MassBridge:

Advanced Manufacturing
Workforce Education Program

Benchmarking Study Phase One Report
Executive Summary

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Massachusetts Institute of Technology
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Executive Summary

American manufacturing has been a troubled sector in recent decades. Between 2000-2010, the manufacturing sector lost close to 6 million jobs and closed 64,000 plants. Between 2010 and 2020, the productivity of U.S. manufacturers declined both in absolute terms and compared to key foreign competitors. The massive U.S. trade deficit in goods rose in 2018 to $891 billion, including more than $120 billion in advanced technology goods.

How will U.S. manufacturing compete with lower-wage, lower-cost competitors? Advanced manufacturing, with its potential gains in efficiency and productivity, offers a solution. Although the U.S. formed 16 advanced manufacturing institutes to help bring on new manufacturing technologies, a purely technology-focused approach will not be enough. The institutes are working to develop technologies in areas such as digital production, robotics, additive manufacturing, flexible electronics, photonics, sensor and systems, and biofabrication. However, our workforce education system is not ready to provide the training we need in these new technologies.

Concerned about the strength of the U.S. industrial base, the Department of Defense funded the MassBridge project. MassBridge will plan and develop advanced manufacturing programs for community colleges and vocational-technical high schools in Massachusetts. The DoD hopes that MassBridge, once successful, can also be a model for efforts in other states.

Benchmarking Approach

The MassBridge project aims to find and train the core skills that are common to advanced manufacturing technician roles but exceed the skills taught in traditional manufacturing programs. For example, photonics, flexible electronics, and additive manufacturing technicians each need specialized skills for working with their specific technologies. However, in these emerging fields, technicians may also need to take a more systems-level view than traditional manufacturing technicians to be able to troubleshoot equipment or optimize production lines or to work more closely with engineers.

In the figure below, if traditional technician programs teach level 2 skills, and the most specialized skills are level 4, then MassBridge aims to identify and train level 3 -- the common skills that can help workers be more ready for careers in any specialized manufacturing technology, with additional training in that technology. In other words, we seek to build the bridge that connects current manufacturing training programs to the advanced manufacturing future being investigated by the Manufacturing USA Institutes.

Here, some quick definitions of categories within the broader concept of workforce “credentials” are in order.[1] A “certification” is a time-limited, revocable and renewable credential awarded by an authoritative body for the knowledge, skills and abilities to perform specific tasks for an occupation. A “certificate” recognizes completion of training and mastery of learning outcomes measured by an exam or other assessment. Community colleges, universities, training providers

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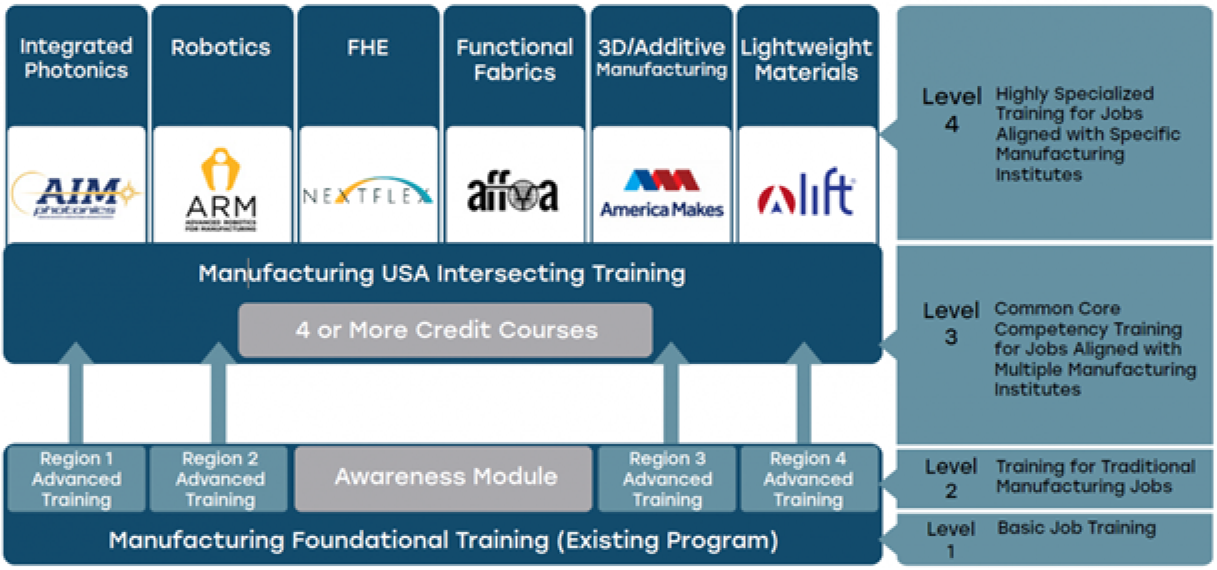
[1] WorkCred, Variable Impacts of Credentials for the Older Worker (2021), 4, https://www.workcred.org/Documents/Variable-Impacts-of-New-Credentials-for-the-Older-Worker.pdf

