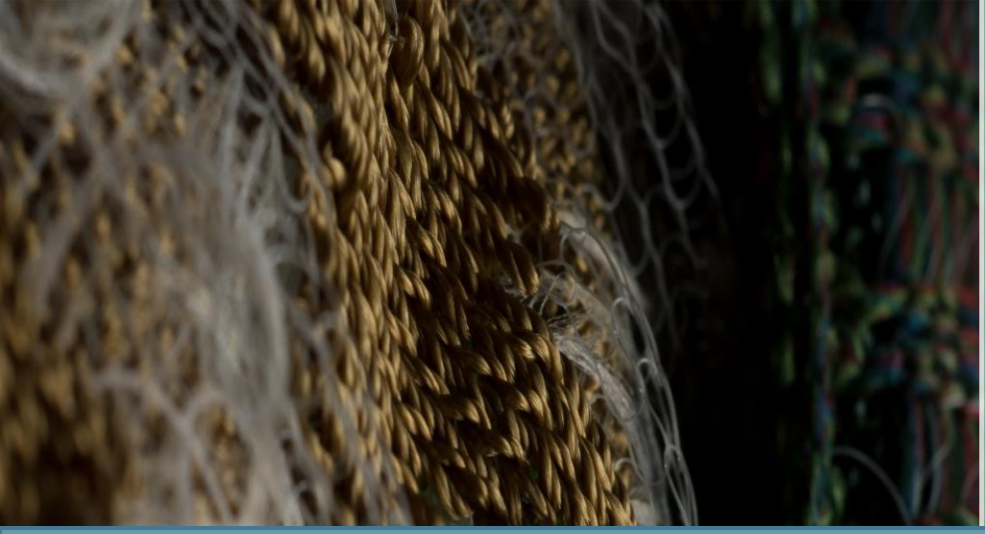

2021

Preparing the Advanced Manufacturing Workforce: A Study of Occupation and Skills Demand in the Advanced Fabric and Fiber Industry

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Cover image: Advanced functional fabric. Photo taken by Greg Hren, Courtesy of AFFOA

Acknowledgement

The authors would like to thank the DOD Office of Manufacturing Technology and the Massachusetts Technology Collaborative for the resources that made this study possible. Additionally, we are indebted to Advanced Functional Fabrics of America and the Massachusetts Manufacturing Extension Program. Without these groups, the survey that underpins this study would not have been successful.

Note: This report is a part of a Workforce Roadmap series that characterize technical workforce needs for advanced manufacturing areas focused on highly specialized training for jobs aligned with specific U.S. Manufacturing Institutes including integrated photonics, robotics, flexible electronics, functional fabrics, 3D/additive manufacturing, and lightweight materials.

Executive Summary

The MIT research team developed a semi-structured interview for operations managers to characterize middle and lower skilled technical workforce needs in the advanced fabric and fiber industry throughout New England. Interviews were conducted with thirty-five firms ranging from textile product designers to weaving/knitting operations to firms engaged in assembling textile products.

> Training for technical workers in the advanced fabric and fiber industry should increase emphasis on
>
> - Information management
> - Analysis of data or information
> - Repairing and maintaining mechanical equipment
> - Working with digital collaboration tools
> - Troubleshooting processing problems

These interviews focused on workforce needs for middle-skilled technical occupations (all technical occupations except information technology) and select lower-skilled occupations (hand sewers, sewing machine operators, textile knitting and weaving machine operators, and textile cutting machine operators). Specifically, the interviews sought to characterize trends in demand, hiring challenges, training gaps, and the importance of specific technical skills and tools for most of the technical occupations relevant to the fiber and fabrics industry.

Overall, interview results indicate that there is growing demand for technical workers in the US advanced fabric and fiber industry (See Figure ES 1 Survey results on future change in demand for the technical occupations evaluated in this study. Five positions stood out with above average anticipated demand growth. In particular, there is stronger growth expected for the ubiquitous middle-skilled positions of maintenance and support technicians as well as other technical production workers (e.g, CNC operators). Of those occupations common across the industry, electrical/electronic engineering technicians, sewing machine operators, and hand sewers are expected to have the largest growth.

