Educating the Workforce in Cyber & Smart Manufacturing for Industry 4.0

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Abstract

The objective of this paper is to outline the details of a recently-funded National Science Foundation (NSF) Advanced Technological Education (ATE) project that aims to educate and enable the current and future manufacturing workforce to operate in Industry 4.0 environments. Additionally, the startup procedures involved, the major ongoing activities during year-one, and preliminary impressions and lessons learned will be elaborated on as well.

Industry 4.0 refers to the ongoing reformation of advanced manufacturing (Operation Technologies - OT) enabled by advances in automation/data (Information Technologies - IT). Cyber-enabled smart manufacturing is a multidisciplinary approach that integrates the manufacturing process, its monitoring/control, data science, cyber-physical systems, and cloud computing to drive manufacturing operations. This is further propelled by the dissolution of boundaries separating IT and OT, presenting optimization opportunities not just at a machine-level, but at the plant/enterprise-levels. This so-called fourth industrial revolution is rapidly percolating the discrete and continuous manufacturing industry. It is therefore critical for the current and future US workforce to be cognizant and capable of such interdisciplinary domain knowledge and skills.

To meet this workforce need, this project will develop curricula, personnel and communities in cyber-enabled smart manufacturing. The key project components include: (i) Curriculum Road-Mapping and Implementation – one that integrates IT and OT to broaden the educational experience and employability via road-mapping workshops, and then to develop/implement curricula, (ii) Interdisciplinary Learning Experiences – through collaborative special-projects courses, industry internships and research experiences, (iii) Pathways to Industry 4.0 Careers – to streamline career pathways to enter Industry 4.0 careers, and to pursue further education, and (iv) Faculty Development – continuous improvement via professional development workshops and faculty development leaves. It is expected that this project will help define and chart-out the capabilities demanded from the next-generation workforce to fulfill the call of Industry 4.0, and the curricular ingredients needed to train and empower them. This will help create an empowered workforce well-suited for Industry 4.0 careers in cyber-enabled smart manufacturing. The collaborative research team's experience so far in starting up and implementing year-one activities has further shed light on some of the essentials and practicalities needed for achieving the grand vision of enabling the manufacturing workforce for the future.

Introduction & Background

Industrie 4.0, a term coined in Germany (during 2011), refers to the ongoing reformation of advanced manufacturing (Operating Technologies - OT) enabled by advances in automation/data (Information Technologies - IT) [1]. Often translated in the United States under the umbrella of Smart Manufacturing [2], it is an emerging trend in the digitization of manufacturing that includes certain key technological components. Among the descriptors of the ***fourth industrial revolution***, many coined by consultancies in first-world countries, perhaps McKinsey [3, 4] captures best, the overarching disruptions that inevitably gave birth to, and essentially constitutes Smart Manufacturing [5]:

(i) The rise in data volumes, computational power, and connectivity,
(ii) The emergence of analytics and business-intelligence capabilities,
(iii) New forms of human-machine interaction, and
(iv) Improvements in transferring digital instructions to the physical world.

As cited in the Industrial Ethernet Book [6], IT is the software, hardware, networks, communication, and systems that store, process, and deliver information across an organization, while OT comprises of machinery, physical plant equipment, and remote industrial software/hardware that can be monitored and controlled. The convergence of such IT and OT is the cornerstone of Industry 4.0, enabling its various facets such as the industrial internet of things (IIoT), big data and analytics, augmented reality (AR), advanced robotics, additive manufacturing, cloud computing, cybersecurity, etc. **Figure 1** shows some of the key elements of the Smart Manufacturing framework and its benefits. This connected enterprise enables operational excellence-focused benefits such as energy optimization, asset utilization, process insights and health monitoring, while at the same time promoting sustainable/profitable manufacturing.