and industry or professional associations can all offer these. An "industry-recognized certificate" is developed in consultation with industry professionals. A "community college certificate" is from a community college. A "degree" is issued by a higher education institution. A "license" is issued by a state or federal regulatory agency for an occupation. In this study, we looked particularly at industry-recognized certifications and community college certificates and degrees.



Source: Massachusetts Technology Collaborative

The benchmarking team took a two-pronged approach to develop insights and recommendations for this preliminary report. In one track, we interviewed academic and industry leaders who engage directly with workforce learning for manufacturing. This included community colleges, manufacturers, credentialing organizations, and providers of advanced manufacturing technologies. In the second track, we compiled information on the contents of 33 associate degrees, drawn largely from community colleges recommended to us for their strong manufacturing programs, and 21 industry-leading certification programs and competency models. We tagged the programs for the skills each provided and then conducted extensive analysis to identify the core skills for programs aimed at different levels of manufacturing technician specificity and sophistication.

The report is organized into five main sections, including challenges facing MassBridge, models for content delivery, recommended curriculum content, developing and launching the curriculum, and recommendations for the MassBridge program.

Challenges to MassBridge Advanced Manufacturing Training

The advanced manufacturing education system is a complex collaboration among numerous independent actors. When they are aligned, the system can work well. However, the actors' independence often leads to misalignment of incentives, programs, and outcomes. So MassBridge will need to overcome a series of barriers, and these barriers need to be considered as the program is designed. A number of the barriers that need to be considered are listed below and described in detail in the report:

1. Limited demand for advanced education from employers, particularly SMEs that have not yet adopted advanced manufacturing technologies.
2. Differing definitions of advanced manufacturing and what should be included in the program.
3. The state's independent system of community colleges makes developing a common program complex.
4. To develop strong advanced manufacturing programs and keep them updated, the linkages between employers and schools must be strengthened.
5. Degrees and certificates should prepare students for (or even embed) industry-recognized credentials, but these must be carefully selected.
6. Adapting existing programs to include extensive new material is difficult because faculty become tied to what they already teach and there is limited space in existing curricula.
7. More programs are needed to reach incumbent workers through their employers because these workers need upskilling.
8. Strong coordination will be needed with MassHire and MassMEP to reach incumbent workers and small manufacturers – they don't compete with college education missions but offer wrap-around services needed for the manufacturing ecosystem.
9. Current programs do not generate enough workers to meet anticipated needs, so scaling elements will be needed.
10. Student attrition is always a challenge; efforts are required to keep students engaged for the full programs, whether they are short-term credentials or degrees where quality jobs are the best outcome measure.
11. The program, particularly certificate programs, will need to be structured to qualify for Pell Grant student aid.
12. Advanced manufacturing equipment will need to be available to schools, whether through industry philanthropy, partnerships, consignment or state programs.
13. The curriculum will need to evolve as advanced manufacturing technologies continue to develop, and must reflect business speeds of weeks and months not semesters and years.
14. "Train the trainer" efforts will be required to help faculty become familiar with advanced manufacturing technologies, and these will need to become frequent and include mandatory externships with advanced equipment.

All of these potential barriers will need to be anticipated and planned for as the MassBridge program is developed and launched.