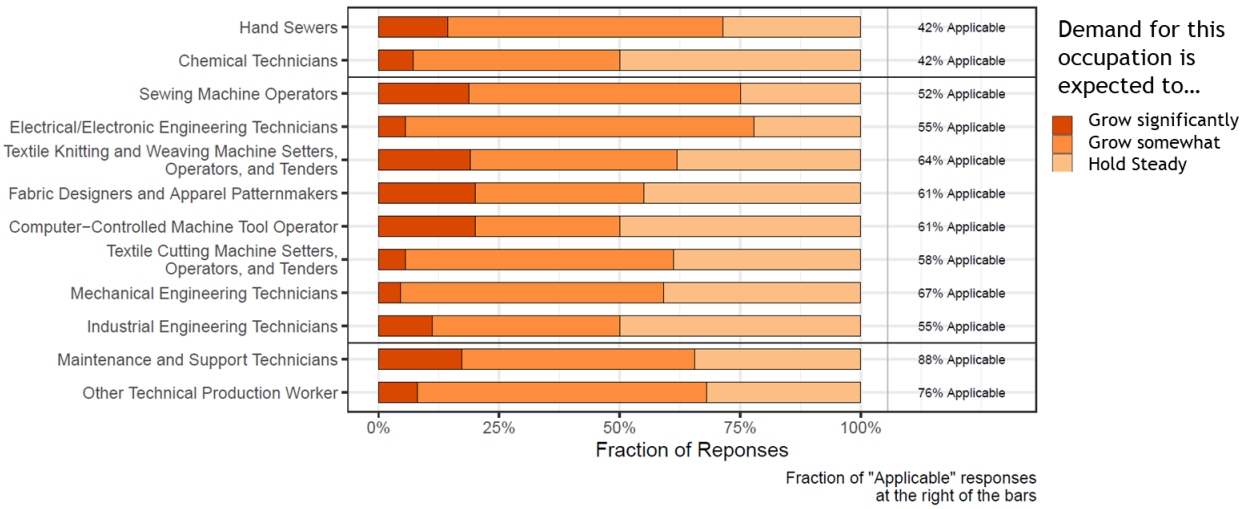

Figure ES 1 Survey results on future change in demand for the technical occupations evaluated in this study.