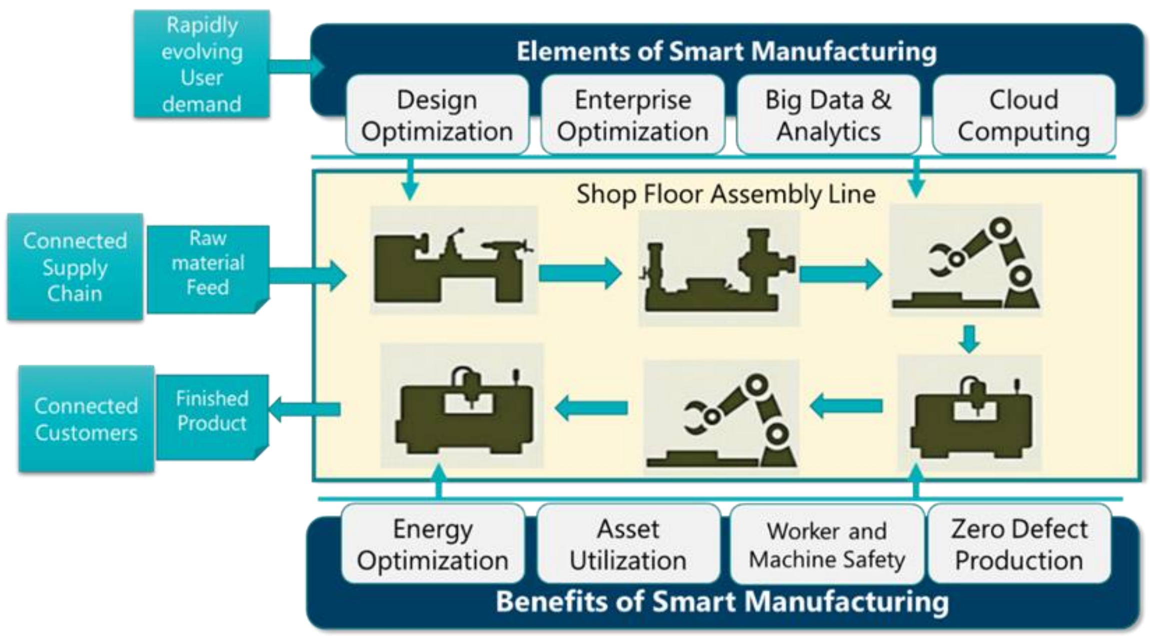

Figure 1: Key elements and benefits of the connected Smart Manufacturing enterprise [5]

Smart Manufacturing is thus a multidisciplinary approach that integrates physics-based process modeling, process monitoring/control, data science, cyber-physical systems, and cloud computing to drive manufacturing operational excellence. The ***convergence of IT and OT is critical*** to allow interaction across the four layers of automation, within the automation pyramid standardized by the International Society of Automation (ISA) in 2010 [7], where, Level-0: Sensors/actuators (field-level); Level-1: Real-time control systems (control-level); Level-2: Data management, modeling, learning (supervisory-level); Level-3: Manufacturing operations management (plant-level); Level-4: Business planning and logistics (enterprise-level).

Application areas span equipment health and status updates provided to consumers of machinery and HVAC systems, mobility avenues (*e.g.*, traffic, monitoring of commercial fleets, telemetry for farming, fuel efficiency, etc.), and infrastructure (building security, climate control, elevators, etc.). While such situational cognizance typically leads to a manual intervention to investigate or remedy a potential problem, growing levels of automated decision making and control are being implemented [8].

Decision-making and control actions are more prevalent in the digital factory [5]. For instance, parts are tracked through the inventory, retrieval, processing, assembly and quality testing/control stages by radio-frequency identification (RFID). In these instances, real-time data is collected through an array of sensors, quality management is accomplished through automated decision-making, tangible actions conducted through control to ensure products translate smoothly through the process, and, finally, the data is recorded in a time-stamped cloud-database for future use. Thus, Smart Manufacturing enabled by the convergence of IT and OT is percolating all sectors within manufacturing, and rapidly being standardized. It is therefore critical to empower the next-generation workforce to respond to the call of Industry 4.0!

Motivations & Rationale

The third industrial revolution (due to the advances in computers/automation) has had the effect of changing the primary role of the American manufacturing workforce from that of a 'field/floor' worker to a supervisory one (much like the analogy of a human harvester to a wheat combine operator). This resulted in a reduction of the labor force needed, but in contrast, yielded many times the productivity; in other words, the worker efficiency or the manufacturing output per worker multiplied. As the report from the *NSF Workshop on Research Needs in Machining and Machine Tools* (from March 2018) put it, "The manufacturing jobs have not been lost, they have changed!" One would expect that this reduction in the needed labor force would lead to a shortage of open positions. On the contrary, it led to thousands of manufacturing jobs going unfilled, simply because the incoming workforce did not possess the needed knowledge/skills. As the *Smart Manufacturing Leadership Coalition (SMLC)* says, "The Biggest Change is in People — Not Technology! [9]" The major reason for this workforce shortage is the cultural divide between IT and OT, which has had traditionally siloed existences; with a growing manufacturing sector, this issue will be exacerbated with manufacturers struggling to fill positions.