Models for Content Delivery

Employers in the U.S. do most workforce training, yet many manufacturing firms, particularly SMEs, will not be able to train new advanced manufacturing skills effectively. Currently, community colleges and vocational-technical high schools already assist many manufacturers in training basic manufacturing skills, while employers take responsibility for training for job-specific skills geared to their production lines. MassBridge will add another layer by providing content and education for core advanced manufacturing skills. This section describes a series of exemplary models from outside Massachusetts that could help guide MassBridge.

Currently, there are several ways that an advanced manufacturing curriculum is being developed and utilized. These include: (a) employer-led regional collaborations with area manufacturers; (b) industry-led programs by manufacturers of advanced technologies, such as in automation, robotics, process controls, and robotic welding; (c) advanced manufacturing institute programs to develop curricula and competencies in their technologies; (d) community college-led programs in collaboration with regional employers; and (e) state-led programs to develop advanced manufacturing curricula and education programs. MassBridge will utilize a combination of approaches (d) and (e), informed by the other approaches.

A series of best practices emerged from this research on models outside Massachusetts:

1. *Break down the work / learn barrier.* In all of the programs we studied, employers and educational institutions collaborate closely on content development and content delivery. Strong programs offer a work component, which can range from internships to formal apprenticeships, along with academic instruction.

2. *Employers should collaborate with each other.* Stand-alone programs where individual firms provide their own training are inherently inefficient; it is better if groups of firms share the costs and risks of workforce education. Better still is where primes and their regional SME suppliers can band together since efficient advanced manufacturing requires adoption across supply chains. Working as employer consortia can generate additional synergies when collaborating with educational institutions and state education and labor programs. Education institutions can help manage the infrastructure for these consortia, shouldering much of the administrative burden.

3. *Reach new entrant, underemployed, and incumbent workers.* Educational institutions need to adapt their program mix to reach all of these participants. If an institution – a community college or employer consortia – can reach all three groups, they become reinforcing. A program for incumbent workers requires close contact with employers, which helps keep programs for all students current with industry needs. Community college or employer programs can also reach high school students, helping to break down the work / learn barrier and link high school students to college opportunities.

4. *Embrace certificates and shorter-term programs.* In contrast to offering only full degrees earned in a fixed period of time, educational institutions should be encouraged to provide shorter-term certificates, based on acquired competencies, that can accumulate to degrees. Certificate programs can help workforce education to fit students with limited time availability and employers with particular skill requirements. Degrees that take two years or more will still be needed but can be based on a series of related, stackable credentials. This, in turn, can enable short programs that help workers get to required skills and employment earlier, plus there is a pathway toward additional skills or a degree, as desired.

5. *Embed an industry-recognized credential into education institutions' certificates.* Academic credentials are not enough. Many employers increasingly want the assurance of skill knowledge that an industry-approved and accepted credential provides. It creates an additional and parallel pathway to help students toward employment. It also ensures that academic programs are relevant to actual industry needs.

6. *Ensure access to advanced manufacturing equipment*. Employers want students who have actual experience with the latest production technologies. Because of the cost of equipment, there is a significant challenge in getting students hands-on learning, particularly for advanced equipment. One approach is for a state to create regional technology centers shared by consortia of community colleges, high schools, and employers. In addition to providing efficient student access to equipment, providing companies access can help them test and experiment with new equipment, evaluating how it can improve their production process, and assist in training for their workers.

7. *Apply new education approaches that can scale.* Offerings with new content can be blended, combining face-to-face with online education, which can help expand their reach to much higher numbers of students. Hands-on learning remains critical, but actual equipment can be supplemented with advanced technologies, including computer gaming-based courses and Virtual Reality and Augmented Reality technologies.

8. *Create programs that are eligible for Pell Grant funding.* The federal Pell Grant program for student aid was set up to promote college degrees, not workforce education, but if workforce credentials are stackable toward degrees, some schools have found ways to make these programs eligible for Pell Grant support. Without a sustainable means for funding this education, it will not be enduring, so connecting students to Pell Grants is a critical step.

9. *Create cross-state industry and community college coordination mechanisms.* A state-wide organization for manufacturers, as well as working consortia of the state's independent community colleges, that work together to implement manufacturing workforce education programs, is needed. This ongoing industry and school collaboration is key to developing new programs and keeping them current.