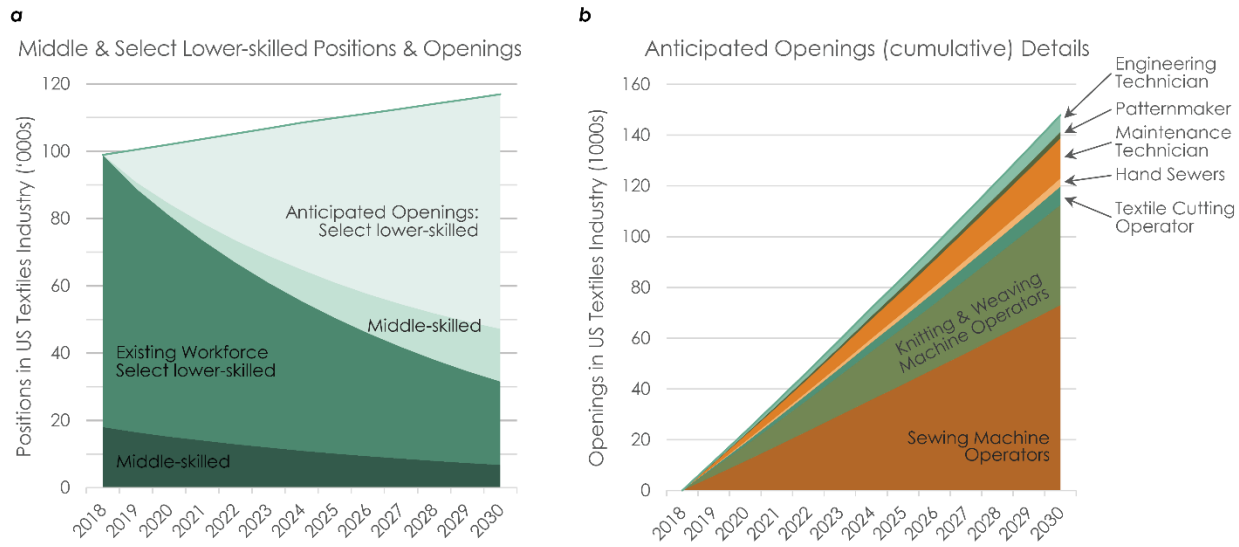

Figure ES 2. Survey results, data from the US Bureau of Labor Statistics, and market intelligence reports were used to project existing positions and expected openings for middle-skilled technical workers and four select lower-skilled technical workers. (a) Shows an overview of trends. (b) Provides details by position.

To further characterize workforce demand in this sector, we made use of data from the US Bureau of Labor Statistics, market intelligence reports, and survey responses to project both anticipated positions and openings. Our projections underscore the growing demand for technical workers. We estimate middle-skilled and our focal lower-skilled positions within this industry to grow from around 100,000 today to 117,000 by the end of the decade (see *Figure ES 2*). Accounting for expected retirement and other separations, nearly 23,000 cumulative middle-skilled technical openings are expected over the next decade or around 2,100 new middle-skilled technical workers per year. If we assume that a typical training program produces about 15 graduates per year, this suggests that the US needs more than 100 training programs to meet the growing needs of this industry. In addition to middle-skilled openings, we project 113,000 cumulative openings or around 10,000 openings per year for the focal lower-skilled occupations in this study.

Mapping these number to a Massachusetts context, we estimate about 35 middle-skilled and 175 lower-skilled openings per year in the fiber and fabrics industry in the state; easily supporting two programs for training technical middle-skilled workers and suggesting a need for certificate programs to train lower-skilled workers.

Interview respondents indicated that nearly all occupations studied also have significant hiring challenges as well as require extensive on-the-job training for new hires. There are five occupations that exhibited both hiring challenges and training gaps including:

- Mechanical Engineering Technicians
- Electrical/Electronic engineering Technicians
- Industrial Engineering Technicians

- Fabric Designers and Apparel Patternmakers
- Textile Knitting and Weaving Machine Operators (lower-skilled position)

In the body of the report, we identify in detail the specific technical skills that are becoming increasingly important for mechanical engineering technicians, industrial engineering technicians, fabric designers and apparel patternmakers, CNC tool operators, textile knitting and machine operators, and textile cutting machine operators. (Because of specific implementation decisions, we did not receive sufficient responses to comment on the technical skill needs for all occupations.)

These detailed results should prove useful for shaping specific elements of the curriculum for these positions, however, they also provide insights into trends across the fiber and fabrics workforce. Because the interviews focused on skills derived from work activities described in the Bureau of Labor Statistics O*Net dataset, it was possible to use the taxonomy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS). Figure ES 3 shows the result of that aggregation across all survey responses.

Looking across all middle-skilled positions, the top five general skills that are expected to be the most important for middle-skilled workers in the fiber and fabrics industry are:

- Information Management
- Data Collection & Synthesis
- Analyzing Data or Information
- Repairing and Maintaining Equipment
- Estimating and Judging Characteristics of Products or Processes

Information management skills include identifying task-pertinent information, appropriate documentation of that information, and developing written or oral communication of that information. Data collection and synthesis involve gathering and measuring relevant data and summarizing the data for others (or yourself) to analyze. Skills to analyze data or information include assessing, cleaning, testing, and transforming the data into a useable product to inform decision making. Beyond data and information processing, repairing and maintaining equipment is common across all positions. This skill entails building, calibrating, and troubleshooting equipment malfunctions to minimize downtime. Finally, estimating and judging characteristics of products or processes involves quality assurance functions such as precise measurement, assessment of and suggestions for process or product improvement, and comparison against performance quality metrics.

