts.

MEEM 5430 Human Factors-Transportation (3) on campus & online
Ye Sun (ME-EM)

This course aims to provide an understanding of drivers as a system component in the operation of vehicles and other transportation systems. Topics covered include human factors, driver-vehicle interaction, intelligent transportation systems, connected vehicle technology, and user interface.

CS 5472 - Advanced Topics in Computer Security (3) on campus
Bo Chen (CS)

This course covers various aspects of producing trusted computer information systems. Topics include network perimeter protection, host-level protection, authentication technologies, formal analysis techniques, and intrusion detection. Current systems will be examined and critiqued.
EE 5821 - Computational Intelligence-Theory and Application (3) on campus
Timothy Havens (ECE/CS)

This course covers the four main paradigms of Computational Intelligence, viz., fuzzy systems, artificial neural networks, evolutionary computing, and swarm intelligence, and their integration to develop hybrid systems. Applications of Computational Intelligence include classification, regression, clustering, controls, robotics, etc.

EE 5841 - Machine Learning (3) on campus
Anthony Pinar (ECE)

This course will explore the foundational techniques of machine learning. Topics are pulled from the areas of unsupervised and supervised learning. Specific methods covered include naive Bayes, decision trees, support vector machine (SVMs), ensemble, and clustering methods.

11. Model Schedule Demonstrating Completion Time:

It is anticipated that degree-seeking students will take at a minimum one course each semester toward the certificate, since certificate credits can be counted toward a degree. It is expected that students will take additional courses each semester so that the certificate is completed within 3-4 semesters. It is also anticipated that the majority of non-degree seeking students will be online students who will take one course each semester toward the certificate, hence it is expected that these students will complete the certificate in five semesters. The core and primary focus courses are offered on the following schedule:

Core (both required)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEEM 5300 / EE 5455</td>
<td>Cybersecurity of Industrial Control Systems</td>
<td>Fall</td>
</tr>
<tr>
<td>MEEM 5310 / EE 5310</td>
<td>Cybersecurity of Automotive Systems I</td>
<td>Spring</td>
</tr>
</tbody>
</table>

Primary Focus (one required)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE 5365</td>
<td>In-Vehicle Communications Networks</td>
<td>Fall</td>
</tr>
<tr>
<td>MEEM 5811 / EE 5811</td>
<td>Automotive Systems</td>
<td>Fall</td>
</tr>
<tr>
<td>MEEM 6320 / EE 6320</td>
<td>Cybersecurity of Automotive Systems II</td>
<td>Fall</td>
</tr>
<tr>
<td>EE 5367</td>
<td>Vehicular Communications Networks</td>
<td>Spring</td>
</tr>
<tr>
<td>MEEM 5750 / EE 5750</td>
<td>Distributed Embedded Control Systems</td>
<td>Spring</td>
</tr>
<tr>
<td>EE 5812 / MEEM 5812</td>
<td>Automotive Control Systems</td>
<td>Spring</td>
</tr>
</tbody>
</table>

12. Library and other Learning Resources: Students in this program will need only the Library resources presently available to all enrolled students.

13. Faculty Resumes:

Jeffrey Burl (ECE) http://www.mtu.edu/ece/department/faculty/full-time/burl/
Bo Chen (CS) http://www.mtu.edu/cs/department/faculty-staff/faculty/chen/
Bo Chen (ME-EM/ECE) http://www.mtu.edu/mechanical/people/faculty/chen/
Christopher (Kit) Cischke (ECE) http://www.mtu.edu/ece/department/faculty/full-time/cischke/
Steven Goldsmith (MEEM/ECE) https://www.mtu.edu/mechanical/people/scholars-instructors/goldsmith/
14. **Equipment**: No additional equipment will be required.

15. **Program Costs**: The courses are presently being taught on a regular basis and are expected to cover the demand. Resources, such as on-line software, are already provided and available to instructors.

16. **Space**: No additional space is required.

17. **Policies, Regulations, and Rules**: Credits earned for this certificate may also be applied toward a single graduate degree at Michigan Technological University per Senate Policy 411.1


19. **Planned Implementation Date**: Summer 2019

20. **Assessment**:

   Students will demonstrate proficiency in the subject matter through the successful completion of the required and elective coursework. A portion of the students will be degree-seeking, while others will be non-degree seeking pursuing only the certificate.

   The Graduate Student Learning Objective for this certificate is:
   
   - Demonstrate proficiency in the safety and security of autonomous cyber-physical systems

   The assessment points for this objective will be grades earned in the 15 credits of coursework for the certificate. The two core courses of the certificate contain required written reports further demonstrating proficiency of the subject matter. The written reports will be assessed and reported using a separate metric from the course grades. The Graduate Director of the department of the undergraduate degree or admission (ME-EM or ECE) will compile the assessment points at the time the certificate audit or degree schedule is completed, and make it part of their graduate assessment portfolio.

   For those students completing the certificate as non-degree seeking, the same procedure will be followed at the time the certificate audit is approved, with the certificate assessment as a separate section of the department’s assessment reporting.
Date: November 13, 2018

From: William W. Predebon, Ph.D.
Chair, Department of Mechanical Engineering-Engineering Mechanics

Subject: Graduate Certificate in Autonomous Cyber-Physical Systems

To Whom It May Concern:

The Department of Mechanical Engineering-Engineering Mechanics (ME-EM) supports and endorses the proposed Michigan Tech Graduate Certificate in Autonomous Cyber-Physical Systems. The proposed certificate is an interdisciplinary program being submitted jointly by the Department of Mechanical Engineering-Engineering Mechanics and the Department of Electrical and Computer Engineering.

The safety and security of autonomous cyber-physical systems is a serious and life-threatening challenge facing industry today, and there is evidence of unmet workforce needs in this area. The graduate certificate is already in demand through discussions with the U.S. Army TARDEC, OEMs and Tier 1 organizations, such as Delphi, FEV, and others. We are confident that it will bring new graduate students, particularly from industry, to Michigan Tech, as well as some who may continue for further graduate study. Our departments have helped establish Michigan Tech as a leader in autonomous vehicles, including land, water and air, and this graduate certificate will further enhance our leadership position and growth in the graduate student area.
To Whom It May Concern:

The Department of Electrical and Computer Engineering supports and endorses the proposed Michigan Tech Graduate Certificate in Safety and Security of Autonomous Cyber-Physical Systems. The proposed program is an interdisciplinary program being put forward jointly by the Department of Mechanical Engineering-Engineering Mechanics and the Department of Electrical and Computer Engineering.

Both of the sponsoring departments believe that the safety and security of autonomous engineered systems is a serious technological issue facing industry today, and that there is evidence of significant unmet workforce needs in the area. The proposed Graduate Certificate will give electrical engineers, mechanical engineers, and technical professionals in closely related fields the training they need to make important contributions to their organizations and to the field. We believe that it will bring new graduate students to Michigan Tech, including some who may continue for further graduate study. Our departments have established Michigan Tech as a credible leader in this field, and this Graduate Certificate is one way to leverage that for the benefit of our industry partners, our students, and the university.
PROPOSAL FOR A
MASTER OF SCIENCE IN MECHATRONICS
AND ASSOCIATED GRADUATE CERTIFICATE
Submitted by the
School of Technology

Task Force Committee:
Chair: Aleksandr Sergeyev* – Electrical Engineering Technology, School of Technology
Trever Hessel - Electrical and Computer Engineering Department
Kevin Johnson – Mechanical Engineering Technology, School of Technology
Mo Rastgaar – Department of Mechanical Engineering – Engineering Mechanics
Yu Cai – Computer Network and System Administration, School of Technology

*Primary Points of Contact:
Aleksandr Sergeyev avsergue@mtu.edu and
Adrienne Minerick, Dean, School of Technology, minerick@mtu.edu