Identifying Advanced Manufacturing Curriculum Content

To identify an initial list of contents for the MassBridge curriculum, we synthesized data on existing programs around the United States. We built a database containing two types of manufacturing programs: associate degrees and certifications / competency models (see Appendix A of the report for the included programs). The rationale for including these two types of programs was simple: we assumed that the content of certifications and competency models represented the specific skills sought after by the manufacturing industry, while the content of associate degrees represented the educational system's approach to meeting those needs for the local business environment. One goal of this benchmarking effort was to identify areas where the two perspectives might not be so well aligned, indicating a gap in one side or the other.

We classified the programs into levels based on the "advancedness" of the manufacturing career that they prepare for, based on the program name and stated focus. These three levels reflect the three main employment opportunities that emerged from data analysis and interviews:

- **Level 10: Manufacturing technician:** In this level, students would learn the basic fundamentals of manufacturing, after which they might enter the workforce as manufacturing technicians.
- **Level 20: Advanced manufacturing technician:** this level adds more sophisticated manufacturing technologies and methods, as well as providing system- and process-level understanding to assist in maintenance and troubleshooting.
- **Level 30: Specialized/connected advanced manufacturing technician:** This level includes extant programs covering technologies and techniques associated with the six Manufacturing Institutes included in MassBridge. It also includes programs that have an explicit focus on connected manufacturing such as Industry 4.0.

In addition to identifying these levels of current content, the report identified a potential need for a "technologist" who could be trained in elements of advanced manufacturing areas now starting to enter the workplace, such as digital production, robotics and additive manufacturing, but also master core skills in such areas as systems operation and thinking, production processes, troubleshooting and critical thinking. While such technologists would not have the full mastery that specialists in particular areas of advanced manufacturing have (these are the level 4 skills in the figure above), they would be able to work above the technician level tied to particular pieces of equipment, and work across equipment types and within a digital thread environment to reach the level 3 area in the figure above.

To identify core topics for the MassBridge curriculum, we coded each element of each degree program or certification using a standardized list of 145 topic tags constructed for this project. We then used this information to identify "core" lists of topics that characterize the content of programs at each "advancedness" level of manufacturing, using the method described in Appendix B of the report.

The following table compares the core topics across all three levels of curriculum. In general, there is extensive overlap since more advanced levels still build upon many of the topics in less advanced ones. The topics that are part of the core at all three levels tend to be industry-specific subjects that are either very comprehensive (e.g., safety, quality, manufacturing processes) or very basic (e.g., blueprint reading, basic measurement). Other industry-specific skills that are crucial components no matter the level include electronics, systems control, manual machining, and machine tools. The list also includes a number of human skills and general education skills such as lower-level mathematics, communication, critical thinking, reading comprehension, and professional skills.

	Core Topic		
	Level 10	Level 20	Level 30
Basic Measurement	Yes	Yes	Yes
Communication	Yes	Yes	Yes
Critical Thinking	Yes	Yes	Yes
Electronics	Yes	Yes	Yes
Lower-Level Mathematics	Yes	Yes	Yes
Machine Tools	Yes	Yes	Yes
Manual Machining	Yes	Yes	Yes
Manufacturing Processes	Yes	Yes	Yes
Problem-Solving	Yes	Yes	Yes
Professional Skills	Yes	Yes	Yes
Quality	Yes	Yes	Yes
Reading Comprehension	Yes	Yes	Yes
Safety	Yes	Yes	Yes
Systems Control	Yes	Yes	Yes
Technical Blueprints & Drawings	Yes	Yes	Yes
CAD/CAM	Yes	Yes	No
CNC Machining	Yes	Yes	No
GD&T	Yes	Yes	No
Manufacturing Systems	Yes	Yes	No
Research	Yes	Yes	No
Manufacturing Materials	Yes	No	Yes
Ethics	Yes	No	No

