

Bridging the Skills Gap: Developing a Smart Manufacturing Engineering Technology Concentration for the Future Workforce

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Abstract

The face of manufacturing has been changing since the 1990s. There are several initiatives to revitalize the traditional manufacturing processes, while there is a big interest in increasing the adaptation and implementation of modern manufacturing techniques like Smart Manufacturing (SM) and Industry 4.0. The integration of advanced technologies like Data Analytics (DA), Internet of Things (IoTs), Artificial Intelligence (AI), Digital Twins (DT), Mixed Reality (MR), Additive Manufacturing (AM), and Control Techniques into manufacturing is a new concept, and that is called SM. Overall, SM integrates all these advanced technologies to enhance productivity, efficiency, and quality in production processes. Lately, universities have been creating degree programs on SM to prepare their students for current and near-future workforces in the manufacturing industry. This paper presents the current gap that the Smart Manufacturing Engineering Technology (SMET) concentration addresses. Specifically, why is this concentration essential for the future workforce? How does it address specific challenges in manufacturing education? It will present a currently developed SMET concentration under an Engineering Technology (ET) program.

1. Background

Since the end of the last century, the manufacturing industry has been significantly evolving due to the quick emergence of novel technologies and the increasing need for more flexible, sustainable, and efficient manufacturing methods [1]. The idea that traditional manufacturing has given way to what is now called SM embodies this change. As can be seen in Figure 1, the notion of smart industry is fundamentally about incorporating advanced technologies into the production process, including several automation, control, and robotic components [2][3]. All of these advanced manufacturing components help producers better meet the market's ever-changing demands while also increasing production, efficiency, and quality [4][5].

SM involves an essential reconsideration of production systems instead of just continuing traditional manufacturing. As can be seen in Figure 2, SM is not merely an evolution of traditional manufacturing but a fundamental reimagining of production systems, including several high-tech technologies in AM, AI, IoTs, and many others [6][7]. The ability to harness real-time data, implement predictive analytics, and optimize processes through interconnected systems has established SM as a cornerstone of Industry 4.0. As these technologies continue to mature, their widespread adoption has created a pressing need for a workforce equipped with the skills to navigate and innovate within this new industrial landscape [8][9][10].

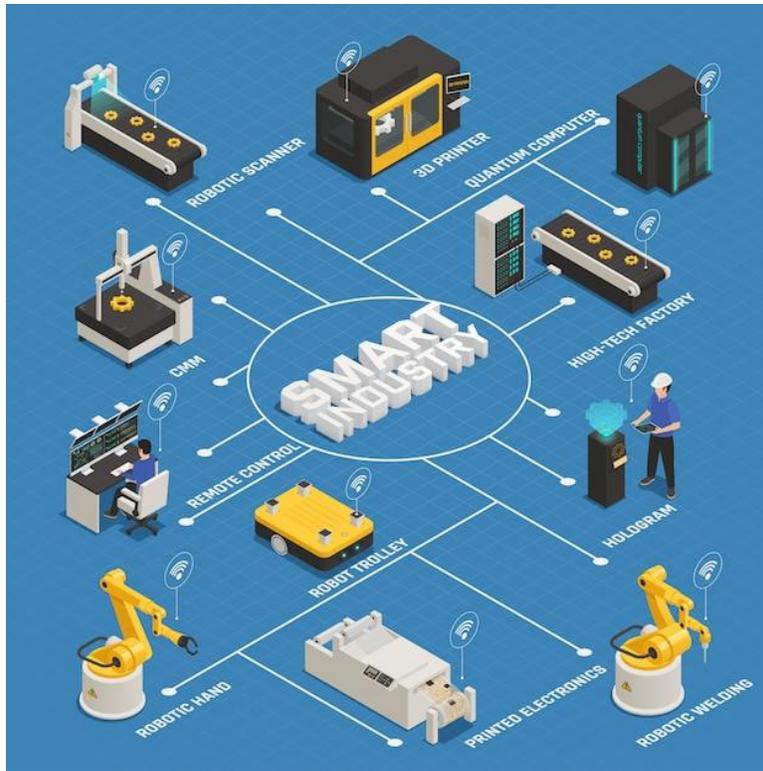


Figure 1: Today's Smart Industry [11]



Figure 2: Diverse Components of the Smart Manufacturing Systems [11]

Despite the growing importance of SM, a significant skills gap persists in the current workforce. Traditional engineering and technology education programs often fall short in preparing graduates for the interdisciplinary and technologically complex nature of modern manufacturing environments. A persistent skills gap in U.S. manufacturing could leave 1.9 million positions unfilled by 2033 (see Figure 3), creating significant challenges for growth and innovation [12]. This gap has highlighted the urgent need for academic programs that specifically address the knowledge and skills required for SM [13].