1. GENERAL DESCRIPTION AND CHARACTERISTICS OF PROGRAM

This proposal recommends the establishment of a Master of Science in Mechatronics (and Controls System Integration) at Michigan Tech. Mechatronics is the synergistic integration of electrical and mechanical engineering, robotics, computational hardware and software in the design of products and processes. Mechatronics is an essential foundation for the expected growth in automation and manufacturing. Figure 1 (source: https://en.wikipedia.org/wiki/Mechatronics) depicts the mix of various science and engineering disciplines that are part of Mechatronics and outlines related job opportunities for degree recipients. There is a demand for graduate education in Mechatronics as the landscape of engineering programs has changed in the past decade, shifting from traditional degrees leading directly to closely aligned positions in industry, to preparing individuals with advanced technical competencies capable of engaging in interdisciplinary research and industry applications. The proposed multidisciplinary degree will fill the need for applied researchers and for entrepreneurs to revitalize the US and global economies in the areas of advanced manufacturing and automation. Graduates will be equipped with multidisciplinary skills in electrical, mechanical, computer, and software engineering. The increased connectivity of smart machinery has resulted in a complete transformation in
the technologies used to create new industrial, commercial, and consumer products. The movement towards smart, connected technologies is transforming the manufacturing industry. Emerging technologies will help manufacturers provide advanced automation, improved communication and monitoring, self-diagnosis in real time, and bring data-driven analyses to realize new heights of productivity. The industry-driven curriculum developed for the proposed program will address the need for a skilled advanced manufacturing workforce and accelerate the development of a digitally-savvy workforce for emerging manufacturing technologies. It will focus on core technical skills, advanced technical design skills, and core technical implementation/instrumentation skills that are used in the design and manufacturing of control systems and devices used in consumer products, aerospace and military applications, and automotive and other advanced manufacturing industries. This degree program is responsive to advice from industrial advisory board members and other industry contacts to meet industry needs and to develop career pathways. This proposed degree program has the potential to increase enrollments in each of the four feeder BS programs that bridge into the MS in Mechatronics: Electrical Engineering Technology (EET), Electrical and Computer Engineering (ECE), Mechanical Engineering Technology (MET), and Mechanical Engineering - Engineering Mechanics (ME-EM).

Figure 2: Overview of the proposed model of Master of Science degree in Mechatronics at Michigan Tech

Figure 2 depicts the overview of the proposed MS degree in Mechatronics; each pathway will be discussed beginning at the top and moving clockwise around the figure. The MS degree has been designed to be flexible and accessible to students originating from various disciplines and academic pathways. Students from Michigan Tech pursuing their bachelor’s degree in EET, ECE, MET, and ME-EM engineering fields will
be able to enroll in an accelerated MS degree in Mechatronics with curricula partially tailored to their originating degree. This program will be available to qualified Michigan Tech undergraduate students (minimum GPA 3.0) who apply in their junior or senior year and are accepted by the Graduate School. Students in EE, EET, ME-EM, and MET programs will be able to apply up to six credits of approved coursework from their BS towards the MS degree in Mechatronics. Students, while pursuing their BS degree, will be allowed to take up to four graduate level courses. Depending on the students’ preparation (i.e. the number of prerequisites needed for graduate level courses, the number of graduate classes taken during their BS degree, courses transferred using Senior Rule), the graduation time for the students pursing coursework can vary between 1 and 2 years. For students who elect the research or industry internship option, the graduation time will be minimum of 1.5 years. Students who have earned BS degrees prior to being accepted into the MS Mechatronics program will not be eligible for Senior Rule and thus the Accelerated Master’s program but will be able to enroll in the stand-alone 2-year MS in Mechatronics program as shown in Figure 2.

The School of Technology has established and maintains several articulation agreements with regional community colleges. The 2+2+(1-2) degree path will provide these community college students pursuing an Associate Degree with the opportunity to first obtain a Bachelor’s degree in electrical or mechanical engineering technology at Michigan Tech and then move into the accelerated MS graduate degree in Mechatronics. These students will be able to follow all pathways enabled above for traditional EET and MET students.

The proposed degree also targets industry representatives who may or may not be able to be full-time students. Discussions with alums suggest there is considerable interest in this Mechatronics degree from those presently working in industry; therefore, online courses will be made available in the second year after program approval and development (potential for partnership with Keypath) for the required masters-level courses. To accommodate the distance, laboratory components will be taught in a week-long format on campus in a condensed fashion at a time that is most convenient for the students. This hybrid (online lectures and in-person hands-on training) approach will not only attract industry representatives but will also provide additional flexibility to the students currently enrolled in the degree.

International students and the students from the other universities will be able to enroll in the resident 2-year MS degree of Mechatronics based upon their earned BS degree (EET, ECE, MET, ME), admittance by the graduate school, and approval of the graduate advisor. The approval will be based on comparing the individuals’ transcripts with the current requirements for similar courses at Michigan Tech. Given the breadth of possible applications, this will be an iterative optimization with the Graduate School to identify which students to admit into the program. Per graduate school policy, students will be able to take graduate courses at another university and apply to have credits transferred to the MS Mechatronics program. Students will be able to transfer in up to 1/3 of the non-research credits required. The Mechatronics program director will be in charge of approving any allowable credits. Students must earn a 'B' or better in the course they are requesting to transfer.

The proposed MS degree will be very flexible, offering three options to complete graduation requirements: a coursework; a research option (likely with thesis); and an internship with industry option (likely with report). The research option (likely with a thesis) will allow students to work with MET, EET, ECE, and ME-EM faculty members at Michigan Tech on various applied research projects, with the goal of
enhancing their knowledge in practical applications. The second, and the option most desirable by both students and industry (see survey below), is an internship with industry, likely culminating in a report.

The graduate learning objectives (GLOs) for the coursework, thesis, and report pathways of the proposed Master’s Degree in Mechatronics are listed below. Topic Areas are outlined in Figure 5.

**Graduate Learning Objectives**

- Demonstrate core proficiency of the hybrid subject matter
- Demonstrate research/applied skills (thesis/report paths)
- Analyze and evaluate one’s own findings and the findings of others (thesis/report paths)
- Demonstrate professional skills
  - Effective written communication skills
  - Effective oral communication skills
- Practice responsible conduct of the profession

2. **RATIONALE AND SURVEY RESULTS**

Modern industrial processes rely on sensor technology to carry out precise functions, from touchscreen tablets and phones to robotic assembly machines. Advanced manufacturing incorporates complicated electromechanical systems with advanced control systems to increase production quality and throughputs. Mechatronics is the science of receiving, processing, and transmitting sensory data, resulting in advanced control of external devices. Industry has a great demand for engineers with overlapping expertise in the fields of electrical, mechanical, computer, robotic and control engineering. The physical systems currently used in industry are electromechanical with advanced controls. To operate, troubleshoot, and develop new systems, the “ideal” engineer needs knowledge about electrical, mechanical, and computer fields. A Mechatronics degree prepares graduates with expertise in all of these fields.

As part of the initial assessment of the need for a new type of Master’s degree in Mechatronics, the task force committee surveyed both students at Michigan Tech (in MET, EET, ECE, and ME-EM) and industry representatives. The student survey targeted currently enrolled engineering students and intended to collect feedback on their perceptions of a new degree: Master of Science in Mechatronics. The survey offered three options to fulfill degree requirements: a) a traditional course-only option; b) a research/project with thesis option; and c) an internship with industry with thesis option. Given the opportunity for the students to extend by 2 years their undergraduate degree to obtain a Master of Science in Mechatronics, the participants were surveyed on two questions: “1) Would you consider this opportunity?; and 2) Which option for the degree completion requirement would you prefer?” Based on 273 responses received in less than a two-week window, the statistical data shown in Figure 3, was compiled.

The industry survey was conducted via an alumni list of recent graduates from the SoT and was open for two weeks. Similar to the student survey, industry representatives were introduced to the proposed initiative and various options for fulfillment of the degree requirements, followed by two questions: “1) Given the opportunity to hire a graduate with a Mechatronics degree, would this person receive priority over a traditional Electrical or Mechanical Engineering Technology graduate?; and 2) As an employer,
which option for the degree completion requirement would you prefer?” Surveyed companies represent a very broad range of industrial sectors: automotive, automation and controls, robotics, additive manufacturing, mechatronics, material handling, energy services, power, steel, computer hardware, industrial machinery, hydraulics, mining, heavy equipment manufacturing, and others. A total of 105 responses were received and the statistical data, shown in Figure 4, was compiled.

Figure 3: Students’ survey on the relevance of Master of Science in Mechatronics at Michigan Tech.