The weighted average skill importance for all of the specific skills included in a GTS class is shown. These overall results make clear the growing importance of information management and data analysis for middle-skilled workers in the advanced fabric and fiber industry.

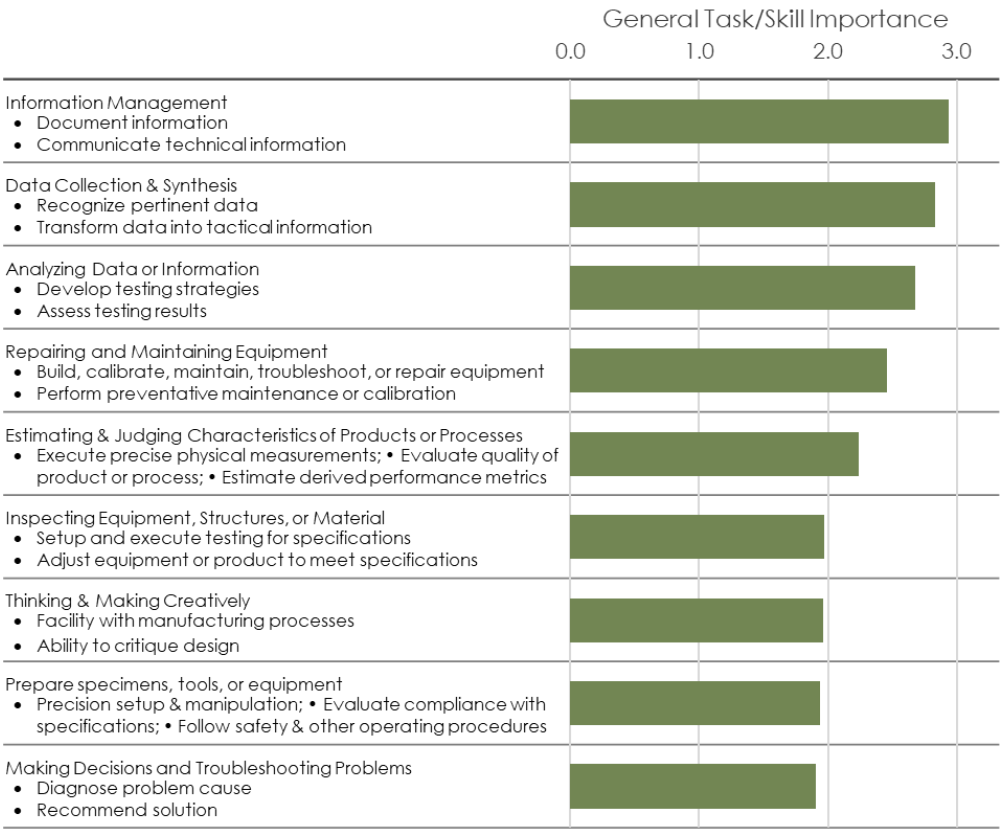

Figure ES 3. General Task/Skill (GTS) are classes that include many related specific skills. Here relevant GTS are ranked by weighted average importance of the specific skills within that class. Only GTS that are shared across at least three occupations are labeled as common and, therefore, included in this figure.

In this study, the focus was on understanding and evaluating technical skills gaps[1]. We explicitly did not ask respondents to evaluate soft skills; however, we did ask about the growing importance of some emerging tools and skills. From this, we found that survey respondents expect increasing importance for technical workers to be skilled in

- Working with digital collaboration tools
- Troubleshooting processing problems
- Monitoring, assessing, and working with automated process equipment (e.g. CNC)

Taken together, these results demonstrate both the growing opportunities for technical careers in the advanced fabric and fiber industry and the presence of key opportunities to improve the training and skills development of those pursuing these occupations.

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[1] *While this study emphasizes the technical skills needed for occupations in the advanced fabric and fiber industry, we recognize the importance of non-technical skills for workers to thrive. The primary purpose of this study was to provide targeted feedback on technical skills for training program improvements. As such, assessment of non-technical skill needs was outside of the scale and scope of this work.*

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Introduction to the Workforce Roadmapping Report Series

Manufacturing – particularly advanced manufacturing[2] – is widely recognized as important for the United States for economic, strategic, and, more recently, public health benefits. Realizing those benefits will require both critical investments and intelligent policies. One challenge facing advanced manufacturing in the US that is less widely discussed is a mismatch between the supply of qualified employees and the needs of industrial employers.