Universities worldwide are beginning to respond to this need by developing specialized degree programs and concentrations focused on SM. These initiatives aim to equip students with the technical expertise, problem-solving abilities, and adaptability required to thrive in a rapidly evolving industry. However, the development and implementation of such programs present unique challenges, including integrating emerging technologies into curricula, fostering industry-academia partnerships, and ensuring alignment with current and future workforce demands [14].

CESMII (Smart Manufacturing Institute) is a non-profit organization funded by the U.S. government [15]. It provides industrial networking opportunities, education and workforce development, funded research initiatives, and access to a Smart Manufacturing Innovation Platform to support the nation's digital transformation.

Currently, the organization provides many educational opportunities, all in one place. All CESMII-endorsed courses, certifications, and degree programs have undergone several verification processes to teach learners the most relevant and cutting-edge content modules. Based on the data provided in January 2025, CESMII has several educational opportunities for its more than 200 member organizations. A partial list of these opportunities is presented in Table 1.

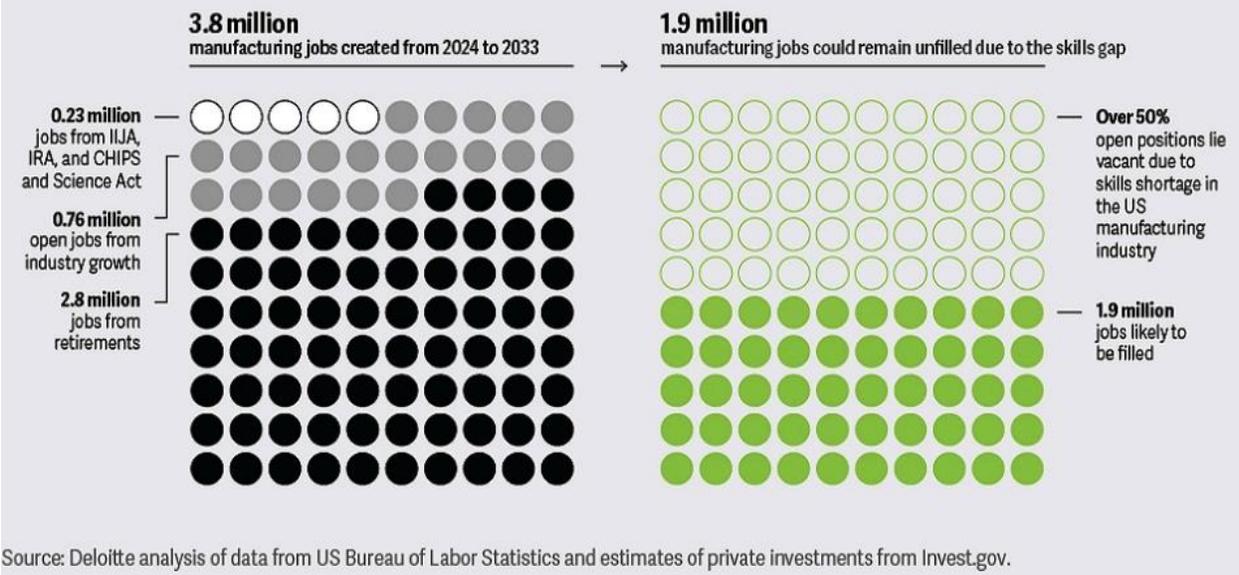


Figure 3: Projected Unfilled Manufacturing Positions by 2033 [12]

Table 1: List of US Academic Institutions Providing Smart Manufacturing Education [16]