Analysis of both data sets clearly indicates that there is a great interest in a Master’s degree in Mechatronics. Students understand the need for advanced education and are ready to consider a graduate degree, and there is great demand and an immediate need in industry for highly qualified graduates with the proposed degree. 77% of student participants indicated an interest in enrolling in a MS degree in Mechatronics. It is interesting to note that the most preferable degree completion option (at a rate of 47%) is through the internship with industry and thesis option while 41% of students would still prefer to obtain the degree via the coursework option. Based on data collected from a broad spectrum of industry, it is clear that there is a strong (a rate of 80%) preference for graduates with a degree in Mechatronics, as opposed to Electrical or Mechanical engineering technology graduates. Industry prefers a graduate with electrical, mechanical, and computer skills in one package. This type of graduate will enable more productive work in complex industrial solutions and will be well-oriented to communicate with other specialists from various disciplines. Industry responses also show that the internship graduation path is preferred, at a rate of 72%. Industry values graduates who, while still in school, experience real-world, application-based challenges. Graduates with industrial experience and hands-on education are ready to immediately implement their skills and contribute to the company mission.

Figure 4: Industry response on the necessity of the Master degree in Mechatronics
3. RELATED PROGRAMS

Mechatronics is a very common degree in Europe and Asia; well-known programs are located in Germany, Spain, Czech Republic, France, Russia, Portugal, Canada, Vietnam, China, and Taiwan. However, only a limited number of mechatronics degrees, and especially master’s programs, exist in the United States. University of Michigan offers a Master of Science in Robotics with a focus on the research and development of human-robot interactions, bio-inspired compliant systems, robotics, and nano-manipulation. Georgia Tech is also ranked among the best universities in the US for people interested in studying mechanical engineering. Georgia Tech has several laboratories specially created for fields such as precision machining, robotic mechanisms, and advanced intelligent mechatronics. Various courses are available, including robotics and mechatronics. Massachusetts Institute of Technology specializes in applications for robotics, looking for advances such as making humanoid robots, designing mechatronic systems, and implementing robots as tools for real-time computation tasks. The School of Engineering at Stanford University offers a Master of Science degree in Engineering that focuses on the development of solutions using robotic tools. Carnegie Mellon’s robotics Master of Science program looks to spread robotics research and solutions across different fields and departments of research and work. The Master’s Degree in Robotics offered by Oregon State University remains one of the best and most straightforward options for professional engineers looking to specialize in a program that is versatile and well-reputed. The University of Pennsylvania offers a Master’s Degree in Robotics and stands out as the one with a high-quality student community, since it attracts multitalented groups of people who have applied robotics to solve different problems. The proposed, interdisciplinary, MS degree in Mechatronics will serve domestic and international students. Currently enrolled students at Michigan Tech in Bachelor’s degrees of EET, MET, ME and ECE departments electing to advance their degree will be able to enter the accelerated MS degree in Mechatronics. Currently, opportunities for engineering technology students to extend their BS degree are very limited. There are approximately 29 relevant Master of Science in Technology programs worldwide; very few are in the U.S. The Department of Technology at the University of Northern Iowa offers a Master of Science in Technology, but without a specialization in Mechatronics. The College of Technology at Purdue University Northwest offers a Master of Science in Technology with a concentration in Mechatronics Engineering Technology. It is perhaps the closest in nature to the proposed Master’s degree in Mechatronics at Michigan Tech; however, it lacks flexibility in degree completion requirements.

4. PROJECTED ENROLLMENT

Based on initial assessment conducted using the students’ survey on the relevance of MS degree in Mechatronics 210 out of 273 students would enroll in the proposed degree. Using an initial conservative rate of 20%, we estimate the Graduate Program to have approximately 40 degree-seeking students over the first three years with an anticipated steady-state enrollment of 40-60 students including international and students from the other universities. Upon program development and availability of the online courses, we expect 80% of the degree-seeking students in the program to be traditional students and the remainder to be industry representatives enrolled through distance learning with intense on-site training. Responsive to the nature of student engagement in the first few years, we will launch a marketing campaign and examine partnering with Keypath to take the online components to a higher level of professional delivery. The School of Technology already carries the status of a FANUC authorized and
certified training center in industrial robotics and offers four industrial certificates (e.g. microcredentials): “Roboguide: Robotic Workcell Assembly” (8 hours), “Robot Operations” (16 hours), “Handling Toll Operation and Programming” (32 hours), and “IR-Vision 2D” (32 hour). Enrollments over the past three years have been in the upper twenties; we expect this trend to continue and potentially guide additional industry students into the MS in Mechatronics. Non-degree seeking students or industry representatives could take courses that can be applied to professional micro-credentials. The details of a proposed graduate certificate are highlighted separately in section 8 on pg. 19.

Also, according to the latest U.S. Bureau of Labor Statistics, the number of jobs for Mechatronics Engineers is expected to experience moderate growth, specifically in Michigan and Wisconsin, which needs to be supported by new specialists as shown in the table below. Michigan Tech is strategically located in close proximity to the largest automotive companies that have expressed they are in need of Mechatronics specialists. We expect that the expected growth in jobs for Mechatronics Engineers will have direct and positive impact on the enrollment in the proposed MS Degree in Mechatronics.

We strongly believe that the unique structure of the proposed graduate program curriculum and the availability of online course delivery will attract both traditional, non-traditional degree seeking, and non-degree seeking students.

5. SCHEDULING PLANS

The classes will be taught on the Michigan Tech campus and via a staged rollout approach, the required courses will be online followed by a majority of the topic area courses (see Figure 5). Some of the courses that are part of the proposed curriculum already have online versions. The new courses that will be developed as part of this initiative will include online content as well. This type of blended learning course meets the needs of distance and on-campus traditional students. Distance education students from industry will be able to complete theoretical portion of courses online, followed by intense on-site
training. The courses not currently selected for online delivery are more suitable for on-campus students who intend to write a thesis.

### 6. CURRICULUM DESIGN

The Mechatronics Graduate Program requires a minimum of 30 credits of course work and research/internship for the MS degree. Table 1 outlines options and requirements for the proposed Master of Science degree in Mechatronics. Participating faculty members from across campus will be able to advise in research-involved students as their schedules permit.

Table 1: MS Degree Requirements

<table>
<thead>
<tr>
<th>Program</th>
<th>Option</th>
<th>Coursework</th>
<th>Research Credits</th>
<th>Total Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS</td>
<td>Coursework</td>
<td>≥30</td>
<td>NA</td>
<td>≥30</td>
</tr>
<tr>
<td>MS</td>
<td>Thesis</td>
<td>≥24</td>
<td>6</td>
<td>≥30</td>
</tr>
<tr>
<td>MS</td>
<td>Report</td>
<td>≥24</td>
<td>6</td>
<td>≥30</td>
</tr>
</tbody>
</table>

Figure 5 depicts the curriculum Model for the proposed MS degree in Mechatronics. The model was designed to be flexible enough to accommodate students enrolling from various disciplines: EET, EE, MET and ME-EM. All majors are required to take EET5144/4144 Real Time robotics and EET5373/4373 Advanced Programmable Logic Controllers. Knowledge of robotic systems and the ability to smartly program robots are absolutely necessary skills for Mechatronics graduates. Job descriptions from Tesla, Ford, Fanuc, GM, and many other companies dealing with automation, all call for a specific knowledge of Fanuc robots and Programmable Logic Controllers. This has been a deciding factor for requiring all majors to be enrolled in EET5144/4144 and EET5373/4373. The prerequisites are designed to allow students from EET, EE, MET, and ME-EM to be able to enroll in these courses.

In addition, the students need to select at least one course from each of the topics (1-4) containing courses related to key identified knowledge areas for the Mechatronics degree. These topics are Cybersecurity of Industrial Systems, Autonomous Robotic Platforms, Controls of Industrial Systems, and Signal Processing of Electromechanical Systems. Availability of similar-in-nature courses in each Topic area that are offered by different majors will avoid foreseeing conflicts with course prerequisites.