	Core Topic		
	Level 10	Level 20	Level 30
Statistical Process/Quality Control	Yes	No	No
Instrumentation & Sensors	No	Yes	Yes
Introductory Physics	No	Yes	Yes
Maintenance	No	Yes	Yes
PLCs	No	Yes	Yes
Robotics	No	Yes	Yes
Troubleshooting	No	Yes	Yes
Mechanical Elements & Power	No	Yes	No
Mechatronics Systems	No	Yes	No
Quality Control	No	Yes	No
Automated Systems	No	No	Yes
Basic Computer Skills	No	No	Yes
Basic Mathematics	No	No	Yes
Data Management	No	No	Yes
Hand Tools	No	No	Yes
Hydraulics	No	No	Yes
Pneumatics	No	No	Yes
Probability & Statistics	No	No	Yes
Process Control	No	No	Yes
Scientific Communication	No	No	Yes
Simulation	No	No	Yes

However, the table also makes it clear how each successive level adds unique topics that are not the focus of traditional Level 10 programs. In Level 20 programs, a focus on more advanced technical subjects starts to emerge, such as knowledge of instrumentation techniques and PLCs. In fact, level 20 programs appear to lay the groundwork for the connected manufacturing that is the focus of a subset of Level 30 programs, as evidenced by the prevalence of both mechatronics systems and robotics. Core technical skills such as troubleshooting and maintenance also appear here for the first time. Finally, Level 30 programs suggest a more integrated and digitized approach to manufacturing, as evidenced by the importance of automated systems, as well as a number of digital skills such as basic computer skills, data management, and simulation. This level's focus on probability and statistics suggests that the ability to manipulate and interpret data is an important element of these programs, potentially in the context of production planning and decision-making roles.

There are a few apparent anomalies in the data, such as the fact that the manufacturing materials topic appears in levels 10 and 30 but not level 20. This is a function of the academic programs and certifications in our database as well as our analysis methodology. For this and other reasons, a purely unsupervised approach such as we used nearly always needs manual intervention to apply knowledge that is not embedded in the data itself. Therefore, as a next step, we plan to work with the MassBridge curriculum team, as well as industry and academic experts, to validate and enhance our initial analysis.

Based on our analysis, after reviewing the findings with industry and academic experts, we recommend that the MassBridge curriculum include topics from the level 20 and 30 columns of the table above. Each topic is mapped back to existing programs that teach the topic, opening the possibility of re-using or adapting existing content instead of building it from scratch. Working with the MassBridge curriculum development team, we can converge on the specific topics and content elements for the MassBridge program.

Developing and Launching the Curriculum

Developing a shared or standardized curriculum is difficult. Developing it in a domain as complex as advanced manufacturing adds even more difficulty. Manufacturing-related AA degrees in most schools have little room to add several new courses and competencies. Finding faculty willing to undertake the change or teach the new skills will also be challenging. Moreover, finding employers who want to hire the graduates or sponsor work-learning collaborations adds difficulty.

Our interviews and other analyses identified four approaches that MassBridge could take to develop its curriculum. These include:

- Building or curating plug-in modules that schools can add to their existing programs,
- Creating a third-year advanced manufacturing technologist program
- Recreating the two-year technician program as an advanced manufacturing program from the ground up
- Focusing on years two and three of a three-year program, where vocational-technical high schools could provide year one and community colleges years two and three.

Recommendations of the Preliminary Benchmarking Study

Detailed recommendations in the final section of the report are briefly summarized here:

Program content

1. *Emphasize the why and how not just the what.* Manufacturing "technologists" require a mindset change from direction-follower to systems thinker. They need to understand manufacturing as a system, including production processes, supply chains, and management.

2. *Build a core for each level plus specialized options.* We need core curriculum components at the traditional, advanced, and connected levels of sophistication. All need to be more "applied learning" oriented. The resulting programs should maintain a multi-level modular approach so that educators can easily understand how to tailor their existing programs for higher tiers of advanced manufacturing.

3. *Include professional and other "human" skills.* In addition to technical skills, employers value non-technical skills that are not typically taught in school. Advanced manufacturing requires skills such as critical thinking, problem-solving, curiosity, leadership, and adaptability.

4. *Break down the work / learn barrier.* In all of the programs described in this report, institutions collaborate closely on both content development and content delivery. Strong programs go beyond that to offer work components that range from internships to formal apprenticeships. We need earlier career/education guided pathways, not adding more time but replacing non-essential material with real-world, project-based learning modules that emphasize competencies not traditional academic approaches.

5. *Tie to industry credentials and badges.* Academic credentials alone can be a weak signal of skill, particularly if employers are not aware of a school's programs. Many employers increasingly want the assurance that an industry-approved and accepted credential provides.