Academic Institution	Delivery	Timeframe	Content
California State University Northridge	Instructor-led	15 hours	Advanced Professional Development – Smart Manufacturing
Cleveland State University	Online	6 hours	Introduction to Smart Manufacturing – Building Professional Expertise in Industry 4.0
Massachusetts Institute of Technology	Instructor-led	50 hours	Smart Manufacturing – Moving from Static to Dynamic Operations
Purdue University	Instructor-Led undergraduate program	Four years	Smart Manufacturing Industrial Informatics Degree
Rensselaer Polytechnic Institute	Both online and instructor-led	20 hours	Smart Manufacturing – Building Your Strategic Roadmap
Rensselaer Polytechnic Institute	Both online and instructor-led	Eight hours	Certification Course on Smart Manufacturing
University of Texas at El Paso	Hybrid, instructor-led, and online	14 weeks – 3 instructional hours per week	Graduate Certificate in Smart Manufacturing
West Virginia University	Instructor-led	Four months, 1.25 hours two days a week	Smart Manufacturing under Industrial Engineering

The Smart Manufacturing Industrial Informatics program at Purdue University is a four-year degree combining mechanical, computer, and electrical engineering technologies [17]. This interdisciplinary major emphasizes the integration of science, engineering, information systems, and computing to advance manufacturing processes. Students gain expertise in Industry 4.0 technologies, including Industrial IoTs (IIoTs), AI, DA, cloud and edge computing, MR, systems modeling and simulation, autonomous human-robot systems, AM, and cybersecurity. Graduates are well-equipped for roles such as digital manufacturing engineers, manufacturing data analysts, process automation engineers, and smart factory managers.

To address the need for the current manufacturing workforce, Cuyahoga Community College (Tri-C) collaborated with industry partners to create two specialized programs: the Bachelor of Applied Science in Integrated Digital Manufacturing Engineering Technology (IDMET), a four-year degree, and the Associate of Applied Science in Mechatronics, a two-year degree. Both programs are part of the broader field of SM [18]. Ohlone College's Smart Manufacturing Technology program provides entry-level manufacturing technicians with the relevant

knowledge and skills for Advanced Manufacturing in the 21st Century [19]. The program provides students with knowledge and skills for Industry 4.0 standards, IIoTs, AM, and emerging Manufacturing processes. Although Penn State – New Kensington has no degree program in SM, its four-year degree program in electromechanical engineering technology and MIT have been playing active roles in workforce development in SM for almost five years [20][21].

This paper focuses on addressing these challenges by developing an SMET concentration within an ET degree program. The concentration is designed to bridge the skills gap by combining theoretical knowledge with practical, hands-on experience in advanced manufacturing technologies. By examining the components and rationale behind this program, this paper aims to demonstrate its potential to meet the needs of the modern manufacturing industry and prepare students for success in an SM environment. Thus, the paper is structured to outline the upcoming SMET concentration, set to launch in Fall 2025.

In the following section, this paper will discuss the specific gaps in traditional manufacturing education that the SMET concentration seeks to address. It will also outline the curriculum's unique features and alignment with industry demands. Ultimately, this developmental effort serves as a model for reimagining manufacturing education to meet the challenges and opportunities of Industry 4.0.

2. Smart Manufacturing Engineering Technology Concentration

Currently, the program is a 123-credit-hour 4-year degree program in ET. It has been accredited by the ETAC of ABET since 2013. All degree students select a concentration when they declare their majors. The program has offered two concentrations in Mechatronics Engineering Technology and Engineering Technology Management. SM is a new concentration that has been added recently. The other unique feature of the program is the Minor in Business. All ET majors graduate with a Minor in Business since they complete the requirements of a Minor in Business. Figure 4 shows the courses taken by the students in the junior and senior years under the SMET concentration.

2. 1. Industrial IoT Networks and Systems

This course is an introduction to IIoT devices, networks, and standards in the context of industrial automation systems. Topics include hardware, architecture, protocols, standards, and security practices. The outcomes of the course are given as follows:

- Describe, apply, and assess the performance of standard input and output components in industrial applications
- Identify the power requirements for the operation of an IoT device
- Define and describe standards, challenges, and best practices relating to security.

The prerequisites of the course are Programming for Engineers and Applied Electricity and Electronics.

2.2 Mixed Reality in Manufacturing

The coverage of this course is on MR applications in IIoT-based manufacturing systems, superimposing digital content onto physical systems, and integrating data from smart and connected manufacturing production operations, processes, and machines. The outcomes of the course are given as follows:

- Outline the benefits and applications of MR in SM systems
- Integrate MR concepts with IIoT technologies to develop SM applications.
- Demonstrate proficiency in using hardware, software tools, and technologies to design and prototype effective MR applications for manufacturing

The prerequisite of the course is Industrial IoT Networks and Systems.