It is expected, and will be required, that students coming from an electrical engineering background will complement their knowledge with mechanical engineering concepts by enrolling in at least one course outside of their discipline, and vice versa for the students with mechanical engineering backgrounds. This will be made possible by supplementing the required courses with various technical elective courses needed to qualify as prerequisites. The specific degree paths, as well as flowchart options, have been developed for all participating majors and available along with the Master’s Degree plan in Appendix A.
Required for all Majors
EET 5144/4144 Real Time Robotics
EET 5373/4373 Advanced PLC

Add at least 1 course from each of the Topics (1-4)
At least one course must be selected from out discipline area

Topic 1: Autonomous Robotic Platforms
ECE 5531 Introduction to Robotics
MEEM 5705 Introduction to Robotics and Mechatronics
EET 5147/4147 Robotic Vision System
MET 5800/4800 Dynamics and Kinematics of Robotic Platforms

Topic 2: Controls of Industrial Systems
ECE 4262 Digital and Non-Linear Control
ECE/MEEM 5750 Model-Based Embedded Control System Design
MEEM 4775 Analysis and Design of Feedback Control Systems
EET 5311/4311 Advanced Circuits and Controls
MET 5801/4801 Controls of Dynamic Systems
MET 5802/4802 Vibrations of Mechanical Systems

Topic 3: Signal Processing of Electromechanical Systems
ECE 4252 Digital Signal Processing and Applications
MEEM 5700 Dynamic Measurements/Signal Analysis
EET 5142/4142 Digital Signal and Image Processing
Applications

Topic 4: Cyber Security of Industrial Systems
SAT 3812 Cybersecurity I
ECE 4723 Network Security
ECE 5455/MEEM 5300 Cybersecurity of Industrial Control Systems
MEEM 5310 Cyber Security of Auto Systems

Figure 5 Curriculum Model for MS Degree in Mechatronics
Description of the required courses for MS Degree in Mechatronics:

Required for All Majors:

EET 5144/4144 Real Time Robotics

- Covers the components of a robot system, safety, concepts of a work-cell system, geometry, path control, automation sensors, programming techniques, hardware, and software.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3)
- Semesters Offered: On Demand
- Restrictions: Must be enrolled in one of the following Level(s): Graduate
- Pre-Requisite(s): EET 1411 or EET 2220 or PH 2230 or EE 2110 or EE 3010

EET 5373/4373 Advanced PLC

- Using Allen Bradley Control Logix and SLC500 programmable controllers, course covers structured programming, Sequential Function Charts, networking, proportional integral differential control, data acquisition and interfacing. The course requires proposing, executing and defending the graduate level, and related to the course material, project.
- Credits: 4.0
- Lec-Rec-Lab: (0-2-3) Semesters Offered: Spring
- Restrictions: Must be enrolled in one of the following Level(s): Graduate Pre-Requisite(s): EET 3373

Topic 1: Autonomous Robotic Platforms

ECE 5531 Introduction to Robotics

- Introduction to autonomous systems and robotics with focus on automated ground vehicles. Project based course using distributed computing to solve problems related to motion planning, perception, and localization. Requires experience with Linux operating systems variants, version control systems, and C++ or Python.
- Credits: 3.0
- Lec-Rec-Lab: (2-0-3)
- Semesters Offered: Spring
- Restrictions: Permission of department required; Must be enrolled in one of the following Level(s): Graduate; Must be enrolled in one of the following College(s): College of Engineering

MEEM 5705 Introduction to Robotics and Mechatronics

- Cross-discipline system integration of sensors, actuators, and microprocessors to achieve high-level design requirements, including robotic systems. A variety of sensor and actuation types are introduced, from both a practical and a mathematical perspective. Embedded microprocessor applications are developed using the C programming language. A final project is required including analysis, design, and experimental demonstration. Cannot receive credit for both MEEM4705 and MEEM5705.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3)
Semesters Offered: Fall, Spring
Restrictions: Must be enrolled in one of the following Level(s): Graduate; Must be enrolled in one of the following Major(s): Mechanical Engineering, Mechanical Eng-Eng Mechanics, Engineering Mechanics
Pre-Requisite(s): MEEM 3750

EET 5147/4147 Industrial Robotic Vision System and Advanced Teach Pendant Programming

- Procedures for setting up, teaching, testing, and modifying robot vision systems widely used in industrial automation. Introduces advanced Teach Pendant Programming to develop complex scenarios for integrating robots into industrial cells. Final project must demonstrate proficiency in setting up and programming an advanced robotic vision scenario.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3) Semesters Offered: Fall, Summer
- Restrictions: Must be enrolled in one of the following Level(s): Graduate Pre-Requisite(s): EET 4144 or EET 5144

MET 5800/4800 Dynamics and Kinematics of Robotics Platforms

- This course covers the dynamics and kinematics of rigid bodies as the foundation for analyzing motion of robots. Robotic kinematics is reviewed by analyzing the motion of the robot. The dynamics is reviewed by analyzing the relation between the joint actuator torques and resulting motion.
- Credits: 3.0
- Lec-Rec-Lab: (0-2-3)
- Semesters Offered: Fall
- Pre-Requisite(s): MET3130

**Topic 2: Controls of Industrial Systems**

ECE 4262 Digital and Non-Linear Control

- Introduction to state space analysis and design (state feedback, observers, and observer feedback); digital control system design and analysis (Z-transforms, difference equations, the discrete-time state model, and digital implementation of controllers); introduction to nonlinear systems (equilibrium states, linearization, phase plane analysis, and describing function analysis); and experiments with physical systems.
- Credits: 3.0
- Lec-Rec-Lab: (2-0-2)
- Semesters Offered: Spring
- Pre-Requisite(s): EE 3261

ECE/MEEM 5750 Model-Based Embedded Control System Design

- This course introduces embedded control system design using model-based approach. Course topics include model-based embedded control system design, discrete-event control, sensors, actuators, electronic control unit, digital controller design, and communications protocols. Prior knowledge of hybrid electric vehicles is highly recommended.
- Credits: 3.0
MEEM 4775 Analysis and Design of Feedback Control Systems

- This course covers topics of control systems design. Course includes a review for modeling of dynamical systems, stability, and root locus design. Also covers control systems design in the frequency domain, fundamentals of digital control and nonlinear systems.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-2)
- Semesters Offered: Fall
- Restrictions: Must be enrolled in one of the following Major(s): Mechanical Engineering, Mechanical Eng-Eng Mechanics, Engineering Mechanics
- Pre-Requisite(s): MEEM 3750

EET 5311/4311 Advanced Circuits and Controls

- Graduate-level students are expected to demonstrate ability in modeling/simulation techniques of linear systems. Topics include: Fourier and Laplace transforms, signal comparison techniques and transfer functions. Control techniques addressed will include feedback, cascade, feedforward, multivariable and model-based methods.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3) Semesters Offered: Fall
- Restrictions: Must be enrolled in one of the following Level(s): Graduate Pre-Requisite(s): EET 3131 or EET 4253

MET 5801/4801 Controls of Dynamic Systems

- This course covers the modeling, analysis, and control of dynamic systems. It uses the controlling equations for the control of mechanical and electrical systems. Theory is verified with simulation and lab testing.
- Credits: 3.0
- Lec-Rec-Lab: (0-2-3)
- Semesters Offered: Spring
- Pre-Requisite(s): MET 4800

MET 5802/4802—Vibrations of Mechanical Systems

- This course deals with the modeling and analysis of mixed physical systems. Introduction to modeling and oscillatory response analysis for discrete and continuous mechanical and structural systems. Time and frequency domain analysis of linear system vibrations. Vibration of multi-degree-of-freedom systems. Free vibration eigenvalue problem. Un-damped system response and viscously damped systems. Vibration of continuous systems with modes of vibration.
- Credits: 3.0
- Lec-Rec-Lab: (0-2-3)
• Semesters Offered: Fall
• Pre-Requisite(s): MET2130

**Topic 3: Signal Processing of Electromechanical Systems**

ECE 4252 Digital Signal Processing and Applications

- Digital signal processing techniques with emphasis on applications. Includes sampling, the Z-transform, digital filters and discrete Fourier transforms. Emphasizes techniques for design and analysis of digital filters. Special topics may include the FFT, windowing techniques, quantization effects, physical limitations, image processing basics, image enhancement, image restoration and image coding.
- Credits: 3.0
- Lec-Rec-Lab: (3-0-0)
- Semesters Offered: Fall
- Co-Requisite(s): EE 4259
- Pre-Requisite(s): EE 3160

EET 5142/4142 Digital Signal and Image Processing

- Provides students with digital signal and image processing techniques with emphasis on applications. Covers concepts of sampling, digital filters and discrete Fourier transforms, image processing, enhancement, and restoration. The course requires proposing, executing and defending the graduate level, and related to the course material, project.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3) Semesters Offered: Spring
- Restrictions: Must be enrolled in one of the following Level(s): Graduate Pre-Requisite(s): EET 4311 or EET 3367 and EET 4141

