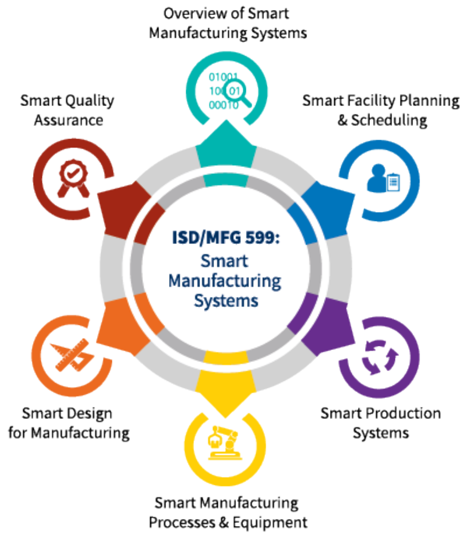
ISD 599 & MFG 599 SMS: Smart Manufacturing Systems (W21)



Instructional Team

- Prof. Judy Jin: Course coordinator & Module 6 instructor (jhjin@umich.edu)
- Prof. Chinedum Okwudire: Module 1 instructor (okwudire@umich.edu)
- Prof. Raed Kontar: Module 2 instructor (alkontar@umich.edu)
- Prof. Semyon Meerkov: Module 3 instructor (smm@umich.edu)
- Prof. Kira Barton: Module 4 instructor (bartonkl@umich.edu)
- Prof. Pingsha Dong: Module 5 instructor (dongp@umich.edu)

GSI: Srinivasa Cheekati, scheekat@umich.edu

Lectures: Mondays and Wednesdays, 9:00-10:30am, remote via Zoom (recorded for later viewing). Attendance to Zoom synchronous lectures or viewing of lecture videos asynchronously is expected for all students. All lecture notes will be posted on Canvas (24 hrs before each lecture), and lecture videos will be posted within 24 hrs after each lecture.

Instructor Office Hours: 1hr per week by the instructor who is teaching in that week. Schedule will be posted on Canvas for each module instructor.

Course Website on Canvas: https://canvas.it.umich.edu/ Select course "ISD 599/ MFG 599 SM WN 2021"

Pre-requisites: None

Objective: The purpose of this SMS course is to equip students with the knowledge and skills needed to meet the demands of the manufacturing workforce of the future. It provides an overview of manufacturing systems from product design to facility planning, processes, production systems, and quality control techniques. The role of smart technologies, like data analytics, cloud computing and automation in reshaping manufacturing engineering is emphasized. Course content is reinforced through case studies.

Course grading policy: 100 points

- Grading (HW, lab, Quizzes/Exam*) for each of Module 2~6: 16 points per module (total 80 points)
- Grading for Module 1 (based on student presentation**): 20 points

  *Assignments and Quizzes/Exam: Module instructors may assign graded assignments and quizzes/Exams covering the contents of each of their modules.

  ** Student presentation will be graded based on
  - How to synthesize your learnings from multi-modules in class?
  - What's your thoughts about SM (contents & integration) beyond the class?

- No final exam in this course.
- Final letter grad: A+ (>95), A (>90), A- (>85), B+ (>80), B(>75), B- (>70), C+(>65)

Course-Specific Policies:

- You are allowed to discuss HW with other students. However, your solutions/reports must be based on your own work and you must indicate whom you discussed with. You are not allowed to share your detail solution or reports with other students. You are also not allowed to possess, look at, use or in any way derive advantage from the existence solutions prepared in prior years from former students' work. Violation of this policy will be treated as a breach of the College of Engineering's Honor Code and will be filed with the Honor's Council.

- All electronic communications with the instructors and GSI on course-related material should happen via email with an optional discussions tab in Canvas based on each instructor's communication rule. When you send your emails, please send your email to both GSI and the instructor who is teaching in that week. Please put email subject with MFG599 SMS. If your question has not been answered within 24 hours during workday, you may resend a remind email to both GSI and the instructor with subject "Remind MFG599SMS," in case your case was missed. GSI and Instructor will try to answer your question within 24 hrs during workday or the first workday if your questions were sent on weekends/holidays.

- Other specific policies will be announced in class and on Canvas as the need arises.