In fact, 83% of manufacturers in the United States report a shortage of qualified employees (Huang et al. 2015). A recent study by Deloitte and the Manufacturing Institute estimates that this shortage may lead to as many as 2 million manufacturing jobs going unfilled over the next decade(Giffi et al. 2018). This structural unemployment has been attributed to both evolving manufacturing technology and to a declining interest in manufacturing jobs.

Furthermore, the emergence of new technologies can initiate new structures for knowledge coordination across formerly well-defined occupational boundaries. Technological changes can impact how worker tasks and therefore skills needs evolve and influence labor- demand effects and training as shown with automation and parts consolidation (Combemale et al. 2019). For example, the introduction of CT scanners changed the balance of knowledge between radiologists and technicians. Radiologists, less familiar with complex CT topics than they were to the simpler X-ray technology, evolved to a more collaborative approach to working with technicians (Barley 1986). Similarly, Frank Gehry's complex designs strained the modular boundary between architect and builder, with the separate roles collaborating much more closely in the design and building processes (Yoo, Boland, and Lyytinen 2006). These relationships can modularize again as technologies and knowledge become more mature, only to re-integrate as new technology or market concepts arise (Christensen, Verlinden, and Westerman 2002).

In a recent study, Combemale et al. (2021) find that new technologies are likely to lead to such workforce changes explicitly within the integrated photonics industry. Specifically, they find that changes in technologies for advanced manufacturing industries impact the distribution of demand for worker skills. Their study captures the labor-demand effects of technological changes in the automation of production processes and consolidation of parts using shop-floor data from various semiconductor firms. The O*NET database was used to identify skills and abilities[3] for each optoelectronic

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[2] Advanced manufacturing includes both the application of new manufacturing processes and the production of innovative new products using either traditional or new processes.

[3] This study complements the work of Combemale et al. (2021) by focusing on O*NET work activities, detailed descriptions of worker tasks, rather than O*NET skills and abilities

occupation for each process step. Results indicate that automation of production processes would reduce the need for middle-skilled operators while conversely product integration would increase demand for middle-skilled workers. While these technical changes are not expected to reduce the number of jobs, they would be expected to change the portfolio of skills that are most valued. Furthermore, there is no reason that such trends would not carry over to other industries as the automate and develop more functionally integrated products.

In light of these needs and trends, this report aims to better characterize the evolving technical workforce needs within a specific advanced manufacturing sector – the advanced fabrics and fibers industry in the New England Region. We give particular focus to middle-skilled occupations[4] but also examine selected lower-skilled occupations that are uniquely important to this industry.

As part of this characterization, we attempt to

- estimate the demand for middle workers by occupation type
- identify what occupations represent the most serious hiring and training challenges
- identify what skills are most important for a given occupation

An understanding of the skills required in the current workforce can aid in informing education and training programs to prepare future advanced manufacturing workers.

To explore these questions, we develop and apply a new research method because traditional sources of information about labor needs are not well suited to answer questions within advanced manufacturing. The most widely consulted source of data on the US labor market is the Occupational Information Network (O*NET) database maintained by the Bureau of Labor Statistics (BLS)(U.S. Department of Labor 2020). That database contains information about workforce needs broken down into around 1000 occupation types across more than 100 industrial sectors. Although this serves as an invaluable source of information for workforce questions, there are at least two challenges to applying it to examine needs within advanced manufacturing. First, despite the scope and detail of the O*NET database, it is difficult to isolate the needs of emerging industries within that data. It will always be the case that advanced manufacturing sectors such as photonics, robotics, and additive manufacturing will operate at the interfaces of traditional sectors and as such will not be simply mapped using conventional industrial classification systems. Secondly, there will always be

[4] Here we define middle-skilled workers as those with training beyond a high-school diploma, but short of a bachelor's degree. The terms middle-skilled worker and middle worker will be used synonymously. Middle-skilled occupations are those filled predominantly by middle-skilled workers. More formal definitions are provided in the methods section.

concern that government databases are not updated frequently enough to capture the trends within rapidly evolving industries.