6. *Ensure that programs are eligible for financial aid.* Short non-degree programs, and certificate programs that occur after graduation from a standard degree program, need to be structured to be eligible for federal student aid such as Pell Grants.

Curriculum design process

7. *Consider multiple development approaches.* We suggested four approaches to developing the MassBridge curriculum, as discussed above. These options are not mutually exclusive and, in fact, can be complementary. Different institutions will be amenable to different approaches.

8. *Shift the mindset from creation to curation.* Our research uncovered numerous exemplary programs ranging from traditional manufacturing to advanced technologies. The programs, and the training systems they are embedded in, provide numerous examples that MassBridge can build upon rather than recreating. Where a new curriculum is required, the advanced manufacturing institutes can be drawn on.

9. *Embed appropriate evaluation mechanisms.* MassBridge should plan for broader program-level measures such as employment outcomes or career growth, in addition to detailed course-level measures.

10. *Use modular approaches to deliver customized programs with standard quality*. MassBridge can develop standard modules and model curricula in a number of advanced manufacturing technologies from which schools can choose. This modular approach can also enable the four curricular approaches suggested above. Schools can even build upon or rebuild modules to adjust them for specific technologies or software tools. In this way, MassBridge can move from being a single set of courses to a library of modules that meet the needs of different schools and employers.

11. *Build collaboration between the six pilot schools – and with employers.* MassBridge could build a collaboration program and curriculum clearinghouse for all of the state's community colleges, through which school representatives meet periodically to share best practices and new manufacturing curricula. To ensure that programs meet employers' needs, MassBridge also needs an ongoing mechanism with employers to coordinate the requirements they present to educational institutions.

12. *Ensure that the curriculum design works for underemployed and incumbent manufacturing workers in addition to new students.* The advanced manufacturing skill gap can only be filled by a combination of training new students and upskilling existing workers. In building curriculum, ensure that the design enables incumbent workers to gain skills they need quickly and easily, while accumulating to broader degrees over time. Modular programs, stackable credentials, credit for existing knowledge and experience, digital / hybrid programs, and collaboration with employers to train their workers can all be helpful in this regard.

Scalability

13. *Better availability and use of equipment.* Community colleges have challenges in providing manufacturing students enough hands-on time with up-to-date, advanced machinery. Shared equipment centers and M2I2 capital equipment programs may help.

14. *Use technology to maximize the value of limited hands-on time*. Software tools and online platforms can be an effective way to scale the productivity of capacity-limited hands-on labs and programs.

15. *Scale up the upskilling.* In addition to demand-side programs to increase participant interest in manufacturing jobs, manufacturing educational programs will need to grow in size and content breadth to meet workforce needs for the new advanced manufacturing skills. As importantly, incumbent manufacturing workers will need upskilling to keep up with new technologies. Programs must scale to meet the need.

16. *Energize a community for content development and delivery.* Consider MassBridge as a library of materials that can grow over time. Enable local schools to customize MassBridge modules for their specific contexts. Foster programs to encourage sharing curricular innovations, not only across Massachusetts but nationwide. Conduct conferences and contests through which educators can share their ideas and receive broad recognition for their contributions. Energize a community around the goals of MassBridge.

Conclusion

It is important to understand, up front, that the success of a new workforce training program for advanced manufacturing skills will only succeed if the state's manufacturing firms are adopting new advanced manufacturing technologies. Firms, particularly SMEs, are reluctant to train skills for new equipment they don't yet have. Therefore, workforce training efforts must proceed in parallel with advanced technology implementation efforts, including Massachusetts' unique M2I2 program to assist firms and research institutions in acquiring advanced manufacturing capital equipment.

Overall, development and dissemination of advanced manufacturing content requires use of existing curricula where available for closer-in manufacturing technologies and new curricula for further-out technologies. For both, the manufacturing innovation institutes may be able to play a constructive role in support of the MassBridge project. DoD ManTech's pending online platform to collect and disseminate advanced manufacturing online content could be a useful resource. The MassBridge advanced manufacturing education content could be implemented through the improved delivery systems discussed above, with employer or educational-led collaborations helping to develop and broadcast the new content, and adopting a series of new best practices to do so.