JUNIOR YEAR			
Fall	Cr. Hrs.	Spring	Cr. Hrs.
MET 3100 Applied Physical Metallurgy or ME 3010	3	MET 3003 Principles of Metal Casting	3
MET 3303 CAD for Technology	3	ACCT 3720 Survey of Accounting	3
MET 3713 Methods Design & Work Measurement	3	MET 3403 Applied Machine Elements	3
MET 3200 Applied Electricity & Electronics	3	MATH 3070 Statistical Methods or ECON 3610 Business Statistics I	3
BMGT 3510 Management & Organizational Behavior	3	*MET 3620 Industrial IoT Networks & Systems	3
Total Credit Hours	15	Total Credit Hours	15
SENIOR YEAR			
Fall	Cr. Hrs.	Spring	Cr. Hrs.
MET 3150 Maintenance Technology	2	LAW 2810 Business Legal Environment & Ethics	3
COMM 2025 or PC 2500 Communications	3	HIST 2010 Early US History	3
FIN 3210 Principles of Managerial Finance	3	*MET 4420 Intro to Additive Manufacturing	3
MKT 3400 Principles of Marketing	3	*MET 4520 Autonomous Robots in Manufacturing	3
*MET 4000 Advanced Foundry Technology	3	*MET 4720 Senior Projects for Smart Manufacturing	3
*MET 4320 Mixed Reality in Manufacturing	3		
Total Credit Hours	17	Total Credit Hours	15

*Courses specific to this concentration

Figure 4: Courses Specific to Smart Manufacturing Engineering Technology Concentration

2.3. Introduction to Additive Manufacturing

This course covers the AM processes and material selection, design for additive manufacturing, support structure generation, printing process planning, and quality control techniques, such as monitoring, inspection, and surface modification. The outcomes of the course are the following:

- Demonstrate comprehensive knowledge of the broad range of AM processes, devices, capabilities, and materials that are available
- Consider the design requirement and freedom for AM and edit the part geometry for better printing performance
- Identify AM-relevant process monitoring, non-destructive evaluation, and surface modification methods

The prerequisite of the course is CAD for Technology.

2. 4. Autonomous Robots in Manufacturing

The Autonomous Robots in Manufacturing course covers robot cognition, the application of robot systems in unstructured manufacturing environments, intelligent robotics, machine vision, and human-robot interaction, with particular emphasis on applications for SM. The outcomes of the course are the following:

- Describe the fundamental concepts of mobile and field robotics in unstructured SM environments.
- Apply intelligent sensory perception algorithms and robot control through sensory feedback for visual and tactile sensing.
- Solve real-world manufacturing problems using collaborative robots and autonomous robots.

The prerequisite of the course is Mixed Reality in Manufacturing.

2. 5. Senior Projects for Smart Manufacturing

This course is the capstone experience, which requires both teamwork and individual skills in identifying and solving an SM problem. It requires the application of design, manufacturing, analysis, project management plan, and public presentation of results. The outcomes of the course are the following:

- Decompose an SM problem into discrete steps and develop processes leading to desired outcomes.
- Complete project development through phases of preliminary design, analysis, drawing submittals, fabrication, and testing.
- Complete a written report detailing the design process and results.
- Develop a work distribution list for the solution of the project tasks and assign a team leader. Present its results as a team.

The course prerequisites are IIoT Networks & Systems and Process and Control Applications. Autonomous Robots in Manufacturing is also a co-requisite.

3. Addressing Skill Gaps in Smart Manufacturing Through Newly Developed Concentration

The field of SM is evolving rapidly, driven by advances in automation, DA, robotics, and connectivity. However, adopting these technologies is often hindered by a significant skill gap among the workforce [22]. The SMET concentration addresses these gaps by equipping students with the knowledge and practical skills necessary for modern industrial environments. Below, we outline the critical skill gaps this concentration seeks to bridge and how its tailored coursework prepares students to meet industry demands.