MEEM 5700 Dynamic Measurements/Signal Analysis

- Assessment of measurement system requirements: transducers, conditioners, and displays of dynamic measurements. Time-, frequency-, probabilistic-, and correlative-domain approaches to dynamic signal analysis: sampled data, discrete Fourier transforms, digital filtering, estimation errors, system identification, calibration, recording. Introduction to wavelet analysis. All concepts reinforced in laboratory and simulation exercises.
- Credits: 4.0
- Lec-Rec-Lab: (0-3-3)
- Semesters Offered: Fall, Summer
- Restrictions: Must be enrolled in one of the following Level(s): Graduate; Must be enrolled in one of the following College(s): College of Engineering

**Topic 4: Cyber Security of Industrial Processes**

ECE 4723 Network Security

- Learn fundamental of cryptography and its application to network security. Understand network security threats, security services, and countermeasures. Acquire background knowledge on well-known network security protocols. Address open research issues in network security.
ECE 5455/MEEM 5300 Cybersecurity of Industrial Control Systems

- General introduction to cybersecurity of industrial control systems and critical infrastructures. Topics include NIST and DHS publications, threat analysis, vulnerability analysis, red teaming, intrusion detection systems, industrial networks, industrial malware, and selected case studies.
- Credits: 3.0
- Lec-Rec-Lab: (3-0-0)
- Semesters Offered: Fall, Spring
- Pre-Requisite(s): EE 4272 or CS 4461

MEEM 5310 Cyber Security of Auto Systems

- Modern automotive control and communications systems from a cyber-security perspective. Topics include: V2X communications, vehicle attack surfaces and vulnerabilities, in-vehicle networks, threat analysis and vulnerabilities, security mechanisms and architectures, security requirements analysis, hardware security modules, and standards.
- Credits: 3.0
- Lec-Rec-Lab: (0-3-0)
- Semesters Offered: Spring
- Prerequisite: MEEM5300
- Restrictions: Graduate Student in EME, MEEM, EEE, ECP, or CSS

SAT 3812 Cybersecurity I

- The evolution of information security into cybersecurity and its relationship to nations, organizations, society, and individuals. Exposure to multiple cybersecurity technologies, processes, and procedures; analyzing threats, vulnerabilities and risks present; and developing appropriate strategies to mitigate potential cybersecurity issues. Applied lab to develop cybersecurity offensive attributes and learn how to prevent and/or mitigate threats.
- Credits: 3.0
- Lec-Rec-Lab: (0-2-2)
- Semesters Offered: Fall, Summer
- Restrictions: Must be enrolled in one of the following Class(es): Junior, Senior
- Pre-Requisite(s): SAT 1200 or CS 1111 or CS 1121 or CS 1131 or CS 1142 or MIS 2100 or EET 2241

List of Possible Elective Courses by Major:

- EET 5144/4144 Real Time Robotics
- EET 5147/4147 Industrial Robotic Vision System and Advanced Teach Pendant Programming
- EET 5373/4373 Advanced PLC
- EET 5311/4311 Advanced Circuits and Controls
As can be seen from the industry survey responses, there is high demand for graduates with an advanced degree in Mechatronics. Technology evolves every day, and industry is a first responder to these changes. This rapid evolution should be frequently reflected in the curriculum by updating course topics to leverage current technologies. Due to the interdisciplinary nature and hands-on approach of the Mechatronics field of study, it is crucially important that we as an educational institution seek feedback from industry. The EET, ECE, MET, ME-EM and Computer Network and System Administration (CNSA) programs at Michigan Tech already have Industrial Advisory Boards (IABs) that provide continuous feedback for the undergraduate curriculum. One of the program goals is to form an IAB for the new Master of Science degree in Mechatronics. The task force committee for the proposed Mechatronics degree has already
identified and received commitments from the following leading automotive and automation corporations: Tesla, Ford, General Motors, Fanuc Robotics, and Kaufman Engineered Systems.

Tesla, the leading automotive company in the production of advanced electrical vehicles, has identified an urgent need for mechatronics specialists with a controls background. Tesla has committed to collaborate with Michigan Tech in the advanced mechatronics curriculum development by being part of the new IAB mechatronics committee and advising on emerging changes in technology. Tesla has also expressed an interest in hiring future highly qualified mechatronics graduates prepared by this new MS degree program.

Fanuc Robotics is a leading industrial robot manufacturing company in the U.S and abroad. Fanuc is represented in 5 continents and > 22 countries with more than 100,000 robots installed in the US and 250,000 robots worldwide. The extensive presence of Fanuc robots in industry requires well-trained and certified specialists with a mechatronics background. Fanuc has a long record of commitment of positively impacting undergraduate education at Michigan Tech and has committed to act on the new IAB for the mechatronics degree by advising on curriculum development and modifications in order to stay tuned with current industry needs. Fanuc has a strong record of hiring Michigan Tech students and has expressed an even stronger interest for graduates with an advanced mechatronics degree.

Kaufman Engineered Systems (KES), is the largest in the U.S. integrator of Fanuc robotics solutions. For over 70 years, KES has been a pioneer in complete line automation. The company has a reputation for single-source convenience, responsive service, and unmatched equipment performance. KES has been a long proponent of Michigan Tech. They have demonstrated continuous support for the undergraduate robotic curriculum development in the EET program. KES has expressed a significant demand for mechatronics specialists with skills that are current and relevant to industry needs. KES has committed to serve on the Mechatronics IAB committee to promote the program and advise on curriculum development.

The Ford Motor Company has deep roots of collaboration with Michigan Tech. The relationship started in 1930 when Henry Ford developed Alberta village, where he established one of his sawmills. For many decades, Ford has supported Michigan Tech’s mission of providing the best possible educational practices for students. Ford’s engagement with Michigan Tech ranges from providing internships and full-time employment opportunities, sponsoring traditional and applied research, sponsoring and advising senior design and Enterprise projects, to supporting summer youth programs for middle and high school students. Ford has expressed a strong interest in the proposed Master's Degree in Mechatronics, since mechatronics specialists are the best-fit engineers for the automotive sector. Not only has Ford committed to be an active member of the Mechatronics IAB, it has also expressed a solid commitment to interviewing and hiring Mechatronics program graduates.

The partnership between General Motors (GM) and Michigan Tech is called “Made for More.” Michigan Tech and General Motors share a long-standing partnership dating back to at least 1940, supporting a wide range of activities across campus including scholarships, Senior Design and Enterprise programs, student organizations, sponsored research, recruiting support, youth programs, diversity initiatives, and more. GM is excited about a new program in Mechatronics and an opportunity to have access to the pool of highly qualified graduates. GM has agreed to collaborate with Michigan Tech by serving as an external
advisor, as part of the newly formed IAB, and to provide valuable industrial feedback on the Mechatronics curriculum development.

In addition to these committed corporations who will serve on the new IAB for the Master’s Degree in Mechatronics, we will also solicit additional feedback from the companies that are already part of our existing IABs for the related undergraduate programs.

7. Course Descriptions

The actual program of study for each student will be developed in consultation with an advisor and will be based on individual educational goals. Table 2 provides an overview of the schedule of course offerings and the associated instructors. Each of the courses, with the exception of Special Topics, are offered annually with some of the courses being offered in each semester and during summer Tracks A and B. The teaching load for participating faculty members is based on two courses per semester, including current undergraduate teaching assignments. Summer courses will be offered for additional compensation and according to Michigan Tech policies.