Course Modules: This course has six interconnected modules:

Module 1: Overview of Smart Manufacturing Systems: Students will: (1) be introduced to the concept and fundamentals of SMS that involve leveraging smart technologies to enable higher quality, faster production and lower costs in manufacturing; (2) be introduced to the two dimensions of SMS: manufacturing technologies and smart technologies. The first dimension of manufacturing technologies involves (i) design for manufacturing; (ii) facility planning; (iii) production systems; (iv) manufacturing processes and equipment and (v) quality assurance and control. The second dimension of smart technologies involves: (a) data analytics; (b) AI; (c) robotics; (d) cloud computing; (e) IoT; (f) cybersecurity; (g) modeling and simulation; and (h) visualization and immersion; (3) demonstrate an ability to integrate and extend concepts learned to topics not covered within the course.

Module 2: Smart Facility Planning & Scheduling: Students will: (1) be given an overview on the benefits of efficient facility and warehouse design; (2) be introduced to facility types for different products and how an economic evaluation can be established for each type; (3) data requirements for layout decisions will then be discussed along with process and relationship charts that help make the final layout decision; (4) location models that provide optimal layout allocation within a facility will explained and implemented with small-scale case studies. The presented facility allocation and management techniques will be studied within the setting of Industry 4.0. This includes (a) IoT enabled systems (b) Cloud based data gathering, storage and analysis (3) AI and smart decision making where connectivity is utilized to establish both smart and connected facilities.

Module 3: Smart Production Systems (SPS): Both analytical foundations and computational tools will be discussed. Students will learn: (1) methods of mathematical modeling of various classes of production systems (e.g., serial lines, assembly systems, closed lines, lines with rework, single- and multi-job production, etc.) with machines obeying various reliability and quality models (e.g., Bernoulli, exponential, etc.). (2) Methods for calculating various performance metrics (e.g., throughput, work-in-process, lead time, leanness, customer demand satisfaction, etc.) and their constrained and unconstrained improvability. Students will develop working knowledge of computational tools such as: (3) Production Systems Engineering (PSE) Toolbox, which implements the analytics mentioned above. (4) Programmable Manufacturing Advisor (PMA), which is based on PSE Toolbox; programming and deploying a PMA at any production system makes it smart (PMA-based SPS). Operation of several PMA-based SPS will be illustrated. The module's labs will be based on PSE Toolbox and PMA.

Module 4: Smart Manufacturing Processes & Equipment: Students will: (1) be given an overview of traditional and current manufacturing processes and equipment; (2) be introduced to the SM concepts that are beginning to be integrated into manufacturing processes and equipment; (3) develop an understanding of a few key technologies that have or are poised to have a significant impact on the integration of SM concepts into manufacturing processes and equipment; (4) will further enhance their understanding through the introduction of a case study focused on SM technologies within additive manufacturing; (5) participate in an experimental demonstration of anomaly/fault detection for additive manufacturing processes. SM technologies that may be integrated into this module include: (a) data analytics; (b) AI; (c) robotics; (d) cloud computing; (e) IoT; (f) cybersecurity; (g) modeling and simulation; and (h) visualization and immersion.

Module 5: Smart Design for Manufacturing: Students will learn how to use mechanics-based first-principle models for achieving smart design of manufacturing processes. These include: (1) mechanics principles underpinning modular design and assembly; (2) basic thermomechanical processes and their interactions in modern manufacturing; (3) reduced-order modeling techniques for optimizing modularity attributes and process sequencing for achieving smart modular assembly in dimensional variation control.

Module 6: Smart Quality Assurance via Integrative Data-Driven Decision-Making: Students will: (1) be given an overview of quality control concepts and fundamental statistical quality control technologies including design of experiments, statistical process control, and acceptance sampling. (2) Gain the concept and principles of smart quality control technologies including the data analytics methods and system-level optimal decision-making. The course will use case studies to show how the smart quality control technologies are applied in real manufacturing systems, which include (a) integrative decision making for process design, process control, and maintenance decision for quality assurance; (b) analytical modeling of process variation propagation for complex multistage manufacturing process control; (3) data analytics and AI methods for in-situ process monitoring, diagnosis, and control for defects reduction and prevention.

Course Outline & Lecture Schedule

Dates	Module Name
	M1: Course Overview (2 Lectures) **Prof. Chinedum Okwudire (okwudire@umich.edu**
1/ 20 (W)	• Course Policy • Overview of Manufacturing Engineering • Flow of manufacturing from product design to planning/scheduling strategies, processes, systems and quality control • Definition of smart manufacturing as the leveraging of advances in information, automation, computation, software, sensing, and networking technologies to enable higher quality, faster production and lower costs in manufacturing.
1/25 (M)	• Overview of key enabling technologies for smart manufacturing · Industrial Internet of Things · Cloud computing and cybersecurity · Big data analytics and machine learning · Digital twin/shadow and thread · Robotics and automation · Visualization and immersion • Goal of course: To enable students to appreciate the roles of enabling technologies to advance manufacturing with regard to improving quality, productivity and cost-effectiveness.
	M2. Facility Planning & Scheduling (4 Lectures) **Prof. Raed Kontar (alkontar@umich.edu**
1/27 (W)	M2-1: Product Development and economic evaluation • Cellular Manufacturing • Assembly line balancing
2/1 (M)	M2-2: Data requirements and layout decisions • Process Flow • Relationship chart
2/3 (W)	M2-3: Relationships and scheduling • Flow analysis
2/8 (M)	M2-4: Location models and • Pair-wise exchange method • Graph-Based Method