3. 1. Skill Gaps in Industrial IoT and Networking

IIoT is at the heart of SM, enabling real-time data exchange, predictive maintenance, and advanced automation. Despite its importance, many current professionals lack expertise in IIoT devices, networks, and security protocols. The course IIoT Networks and Systems directly

addresses this gap by providing foundational knowledge in IIoT hardware, architecture, and standards. Students learn to assess the performance of IIoT components, manage power requirements, and implement best practices for cybersecurity—a critical concern in interconnected systems. Prerequisites in programming and applied electronics ensure that students are well-prepared for the technical depth of this course.

To complement this foundational knowledge, the course integrates practical applications through lab exercises and industry-aligned projects, ensuring students gain hands-on experience with IIoT system deployment and troubleshooting. These projects include real-world scenarios such as configuring IIoT sensors for predictive maintenance, optimizing data flow within networked manufacturing environments, and addressing power management challenges in resource-constrained devices. By incorporating the latest tools and standards in IIoT architecture, the course aligns with evolving industry needs, fostering proficiency in integrating IIoT systems with emerging technologies like cloud platforms and edge computing. Additionally, partnerships with local manufacturers provide students opportunities to apply their skills in internships and cooperative programs, further bridging the gap between academic training and industry expectations.

3. 2. Bridging Mixed Reality Knowledge for Manufacturing

MR technologies hold immense potential for transforming manufacturing through enhanced visualization, simulation, and remote collaboration. However, few professionals are proficient in integrating MR with IIoT technologies. The MR in Manufacturing course prepares students to leverage MR in industrial applications by teaching them to design and prototype MR solutions. This course ensures graduates can address the growing demand for immersive technologies in manufacturing environments, filling a niche skill gap in the workforce.

Emphasis is placed on the seamless integration of MR with IIoT systems, ensuring compatibility with data-driven manufacturing processes and enabling real-time visualization and decision-making. Additionally, students learn to address challenges like latency optimization, cybersecurity, and interoperability, making them industry-ready to implement MR solutions that enhance efficiency, collaboration, and innovation in smart manufacturing environments.

3. 3. Developing Expertise in Additive Manufacturing

AM is revolutionizing product development and customization, yet its adoption is often slowed by a lack of skilled personnel. Professionals frequently struggle with process planning, design for AM, and quality control techniques. The course Introduction to AM provides students with hands-on experience in AM processes, material selection, and design optimization. By focusing on non-destructive evaluation and surface modification techniques, students are trained to ensure high-quality production, thus addressing the industry's demand for AM specialists.

To complement this foundation, the course incorporates industry-relevant projects and case studies that allow students to address real-world challenges in additive manufacturing. These projects include tasks such as optimizing designs for specific AM technologies, developing process parameters for new materials, and implementing quality assurance protocols using

cutting-edge tools. Students also explore the integration of AM with broader smart manufacturing systems, such as linking AM processes to IIoT networks for real-time monitoring and control. This practical, systems-oriented approach ensures that graduates not only possess technical expertise but also understand how to align AM processes with the evolving demands of modern manufacturing ecosystems.

3. 4. Addressing Robotics Proficiency in Unstructured Environments

Robotics is a cornerstone of SM, particularly in unstructured environments where flexibility and adaptability are crucial. The Autonomous Robots in Manufacturing course equips students with knowledge of robot cognition, sensory perception algorithms, and human-robot collaboration. By solving real-world manufacturing problems using autonomous and collaborative robots, students gain the practical experience needed to thrive in the robotics-driven future of manufacturing. This course bridges the gap between theoretical understanding and application, preparing students for challenges in diverse manufacturing settings.

3. 5. Cultivating Project Management and System Integration Skills

SM requires not only technical expertise but also the ability to integrate systems and manage complex projects. The Senior Projects for SM course acts as a capstone experience, allowing students to apply their knowledge to real-world problems. Through project planning, design, analysis, and fabrication, students develop essential skills in teamwork, leadership, and communication. By working on multidisciplinary projects, they learn to decompose complex problems, distribute tasks effectively, and present their findings—skills highly sought after in the industry.

Conclusion

The SMET concentration is designed to address the critical skill gaps in IIoT, MR, AM, robotics, and project management. Through a comprehensive and hands-on curriculum, this concentration prepares graduates to meet the challenges of modern manufacturing environments, ensuring they can contribute effectively to the industry's ongoing transformation. By aligning educational outcomes with industry needs, this program empowers students to become leaders in the field of SM. At this stage, the concentration was initiated in Fall 2024. The findings of the initial implementation and attainment of the developed course outcomes will be presented in future publications.

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