Next, according to the research report published by MarketsandMarkets [10], the Smart Manufacturing market was estimated to be worth $170 billion in 2018, and expected to be worth $300 billion by 2023 (a compound annual growth rate of 12%); the energy and power industry is forecasted to hold the largest share of the Smart Manufacturing market during this period. The south-central US (that includes the gulf coast states), has economies rapidly growing in the energy/manufacturing sectors, and hence is projected to have a significant upcoming workforce need. Further, workforce development responds to workforce needs. What this results to in a rapidly changing industrial landscape, is a significant lag between the need and the supply of a qualified workforce. As predicted in *SME's 3rd Smart Manufacturing Report* [11], there is an inevitable and impending need, and hence it would be prudent and beneficial to aggressively build a Smart Manufacturing workforce [12] for the near future.

Finally, as per the *FY-2020 Administration Research and Development Budget Priorities* memo (M-18-22) [13] from Washington DC, American Manufacturing (one of the 8 *R&D Priority Areas*), calls for agency investment in the first priority technology area of smart/digital manufacturing. Further, the first (among 5) of the *R&D Priority Practices* is Educating and Training a Workforce for the 21st Century Economy, which calls specifically for alignment of curriculum with workplace demands, and to prioritize initiatives that *reskill* Americans for the jobs of today and the future. Altogether, this ATE project is expected to serve as the vehicle to meet the critical regional workforce need, and will be the first-of-its-kind that places emphasis on technician training at the convergence of IT and OT.

Targeted Regions & Populations

The primary target regions include the south-central states of our nation; these include the five gulf coast states, with the state of Louisiana at the center. Among these, the states of Texas and Louisiana have economies that are rapidly growing in the energy and manufacturing sectors, and therefore are expected to have a significant workforce demand; hence, these are ideal candidate locations to generate and train the future Smart Manufacturing workforce. Louisiana's Community and Technical College System (LCTCS) is responsible for managing all the 13 2-year IHE in the state [14], and is headquartered at Baton Rouge. It serves a large technician student community, with a graduating class of 28,853 alone in 2015-16 [15]. The northwest corner of the state (in the vicinity of the city of Shreveport), houses Northwest Louisiana Technical College (NWLTC) [16], which was named as one of "*The Top 25 Two-Year Trade Schools: Colleges That Can Solve The Skills Gap in the nation*," by Forbes magazine in 2018 [17]. With the majority of 2-year IHE within LCTCS focusing on student transfer to universities, NWLTC is one among the few remaining 2-year IHE that places primary emphasis on supplying the workforce to their industry 'customers.' NWLTC is accredited by the Commission of the Council on Occupational Education (COE), and offers a variety of training programs and has close ties with neighboring industries. Further, the demographics of Louisiana is such that these institutions serve a high percentage of underrepresented minorities; Louisiana has *second largest proportion of black Americans* (32% according to 2010 census) in the US [18]. The target academic programs include those spanning manufacturing, maintenance, energy, information technology, instrumentation/electrical, automotive, and other service majors.

Project Goals, Personnel Roles & Activities

The overarching vision of this project is to develop curricula, personnel, and communities in cyber-enabled smart manufacturing technologies, in order to fulfil the current and future workforce need of industries rapidly adapting to the fourth industrial revolution. Though it is critical for next-generation American Manufacturing all across the US to respond to the call of Industry 4.0, the primary target region of this project is the gulf-coast states, starting with Louisiana. Within Louisiana, the cities of Minden, Shreveport and Mansfield collectively house the three campuses of Northwest Louisiana Technical College (NWLTC), who is the primary driver of the project activities. NWLTC is one of the few 2-year Institutions of Higher Education (IHE) that is a member of the Clean Energy Smart Manufacturing Innovation Institute (CESMII), one of the 14 Manufacturing USA institutes, and a core facilitator of the project activities. The Regional Manufacturing Center (RMC) of the southern region/zone of CESMII (comprising of 15 states that include all the gulf-coast states) is headquartered at Texas A&M University (TAMU), who is the primary coordinator of the project activities. These three institutions, along with stakeholders from the industry, are the major players working to fructify the project vision. The project goals and tasks pertaining to this endeavor is briefly outlined next.