Defining the Advanced Fabrics and Fibers Industry

While the production of fabrics and fibers has always been a large part of the United States manufacturing industry, much of US manufacturing capacity has shifted to Asia over the last few decades. However, the fabrics and fibers industry is evolving due to innovations in the functionality of the materials (Sinha Mahapatra et al. 2020; Honnet et al. 2020; Sela et al. 2020; Park and Rutledge 2017). These materials are now being transformed into integrated networked devices and systems (AFFOA 2021), moving beyond the traditional use of the materials in sectors like clothing, home furnishings, and buildings(Park and Rutledge 2017). These advanced products can "see, hear, sense, communicate, store and convert energy, regulate temperature, monitor health, and change color" all to provide added value for the end user (AFFOA 2021). Emerging applications in this industry includes electronics in fabrics, chemical sensing garments, nanofibers for medical applications, nonwovens, flame-resistant fabrics, high-strength fibers for defense applications, and more (Schreuder-Gibson and Realff 2003). As a result of this industry's paradigm shift, there has been a revival of fabrics and fibers manufacturing in the U.S. with many U.S.-based firms participating in the manufacture, production, design, integration, or assembly of traditional fibers, yarns, and textiles into advanced integrated and networked devices and systems.

Methods

To characterize workforce needs within the advanced fabrics and fibers industry we have relied primarily on interviewing firms within that industry. Development and deployment of that structured interview followed a process involving four major steps. (See Figure 1) These are to 1) discern the firms that make up the industry of interest; 2) posit occupations most relevant to those firms and skills most relevant to those occupations; 3) develop and deploy a survey to characterize the relative importance of those occupations and skills; and 4) analyze the survey results to identify workforce and skills gaps. The following sections summarize key elements of these steps for studying the fiber and fabrics industry. More details of the research method are provided in the appendix to this report.

Figure 1. Key steps in the research method applied in this study.

Discern emerging advanced manufacturing industries

The United States fabric and fiber industry is growing at a solid pace and is projected to generate revenues in excess of $90B by 2025.

The D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, was used to discern the firms that comprise the fabric and fiber industry. These were in turn mapped to industrial classification codes used by the Bureau of Labor Statistics (these are modifications of three to four-digit NAICS codes) to characterize workforce levels and economic activity by sector within the US economy. The specific codes and sectors that were used to represent the fabric and fiber industry are listed in Table 12 and Table 13 in the Appendix. The detailed process used to classify firms is described in the Appendix section, Detailed Methods.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the US Department of Labor O*NET database(U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest. Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database.

Middle-skilled workers are often defined as those with an education level beyond a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle-skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 28 relevant middle-skilled positions associated with the advanced fabrics and fibers industry. To facilitate survey data collection, these were grouped into twelve representative positions, as shown in bold in Table 1. This set includes five types of engineering technicians – electrical / electronic, industrial, mechanical, and chemical– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, fabrics designers and patternmakers, and machinists.

Additionally, four lower-skilled (i.e. positions where most workers highest level of education is high-school or less) were selected to better understand firm needs and trends. These were: sewing machine operators, hand sewers, textile cutting machine operators, and textile knitting and weaving machine operators. These lower-skilled positions were selected because they each were highly concentrated in some portion of the advanced fabrics and fibers supply chain.

Table 1. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electro-mechanical technicians	17-3024
Electrical and electronics drafters	17-3012
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical technicians	19-4031
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
HVAC mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042
Electrical & electronics repairers, commercial & ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111
Fabrics Designers and Patternmakers	51-6092
Lower-skilled	
Sewing Machine Operators	51-6031
Hand Sewers (representing)	
Hand Sewers	51-6051
Upholsterers	51-6051
Fabric menders, except garment	49-9093
Tailors, dressmakers, and custom sewers	51-6052
Textile Cutting Machine Operators	51-6062
Textile Knitting and Weaving Machine Operators	51-6063

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from the U.S. Department of Labor O*Net database, an online tool for career exploration and job analysis (U.S. Department of Labor 2020). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001)and helps create a common language for job descriptors.