Table 2: Schedule of Course Offerings

<table>
<thead>
<tr>
<th>Course Title</th>
<th>Pre-requisites</th>
<th>Credits</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>EET 5144/4144 Real-Time Robotics Systems</td>
<td>EET1411 or EET2220 or PH2230 or EE2110 or EE 3010 or MEEM 3750 or MEEM4705</td>
<td>4</td>
<td>Sergeyev</td>
<td>Sergeyev</td>
</tr>
<tr>
<td>EET 5147/4147 Industrial Robotic Vision Systems and Advanced Teach Pendant Programming</td>
<td>EET4144</td>
<td>4</td>
<td>Sergeyev</td>
<td></td>
</tr>
<tr>
<td>EET 5373/4373 Advanced PLC</td>
<td>EET3373</td>
<td>3</td>
<td>Hamouz</td>
<td>Hamouz</td>
</tr>
<tr>
<td>EET 5311/4311 Advanced Circuits and Controls</td>
<td>EET3131 or EET4253</td>
<td>4</td>
<td>Hazaveh</td>
<td></td>
</tr>
<tr>
<td>EET 5142/4142 Digital Signal and Image Processing (new course)</td>
<td>EET5311 or EET3367 and EET4141</td>
<td>4</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>MET 5800/4800 Dynamics and Kinematics of Robotics Platforms (new course)</td>
<td>MET2130</td>
<td>3</td>
<td>Labyak</td>
<td></td>
</tr>
<tr>
<td>MET 5801/4801 Controls of Dynamic Systems (new course)</td>
<td>MET5800/4800</td>
<td>3</td>
<td>Labyak</td>
<td></td>
</tr>
<tr>
<td>MET 5802/4802 Vibrations of Mechanical Systems (new course)</td>
<td>MET2130</td>
<td>3</td>
<td>Labyak</td>
<td></td>
</tr>
<tr>
<td>MET 5378/4378 Electrohydraulic Components and Systems (new course)</td>
<td>MET4377</td>
<td>3</td>
<td>Johnson</td>
<td></td>
</tr>
<tr>
<td>MEEM 4775 Analysis and Design of Feedback Control Systems</td>
<td>MEEM 3750</td>
<td>4</td>
<td>Parker</td>
<td></td>
</tr>
<tr>
<td>Course Code</td>
<td>Course Title</td>
<td>Credits</td>
<td>Instructor</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------------------------------------------</td>
<td>---------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>MEEM 5705</td>
<td>Introduction to Robotics and Mechatronics</td>
<td>4</td>
<td>Sun</td>
<td></td>
</tr>
<tr>
<td>ECE/MEEM 5750</td>
<td>Model-Based Embedded Control System Design</td>
<td>3</td>
<td>Chen</td>
<td></td>
</tr>
<tr>
<td>MEEM 5700</td>
<td>Dynamic Measurements/Signal Analysis</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECE 5455/MEEM 5300</td>
<td>Cybersecurity of Industrial Control Systems</td>
<td>3</td>
<td>Goldsmith</td>
<td></td>
</tr>
<tr>
<td>MEEM 5310</td>
<td>Cyber Security of Auto Systems</td>
<td>3</td>
<td>Goldsmith</td>
<td></td>
</tr>
<tr>
<td>MEEM 4775</td>
<td>Analysis and Design of Feedback Control Systems</td>
<td>4</td>
<td>Parker</td>
<td></td>
</tr>
<tr>
<td>ECE 5531</td>
<td>Introduction to Robotics</td>
<td>NA</td>
<td>Boss</td>
<td></td>
</tr>
<tr>
<td>ECE 4262</td>
<td>Digital and Non-Linear Control</td>
<td>3</td>
<td>Burl</td>
<td></td>
</tr>
<tr>
<td>ECE 4252</td>
<td>Digital Signal Processing and Applications</td>
<td>4</td>
<td>Amabardar</td>
<td></td>
</tr>
<tr>
<td>ECE 4723</td>
<td>Network Security</td>
<td>3</td>
<td>Cischke</td>
<td></td>
</tr>
<tr>
<td>SAT 3812</td>
<td>Cyber Security I</td>
<td>3</td>
<td>Cai</td>
<td></td>
</tr>
</tbody>
</table>

8. MECHATRONICS AND ROBOTICS GRADUATE CERTIFICATES AND MICRO-CREDENTIALS

In close coordination with the proposed MS degree in Mechatronics, graduate certificates and micro-credentials are also being packaged together and/or proposed.

Disclaimer: Terminology usage varies slightly between industry and academia. In industry, individuals completing short courses in specific areas are traditionally issued certificates of completion. In academia, we tend to refer to these as micro-credentials. At Michigan Tech, we have developed Graduate Certificates to enable students to earn recognition on their transcript for completing 10-16 graduate credits in a focused field. To keep this language straight, the term micro-credentials is added in parenthesis after short course sequences and Graduate Certificate is separately discussed.

Micro-credentials: History and Current Context

In 2013, and under Dr. Sergeyev leadership, Michigan Tech became a FANUC Authorized Certified Training Facility. Under this agreement, Michigan Tech is a regional training center specializing in industrial automation, eligible to train and certify students from other institutions, industry representatives, and displaced workers. Michigan Tech is one of only three existing FANUC Authorized Satellite Training Programs in the United States, and the only one in the state of Michigan. Dr. Sergeyev has developed four stand-alone certification (micro-credentials) programs in industrial robotics.

Considering the current state of automation and advanced robotic solutions in industry, special attention will be devoted in EET curriculum to industrial robotics. Students enrolled in the Master’s degree in
Mechatronics must have an in-depth knowledge in the field of robotics and will be required to take two robotics courses: Real-time Robotics Systems and Industrial Robotic Vision Systems. The first course covers a wide range of topics related to designing, installing, and programming advanced robotic systems and solutions. The second course exploits the concepts on robotic vision systems and their configuration, installation, and implementation. Considering that Fanuc robots are widely utilized in industry, (about 80% of the market share in the U.S.), both courses have been developed on FANUC’s platform. Knowledge of robotic systems and being able to smartly program robots are absolutely necessary skills for the Mechatronics graduates. Job descriptions from Tesla, Ford, Fanuc, GM, and many other companies dealing with automation, all call for a specific knowledge of Fanuc robots. Both of these courses offered at Michigan Tech come with FANUC certification (micro-credentials) issued by Dr. Sergeyev, FANUC-certified instructor. The students enrolled in the Mechatronics program will not only receive valuable and necessary knowledge, but will also get certified (micro-credentialled), which makes them more competitive on the job market.

In addition to the certification (micro-credential) program for university students, Dr. Sergeyev has developed four certifications (micro-credentials) in robotics for industry representatives, displaced workers, and students from the other universities. These certificates are: “Roboguide: Robotic Workcell Assembly” (8 hours), “Robot Operations” (16 hours), “Handling Toll Operation and Programming” (32 hours), and “IR-Vision 2D” (32 hour). All four certificates (micro-credentials) are in place at Michigan Tech and endorsed by FANUC. The certificates have been designed with the goal to take as little work time away from participants as possible. To achieve that, all the theoretical content is delivered online with the remaining hands-on training being delivered at Michigan Tech utilizing FANUC industrial robots. Availability of these certification (micro-credential) programs provide additional opportunities for the students currently working in industry and those entering the MS degree program in Mechatronics. To date, more than 200 university students and 50 industry representatives have been certified by Dr. Sergeyev through these programs. The certification (micro-credential) programs are highly indorsed by industry since they provide their employees with the opportunity to revamp their skills in emerging field of industrial robotics. While the FANUC-authorized certification (micro-credential) programs in industrial robotics existing at Michigan Tech cannot be claimed as courses by industry representatives enrolled in 2-year MS degree hybrid plan, they provide industry with additional options to train their workers. This also forms a stronger and well recognized connection between Michigan Tech and industry, which in turn makes the Mechatronics degree marketable.

Proposed Graduate Certificate

In addition to the above existing micro-credentials, we propose a Graduate Certificate in Mechatronics specifically designed for enrolled Michigan Tech students. The Graduate Certificate will be available for both graduate and undergraduate students as long as they complete required courses in Mechanical, Electrical, and Cybersecurity (13 credits). The key courses, shown in Table 3, have been selected to fulfill the Graduate Certification requirements. The students will have a choice to select either EET 5144/4144 Real-time Robotics Systems or EET 5373/4373 Advanced PLC. Additional courses have been added to emphasize electrical, mechanical and cybersecurity aspects of the certificate.

Table 3: Courses for Graduate Certificate in Mechatronics

<table>
<thead>
<tr>
<th>Disciplines</th>
<th>EET</th>
<th>MET</th>
<th>MEEM</th>
<th>ECE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EET</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECE</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
The learning objectives (LOs) for the proposed Graduate Certificate in Mechatronics are listed below.

Learning Objectives

- Demonstrate proficiency in the selected coursework
- Demonstrate professional skills
  - Effective written communication skills
  - Effective oral communication skills
- Practice responsible conduct of the profession

9. Library and Other Learning Resources

Students will have access to all Library resources, Michigan Tech subscription based IEEEXplorer digital data base, interlibrary loans, and degree specific subscription-based journals and conference proceedings.

Since this Master’s Degree in Mechatronics builds from foundations in EET, MET, ME-EM, and ECE, additional library and learning resources are expected to be minimal.