Goal-1 strives to create a pipeline of the next-generation workforce that is empowered with the knowledge/skills to merge manufacturing IT & OT. The first step for achieving this is to conduct industry-needs analyses in cyber and smart manufacturing via the organization of annual curriculum road mapping workshops where all relevant stakeholders can together explore and chart out how to respond to the changing industrial landscape, one that is becoming increasingly connected and efficient. This effort is not just to satisfy a current-needs itinerary, but rather what the near and long-term projected needs are. Thus, what this effort intends to accomplish at a holistic level is to move away from the need for a reactionary impulse to an industry demand, but rather to explore together as a group and define what is coming and what is needed, and accordingly lay out a plan of action to meet the call of Industry 4.0; this will actually involve the industry participants evaluating themselves and their future directions/needs. Such a road-mapping exercise that is refined at regular intervals will be extremely beneficial to not just the parties involved, but also to the broad community of 2-year Institutions of Higher Education (IHE). Drawing from these workshop outcomes, curricula will be developed in collaboration with all stakeholders to create course material and hands-on labs that allow for manufacturing technology students and information technology students to gain an appropriate level of understanding of the essentials of each other's programs. This will be achieved via introductory smart manufacturing courses, and then add-on modules to existing courses that expose them to the counterpart side (IT vs. OT) of applications through real world examples, and finally via integrated smart manufacturing courses that assimilates IT-OT knowledge/skills. This will be evaluated for technical content effectiveness and technician readiness via a certification process.

Goal-2 will prepare and train student technicians to operate competently in an interdisciplinary Industry 4.0 environment, and foster their proclivity to embrace change and lifelong learning. Students from counterpart IT/OT programs will work on interdisciplinary collaborative projects (within their courses) by using a Portable Process Training Unit (PPTU) as a development platform along with a networked IT interface. The PPTU is a full scale working kit with on-line instrumentation and controls; it is essentially a mini instrumented process plant that can be automated. Students will use real-time measurement and control equipment to measure flow and level utilizing programmable logic controller (PLC) hardware and software incorporating smart sensors with remote data transfer capabilities through a cloud and/or network communication. They will have further exposure via industry internships and research experiences at 4-year IHE. ***Goal-3*** will create pathways and career maps for students to advance in their careers/education by publishing career development and industry landscape newsletters as well as establishing a virtual industry-internship and job liaison office to disseminate opportunities to students. ***Goal-4*** will build a continuous improvement culture for faculty through professional development by organizing annual faculty professional development symposiums and workshops during conferences (or standalone events) as well as facilitating faculty development leaves in industry and opportunities for leadership training.

Additionally, a comprehensive project evaluation plan and timeline was set up to evaluate institution outcomes, faculty outcomes, student outcomes and regional outcomes.

Year-1 Startup & Activities

Following the official approval of the collaborative grant, the TAMU team visited the NWLTC campus in Minden, LA for a kickoff meeting. This campus houses the NWLTC team and is also one of the main locations for deployment of certain project deliverables. During the visit, the teams were able to meet up with the relevant personnel and tour the existing facilities as well as the planned space for housing the Portable Process Training Unit (PPTU) laboratory (see goal-2). Following this, the teams discussed and formulated plans and timelines to execute each of the proposed project tasks that were outlined in the earlier section. The team members also discussed collectively the format/procedures for interfacing with the external evaluator, the need for the continual documenting of activities, the annual reporting expectations (to NSF), budgeting guidelines, and plans for attending/presenting-at the ATE grantee conferences, among others.

Being a 3-year project with a broad array of intended tasks/deliverables, the majority of year-one activities were focused on starting up the sub-tasks outlined under goal-1. This primarily included the *curriculum road mapping* efforts that are intended to gather feedback from stakeholders (especially, from industry) on what they perceive the knowledge/skill-needs of an Industry 4.0 worker to be are. Further, the industry will also be encouraged to reflect on what they perceive is missing from some of their current workforce as well as what their future projected new needs might be. To facilitate this, the project team has prepared an online survey questionnaire that will be distributed to the participants of the CESMII annual meeting in Los Angeles, CA that is attended by a couple of hundred industry representatives (members of CESMII) spanning the US and representing numerous industry sectors. Further, this online survey is also being distributed through CESMII's monthly newsletter which has a much larger and broader readership. The contents of the survey primarily involve gathering basic data on each industrial organization's current workforce needs and what they project their evolving future workforce needs would be based on their strategic company vision. Additionally, the survey will ask for their opinions on existing OT and IT curricula (based on an existing program), the refinements needed in both technical content areas and skills, and finally their perceptions on what each group (OT and IT) needs to see in their workforce from the other side. Further, NWLTC will administer similar surveys during their industrial advisory board (IAB) meetings that occur twice per year as well as during other larger meetings of the Louisiana's Community and Technical College System (LCTCS). In addition, a road mapping workshop is being put together at a major city (possibly, Baton Rouge, LA) in the vicinity of the NWLTC campuses that will bring together all project stakeholders including the local industries that are directly served by NWLTC, and additionally other 2-year IHEs and industries in the region and nearby cities. Such a smaller and more focused curriculum road mapping workshop exercise during year-one is expected to yield a focused outcomes document that is tailored to the curricular development needed at NWLTC. In the subsequent years, it is planned to organize these workshops at a larger national scale so as to gather perceptions from across the nation, and spanning numerous industry sectors.