The research team selected six to ten technical skills for each occupation to better understand its importance. The specific skills explored are listed in the results plots and tables in the results section of the report.

What about "Soft" skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes that such technical skills are more important than other non-technical skills (also known as "soft" or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the fiber and fabric industry. Such programs themselves focus on technical skills and, therefore, require feedback on the same. Secondly, the survey tool applied in this research was already of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content.

Although they were not the focus of this study, it is important for training programs to recognize that human skills complement technical skills, enhance employability, and improve productivity (Schulz 2008; Rao 2014). Although both industry and academia are reaching consensus that employees need human skills in addition to the technical skills taught in most STEM training programs (Kumar and Hsiao 2007), there is no consensus on which human skills are most important or even how to frame and organize human skills. A recent study by researchers at MIT's Jameel World Education Lab attempts to bridge that gap by synthesizing more than 40 skills frameworks into the Human Skills Matrix (HSM). Their analysis found that communication skills were the most commonly identified important human skill. This was followed by creativity, problem solving, teamwork and critical thinking. The HSM synthesizes this information into 24 non-technical skills that employees need to thrive (Stump, Westerman, and Hall 2020). These skills are grouped into four categories including thinking, interacting, managing ourselves, and leading. Although not the focus of this study, where possible, we attempt to map survey results about technical skills onto the human skill categories they most complement.

Emerging Skills

While the O*NET database gives a sense of the current technical skills needed for these occupations, the research team also wanted to get a sense of what additional types of skills would be expected to become important within the advanced fabrics and fibers industry. Considerable work has been invested into exploring what might be the consequences of the changing technological composition of manufacturing work, and we sought to leverage some of that learning into devising a set of questions that would explore how the survey respondents imagined the skills required for these occupations would change.

The specific emerging skills evaluated within the survey were:

- Conducting (and assessing the results of) statistical process control analyses
- Evaluating and making use of process management analyses
- Collaborating with engineering and management staff
- Working with digital collaboration tools
- Knowing the science & engineering underlying the product
- Troubleshooting processing problems
- Working with CAD products

Table 16 in the Appendix illustrates one mapping of these abstractions to the "essential skills" framework that is used by the Canadian government(Government of Canada 2015).

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. Combemale et al. (2021)also recommend that formal training must become more general for technician-level positions to be valuable in various types of advanced manufacturing industries. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. Weighted average importance levels for generalized tasks/skills (GTS) and intermediate tasks/skills (ITS) were computed based on survey responses for occupation-specific tasks and skills. Details of the relationships among specific skills and higher levels of aggregation and the method of computing an importance score are described in the Appendix.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

1) firm characterization,
2) hiring and training challenges
3) workforce scaling, and
4) emerging skill needs.

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the advanced fabric and fiber supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

In the third section of the survey, respondents were asked to quantify how many individuals were employed at their firm for each type of relevant occupation.

In the final section of the survey, respondents were randomly assigned three relevant occupations. For each of these, they were asked to rank the importance of specific skills and tools for the future.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform(Qualtrics XM 2021) and interviews were conducted with advanced fabrics and fibers firms located in the New England area. Thirty-five responses where the respondent completed the entirety of the interview template were received and incorporated into the following results.

Results

Interview results demonstrate the challenges of hiring and training middle- and lower-skilled workers in the advanced fabrics and fibers industry. The first section of the results includes responses about the overall demand for middle- and lower-skilled workers, with estimates for future demand for these workers based on the projected growth of the industry. The interview results also detail the changing importance of technical skills for each position with recommendations for focused training and curriculum development for future workers.