	M3. Production Systems (4 Lectures) **Prof. Semyon Meerkov (smm@umich.edu)**
2/10 (W)	M3-1: Introduction and module overview • Smart Production Systems (SPS) • Programmable Manufacturing Advisor (PMA) • PMA-based SPS • SPS vs. Industry 4.0 • On-line demonstration PMA-based SPS operation • Module goals
2/15 (M)	M3-2: Analytical foundation of SPS: Production Systems Engineering (PSE) • Elements of PSE • Production system types • Machine and buffer parameters • Performance metrics • Mathematical modeling of production systems Lab: Develop a mathematical model of a given production system
2/17 (W)	M3-3: Analytical foundation of SPS: Production Systems Engineering (PSE) (cont) • PSE analytics for performance evaluation, leanness, quality, transients, and “what if” analysis • System-theoretic properties of production systems • PSE Toolbox (http://productionsystemsengineering.com) Lab: Design of continuous improvement projects with analytically predicted results (using PSE Toolbox)

2/22 (M)	M3-4 PMA-based Smart Production Systems
	• PMA-based SPS architecture
	• PMA software architecture
	• PMA-based SPS databases
	• On-line demonstrations (https://psetoolbox.com/#/pma)
	  · Automotive underbody assembly systems (large manufacturing organization)
	  · LED streetlight assembly (mid-size manufacturing)
	  · Hot-dip galvanization plant (small manufacturer)
	Lab: Making production systems smart (using PMA)

	M4: MFG Processes & Equipment (4 lectures) **Prof. Kira Barton (bartonkl@umich.edu)**
2/24 (W)	M4-1 • Introduction and module overview • Examples of manufacturing processes • Examples of equipment

3/1 (M)	M4-2 • Overview of SM concepts in processes and equipment • Key technologies
3/3 (W)	M4-3 • Example Case Study: AM • process overview • Integration of SM technologies: IIoT, DT, AR/VR, data analytics
3/8 (M)	M4-4 • Case Study continued • Tour of instrumented set-up; data collection • Data analysis and analytics - anomaly detection
	M5. Math-based Design for Manufacturing (4 Lectures) **Prof. Pingsha Dong (dongp@umich.edu)**
3/10 (W)	M5-1: Mechanics-based principles for modular design and assembly • Modern challenges – structural lightweigting • Key quality attributes for modular assembly • Principles of modular/interim products • Real world examples
3/15 (M)	M5-2: First-principle based modeling of thermomechanical processes–theory • Simple thermoplasticity descriptions (1D) • 1-bar, 3-bar, and n-bar models • Applications in plate rolling, cutting, welding assembly
3/17 (W)	M5-3: First-principle based modeling of thermomechanical processes – applications • Plate/sheet rolling • Thermal cutting • Welding/joining and assembly • Process interactions and sequencing
3/22 (M)	M5-4: Reduced-order finite element process modeling and applications • Plastic zone estimation • Residual stress and distortion evaluation • Application examples • In-class computer lab
	M6: Smart Quality Assurance (4 Lectures) **Prof. Judy Jin (jhjin@umich.edu)**
3/24 (W)	M6-1: Introduction and module overview • Quality control concept • Overview of statistical quality control technologies · SPC, DOE, Acceptance Sampling

3/29 (M)	M6-2: Quality Assurance Systems • System architectures • Design for quality • Process oriented quality control • Integrative quality control in PLM • Case study
3/31 (W)	M6-3: Quality control in multistage assembly processes • Variation propagation analysis and inference using state space model • Integration of SPC and APC for adaptive process adjustment • Case study
4/5 (M)	M6-4: Quality control in the process with cyclic operations • Mixed effect modeling for process variation analysis and inference • Response surface modeling for quality prediction and control • Case study
4/7 (W)	**No lecture (Students prepare their presentation)**
4/12 (M) 4/14 (W) 4/19 (M) 4/21 (W)	**Students' presentation (4 Lectures)** **Prof. Chinedum Okwudire (okwudire@umich.edu**