10. Additional Fees

A university online learning fee of $38/per credit will be required for on-line courses. Laboratory courses are expected to have $50 lab fees and will be adjusted in the future as usage and infrastructure needs are better understood.

11. Faculty Resumes

Key faculty members for this graduate program are listed below:

Graduate Program Director in Mechatronics: Dr. Sergeyev, https://www.mtu.edu/technology/about/faculty/sergeyev/index.html
Dr. Hamouz, http://www.mtu.edu/technology/about/faculty/
Dr. Hazaveh, http://www.mtu.edu/technology/about/faculty/
Dr. Labyak, http://www.mtu.edu/technology/about/faculty/
Mr. Johnson, http://www.mtu.edu/technology/about/faculty/
Dr. Parker, https://www.mtu.edu/mechanical/people/faculty/parker/
Dr. Ye Sun https://www.mtu.edu/mechanical/people/faculty/sun/index.html
Dr. Chen, https://www.mtu.edu/mechanical/people/faculty/chen/
Dr. Coldsmith, https://www.mtu.edu/mechanical/people/scholars-instructors/goldsmith/index.html
Dr. Bos, https://www.mtu.edu/ece/department/faculty/full-time/bos/index.html
Dr. Burl, https://www.mtu.edu/ece/department/faculty/full-time/burl/index.html
Dr. Amabardar, https://www.mtu.edu/ece/department/faculty/full-time/ambardar/
Mr. Cischke, https://www.mtu.edu/ece/department/faculty/full-time/cischke/index.html
Dr. Cai, http://www.mtu.edu/technology/about/faculty/cai/

Key staff members for this graduate program are listed below:

**Keypath Lead:** Dean, SoT: Dr. Minerick, https://www.mtu.edu/technology/about/staff/minerick/
MEEM Department Chair: Dr. Predebon,
https://www.mtu.edu/mechanical/people/faculty/predebon/index.html
ECE Department Chair: Dr. Fuhrmann,
https://www.mtu.edu/ece/department/faculty/fulltime/fuhrmann/index.html
ECE Academic Advisors: Hassell, P.E. and J. Donahue, https://www.mtu.edu/ece/department/staff/
SoT Academic Advisor: D. Jarvey, https://www.mtu.edu/technology/resources/undergraduate/advising/
MEEM Academic Advisors: T. Stein and R. Towles, https://www.mtu.edu/mechanical/people/staff/

12. **DESCRIPTION OF EQUIPMENT**

The School of Technology, ECE and ME departments are well equipped with various laboratory and research instruments deliver the proposed courses. Some of the equipment and lab resources sharing between EET and ECE as well as ME and MET programs are expected upon mutual agreement. The two courses, Advanced PLC Programming and Real-Time Robotics required for all majors, will be taught in the School of Technology using state-of-the-art laboratory equipment. The SoT robotics lab is equipped with four FANUC LR-Mate 200iC industrial robots retrofitted with advanced FANUC vision system: three of the robots have been assembled as an industrial robotic workcell, shown in Figure 6, and incorporated with the conveyer, various sensors and actuators. The individual control of the robots can be achieved via manual mode utilizing teach pendants. The production mode of all three robots is accomplished via PLC.
as a master controller and initializing handshaking protocol between the robots. The forth robot is incorporated with four mechatronics stations, Shown in Figure 7.

Each mechatronics station is equipped with Allen Bradley ControlLogix PLC enabling individual control for the station’s components, as well as handshaking control between all the stations while acting as an assembly line. The SoT PLC lab, shared with ECE department, is equipped with nine the latest Amatrol 990PAB53 Portable PLC Learning Systems, shown in Figure 8 (a) and one process control system, shown in Figure 8 (b).

This equipment allows teaching modern PLC systems as they are used in the industry today. Students learn both basic and advanced applications using the powerful Allen Bradley Compact Logix 5300 PLC, a Panel View Plus terminal, and networks throughout the curriculum. The 990PAB53 System comes with a mobile carrying case, workstation mounting panel, master control relay circuit, Allen Bradley Compact Logix 5300 Programmable Controller, RS Linx and RS Logix 5000 software, a Panel View Plus terminal, an Ethernet Switch, I/O Simulator, five application circuits. Learners will study industry relevant skills, including how to operate and program PLC systems for a wide range of real-world applications. The 990PAB53 Learning System enhances learning by featuring a wide array of real-world applications to allow students to actually see their programs control real systems. In addition to a discrete I/O simulator with discrete switches and indicators, the 990PAB53 includes application circuits and components for thermostatic temperature control, analog temperature control, reversing constant speed motor control, variable speed
motor control with feedback, and stepper motor homing and commissioning. These circuits include basic and advanced applications starting with discrete I/O projects and extending to projects involving analog I/O. In addition to all the features mentioned above, the portable system has outstanding capabilities of fault insertion of software and hardware levels and features 35+ electrical faults. The fault insertion capability provides students with unique, real world like opportunity to troubleshoot the industrial equipment in academic settings.

Availability of the state-of-the-art industrial equipment are important to enable the teaching of critical skills that are very relevant to current industry needs. Currently, laboratory equipment associated with teaching introductory and advance concepts of Programmable Logic Controllers is adequate for a class of 50 students with three laboratory sections. Robotics equipment that is used in Real-Time Robotics and Robotic Vision courses can accommodate a class of 36 students with three laboratory sections. Upon the growth of the program enrollment and subject to available profit, additional equipment will be acquired to support larger classes and provide valuable hands-on training with adequate equipment to student’s ratio. The Dean of the School of Technology is currently communicating with potential industrial partners, donors, and friends to bolster the equipment availability.

13. PROGRAM COSTS

<table>
<thead>
<tr>
<th>PROGRAM REVENUE</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Years 4-n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrollment (MS students)</td>
<td>25</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Tuition revenue (MS students-15 credits/year at $1,143/credit)</td>
<td>$428,625</td>
<td>$514,350</td>
<td>$685,800</td>
<td>$857,250</td>
</tr>
<tr>
<td>Tuition revenue (@ 6 certification courses/year/minimum 3 students in the course with 20% increase every year)</td>
<td>$27,000</td>
<td>$32,400</td>
<td>$38,880</td>
<td>$46,656</td>
</tr>
<tr>
<td>Total tuition revenue</td>
<td>$455,625</td>
<td>$546,750</td>
<td>$724,680</td>
<td>$818,181</td>
</tr>
</tbody>
</table>

ADDITIONAL PROGRAM EXPENSES

| Program Director (in addition to the faculty salary) | $9,000 | $9,360 | $9734 | $10,124 |
| Professor of Practice /Assistant Professor for EET Yr 1 and MET Yr 2. | 1 | 1 | 1 | 1 |
| Salary ($75,000, startup $100,000) | $175,000 | $253,750 | $161,438 | $169,510 |
| Graduate Assistantships (3 GTAs or GRAs/year) at $33,141/student increased by 4% per year. | $99,423 | $103,400 | $107,536 | $111,837 |
| Total annual expenses | $283,423 | $366,510 | $278,708 | $291,471 |

REVENUE – EXPENSES | $172,202 | $180,240 | $445,972 | $526,710 |
One-time Startup Costs:

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketing &amp; Recruiting</td>
<td>$10,000</td>
</tr>
<tr>
<td>Courses development</td>
<td>$48,000</td>
</tr>
<tr>
<td><strong>Total One Time Costs:</strong></td>
<td><strong>$58,000</strong></td>
</tr>
</tbody>
</table>

The anticipated revenue and expenses, based on projected enrollment for the first four years, are presented below. Enrollment is expected to reach steady-state by year four. Non-degree seeking students are individuals who are registered to take courses, possibly to obtain their Robotic certificates, but are not enrolled in the Mechatronics Graduate program.

**Note:** Upon the growth in enrollment, additional laboratory equipment will be acquired to adequately support larger classes. The first priority for the laboratory expansion will be given to Fanuc Industrial Robots, mechatronics and PLC training stations. The revenue funds will be used for additional laboratory acquisition.

### 14. SPACE

The School of Technology has graduate offices located in EERC #228 (seats approximately 8 graduate students). Additional office space for graduate students will be required. Faculty offices and one research lab has also been secured in the EERC.