Regarding the major central task of developing curricular materials for the project, a number of discussions were held to decide on the combination of avenues needed to accomplish these tasks: add-on components and modules to existing courses, standalone new courses, interdisciplinary capstone projects, and course plans to add up to a certificate. It was also decided to use a combination of flexible course units (such as special projects, work-based courses, internships, etc.) to build the Portable Process Training Unit (PPTU), which is to be built at multiple NWLTC campuses with the capability for networking and remote access between different locations. To accomplish this, the instrumentation and electrical program teams at NWLTC have come together to design training modules, and the process of equipment/materials selection and purchasing have already begun. Related to this, accreditation was secured for the Industrial Instrumentation & Electrical Technology program at NWLTC from the accreditation board in addition to NWLTC updating its status to NWLTCC (…Technical & Community college). Next, building on NWLTC staffs' prior experience with students in special circumstances (*i.e.*, students with personal problems, new students who are not used to the rigor, industry personnel with relatively-rigid schedules and others with heavy external workloads), it was decided that a 4-week course/module schedule was the most conducive to success as well as afforded the most flexibility to these populations; often such a timeline was key to individual successes. Finally, the teams confirmed their commitment to develop the educational materials (curricula) in an open access/education format to allow for scalability and broadening participation. The remaining project goals will be tackled subsequently once the central goals of curricula road mapping and development have gained significant traction during year-one.

The collaborative project teams from TAMU and NWLTC were also able to attend the annual NSF ATE grantees conference in Washington, DC and present the project details at the conference showcase exhibit. This was an excellent avenue to gain exposure to other ATE projects and centers, meet grantees further along in their successful implementations, and most importantly garner interest for collaborative efforts. The conference also allowed for learning more about the success stories of the ATE program and gathering valuable pointers for success.

Project Evaluation

An external evaluation firm has been hired to conduct project evaluation activities as outlined in the proposed project. Taking guidelines for good evaluation plans [19], the formative and summative evaluation plan utilizes a comprehensive and widely used CIPP (Context, Input, Process, Product Evaluation) model [20]. Given the relatively small sample size, statistical analysis is expected to be largely descriptive, both aggregate and by subgroup, to report on project implementation and progress toward performance measures. T-tests will be used to determine significant differences in teachers' self-efficacy survey responses from pre- to post-test. Qualitative data collected through interviews, product review, and observation, will be analyzed throughout the project. The outcomes that are being evaluated are briefly outlined:

- Institution Outcomes: To strengthen a higher education-workforce infrastructure for sustained, innovative Industry 4.0 workforce preparation. The factors being evaluated primarily involve objectives related to curriculum development, course integration, career pathway establishment, building partnerships and dissemination.
- Faculty Outcomes: To increase community college faculty members' skills and comfort level with teaching Industry 4.0 curricula. The evaluation factors involve objectives related to the use of industry 4.0 curricula, and faculty and student satisfactions.
- Student Outcomes: To increase the number of workers (including underrepresented students) qualified to merge manufacturing OT & IT skills for an Industry 4.0 environment. The evaluation factors involve objectives related to student performance in industry 4.0 courses, and their employability and qualification to work in related jobs.
- Regional Outcomes: To fill regional workforce needs surveyed via employment data.

Conclusions & Lessons Learned

The purpose of this paper was to outline the details of a recently-funded NSF ATE project that aims to educate and enable the manufacturing workforce to operate in Industry 4.0 environments. The startup procedures, activities during year-one and preliminary impressions were elaborated as well. Headway was made regarding the major sub tasks under goal-1, *i.e.*, curriculum road mapping and course/lab development to enable the workforce suited to work in Industry 4.0 environments. Based on the project discussions so far, the central research question remains: how the faculty needs to design the curricula to suit the learning process of community and technical college students in the region, the logistics that would enhance chances of success, and the demographical differences to account for. In this regard, the purchasing of equipment and platforms is progressing, with significant long-term planning for sustained support/compatibility. The collaborative project team is in the process of organizing a local face-to-face curricula road mapping event, and is eager to consolidate its outcomes to drive curricular development decisions. Altogether, the lessons learned from year-one has been very helpful to advance the vision of the project to create an empowered future workforce well-suited for Industry 4.0 careers, especially in cyber-enabled smart manufacturing technologies.

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