Lab repurposing involves ongoing coordination between the School of Technology and the Department of Electrical and Computer Engineering. Currently, EERC 418 is undergoing renovations and plans are underway for this to be used for undergraduate EET and ECE students as well as assist with Master’s in Mechatronics training. Collaborative research space with ECE as well as ME-EM will be needed for the research projects and will progress via faculty advisor need-based decisions.

### 15. POLICIES, REGULATIONS AND RULES

**Admission Requirements:** This graduate program is open to excellent candidates who hold or are close to earning a Bachelor’s degree with sufficient technical and engineering related backgrounds. We anticipate our graduate student population to have undergraduate degrees in technical areas of electrical engineering technology, electrical and computer engineering, mechanical engineering-engineering mechanics, and mechanical engineering technology. Graduate applications will be reviewed following Graduate School policies.

**Recommended test scores for admission are as follows:**

Bachelor degree-seeking students with GPAs above 3.0 will be encouraged into the program. Students will GPAs less than 2.5 will not be admitted by the Graduate School.

These scores serve as general guidelines for admission. The Admissions Committee, in making its final decision, will consider the combination of professional knowledge, academic excellence, letters of recommendation, and the Student statements.
17. **ACCREDITATION REQUIREMENTS**


18. **INTERNAL STATUS OF THE PROPOSAL**

Approved by: Dean’s Council  
Date: (needed in Nov 2018)

Approved by: Graduate Faculty Council  
Date: (needed by February 2019)

Approved by: University Senate (Curriculum Policy Committee)  
Date: (needed by March 2019)

19. **PLANNED IMPLEMENTATION DATE**

Deployment of the first courses is expected in fall semester of 2019. This is possible because the proposed degree program relies heavily upon existing courses. Please refer back to Table 2 on pages 17 and 18 for details.
### Appendix A: Master and Major Specific Degree Plans

#### Master’s Degree in Mechatronics cross-disciplinary flowchart

<table>
<thead>
<tr>
<th>Fall</th>
<th>Spring</th>
<th>Fall</th>
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</thead>
<tbody>
<tr>
<td>EET 5144/4144 Real-Time Robotics Systems</td>
<td>EET 5373/4373 Advanced PLC</td>
<td>EET 5144/4144 Real-Time Robotics Systems</td>
<td>EET 5373/4373 Advanced PLC</td>
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<tr>
<td>EET 4311 Advanced Circuits and Controls</td>
<td>EET 5147/4147 Robotic Vision Systems</td>
<td>EET 4311 Advanced Circuits and Controls</td>
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<tr>
<td>MET 5800/4800 Dynamics and Kinematics of Robotics Platforms</td>
<td>EET 4142 Digital Signal and Image Processing</td>
<td>MET 5800/4800 Dynamics and Kinematics of Robotics Platforms</td>
<td>EET 4142 Digital Signal and Image Processing</td>
</tr>
<tr>
<td>MET 5801/4801 Controls of Dynamic Systems</td>
<td>ECE/MEEM 5750 Model-Based Embedded Control System Design</td>
<td>MET 5801/4801 Controls of Dynamic Systems</td>
<td>ECE/MEEM 5750 Model-Based Embedded Control System Design</td>
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<tr>
<td>MEET4378 Electrohydraulic Components and Systems</td>
<td>ECE 5531 Introduction to Robotics</td>
<td>MEET4378 Electrohydraulic Components and Systems</td>
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<td>MEEM 4775 Analysis and Design of Feedback Control Systems</td>
<td>ECE 4262 and Non-Linear Control</td>
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<td>ECE 4262 and Non-Linear Control</td>
</tr>
<tr>
<td>ECE 5455/MEEM 5300 Cybersecurity of Industrial Control</td>
<td>Research EET/EE/MET 5990 MEEM 5999</td>
<td>ECE 5455/MEEM 5300 Cybersecurity of Industrial Control</td>
<td>Research EET/EE/MET 5990 MEEM 5999</td>
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<tr>
<td>MEEM 4775 Analysis and Design of Feedback Control Systems</td>
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<td>MEEM 4775 Analysis and Design of Feedback Control Systems</td>
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<tr>
<td>ECE 4252 Digital Signal Processing and Applications</td>
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<tr>
<td>ECE 4723 Network Security</td>
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<tr>
<td>SAT 3812 Cyber Security I</td>
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<td>SAT 3812 Cyber Security I</td>
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</tr>
</tbody>
</table>
EET Degree Flowchart: Coursework Option

Fall                      | Spring                      | Fall                      | Spring                      
---                       |---                          |---                       |---                          
SAT 3812 Cyber Security I | EET 5373/4373 Advanced PLC  | EET 5311/4311 Advanced Circuits and Controls | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms  
EET 5144/4144 Real-Time Robotics Systems | EET 5142/4142 Digital Signal and Image Proc. | 5XX0/4000 Elective | EET 5147/4147 Robotic Vision Systems  
MET 3130 Statics and Dynamics | EET 5144/4144 Real-Time Robotics Systems | EET 5142/4142 Digital Signal and Image Proc. | MET 3130 Statics and Dynamics  
EET 5590 Research Credits | EET 5144/4144 Real-Time Robotics Systems | EET 5142/4142 Digital Signal and Image Proc. | MET 3130 Statics and Dynamics  
EET 5590 Research Credits | EET 5144/4144 Real-Time Robotics Systems | EET 5142/4142 Digital Signal and Image Proc. | MET 3130 Statics and Dynamics  

EET Degree Flowchart: Thesis Option

Fall                      | Spring                      | Fall                      | Spring                      
---                       |---                          |---                       |---                          
MET 3130 Statics and Dynamics | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms | EET 5590 Research Credits | EET 5590 Research Credits  
EET 5590 Research Credits | EET 5373/4373 Advanced PLC  | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms | EET 5590 Research Credits  
MET 3130 Statics and Dynamics | EET 5373/4373 Advanced PLC  | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms | EET 5590 Research Credits  

EET Degree Flowchart: Report Option

Fall                      | Spring                      | Fall                      | Spring                      
---                       |---                          |---                       |---                          
SAT 3812 Cyber Security I | EET 5373/4373 Advanced PLC  | Graduate Core Electives | EET 5147/4147 Robotic Vision Systems  
EET 5144/4144 Real-Time Robotics Systems | EET 5373/4373 Advanced PLC  | Graduate Core Electives | EET 5147/4147 Robotic Vision Systems  
MET 3130 Statics and Dynamics | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms | Graduate Core Electives | EET 5147/4147 Robotic Vision Systems  
MET 3130 Statics and Dynamics | MET 5800/4800 Dynamics and Kinematics of Robotic Platforms | Graduate Core Electives | EET 5147/4147 Robotic Vision Systems  

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## MET Degree Flowchart: Coursework Option

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<th>Fall</th>
<th>Spring</th>
</tr>
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<tbody>
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<tr>
<td>EET 5147/4147 Robotic Vision Systems</td>
<td>MET 5800/4800 Dynamics and Kinematics of Robotic Platforms</td>
<td>MET 5802/4800 Vibrations of Mechanical Systems</td>
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<tr>
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<td>SAT 3812 Cyber Security 1</td>
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<td>ECE 4262 Digital and Non-Linear Control</td>
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</tbody>
</table>
Minimum Requirements for Graduate Student Handbook (to date)

a) milestones and timelines for graduation,
b) a procedure for changing research advisor, and
c) provision for timely written feedback to all graduate students.

Minimally Compliant programs:

- Humanities (Rhetoric, Theory and Culture)
- Civil and Environmental Engineering
- Materials Science (web site updated since original communication)

These programs do not meet one or both requirements, but do have a handbook online.

- Cognitive and Learning Sciences (ACSHF) (has review process)
- Computer Science (has review process)
- Electrical and Computer Engineering (neither)
- Mathematical Sciences (neither)
- Physics (neither)
- School of Business and Economics (MBA) (neither)

We couldn't find a handbook for these programs, and they didn't email us one.

- Atmospheric Sciences
- Biochemistry and Molecular Biology
- Biological Sciences
- Biomedical Engineering
- Chemical Engineering
- Chemistry
- Computational Science and Engineering
- Data Science
- Environmental Engineering
- Geological/Mining Engineering and Sciences
- Kinesiology and Integrative Physiology
- Mechanical Engineering-Engineering Mechanics
- Meng - Engineering
- School of Business and Economics (BNRE, BACC)
- School of Forest Resources and Environmental Science
- School of Technology