> "We need to overcome the stigma of textiles and fibers being old and dirty manufacturing. We should be introducing this technology at the elementary and middle school level and teach students how to be intrinsically motivated to challenge themselves. This will help fill in these gaps over time."
>
> New England Advanced Fabrics and Fibers Company Representative, February 2021

Demand for occupations

Question
We expect demand for this type of position in our firm will....

The results of the interviews demonstrate that the overall demand for technical workers at the middle- and lower-skilled level is strong and many of the positions will grow over the next five years. It is important to note that there is not a single position where we expect strong growth (Figure 2). However, many of the positions are expected to have moderate growth. The positions with the greatest expected demand growth include technical maintenance and support workers or technical production workers (e.g. machinists), largely because these are ubiquitous positions that are relevant for most of the respondent companies (>75%). This suggests that a greater curriculum focus on more general technical training can help improve the workforce gaps at many of the companies in the advanced fabrics and fibers industry. Of the positions common to the companies interviewed (>50%), the lowered skill position, Sewing Machine Operator and the middle-skilled position, Electrical/Electronic Engineering Technician demonstrated the strongest growth. Finally, for the specialty positions (<50%), the Hand Sewer occupation is expected to have moderate growth with the Chemical Technician's demand remaining constant over time.

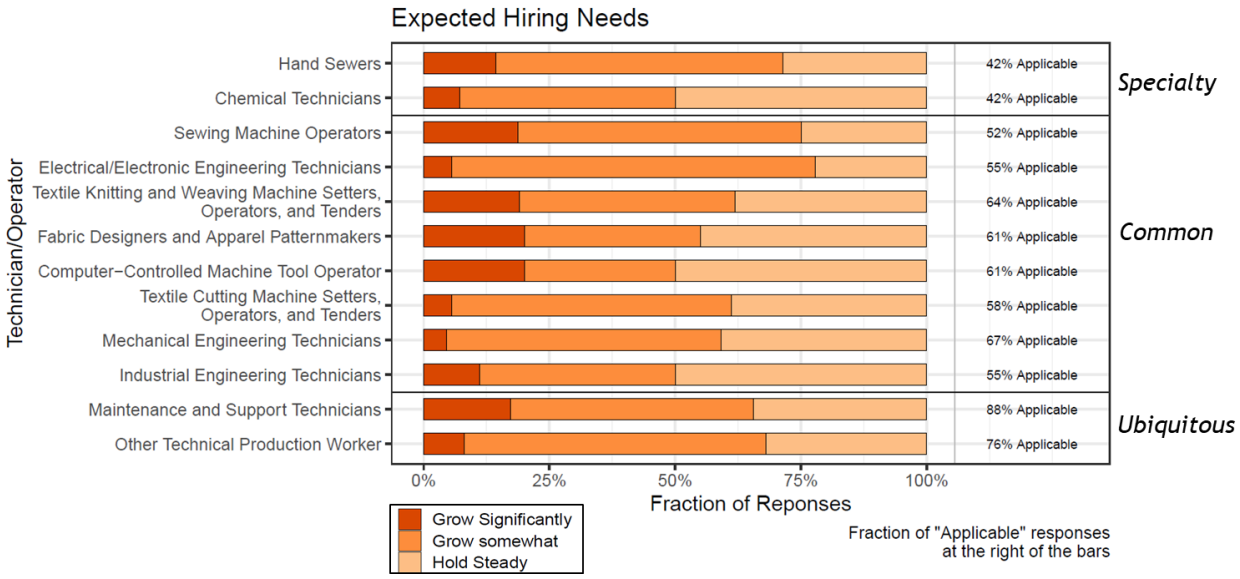

Figure 2. The technical worker occupations studied were classified according to future demand growth in the advanced fabrics and fibers industry. Occupations were also segmented into three categories of prevalence: ubiquitous (present in > 75% of firms), common (>50%), and specialty (<50%). Number of respondents, n =34.

The demand for each position can be summarized as follows:

Strong Growth	Moderate Growth	Hold
	• Hand Sewers • Sewing Machine Operators • Electrical/Electronic Engineering Technicians • Textile Knitting and Weaving Machine Setters, Operators, Tenders • Fabric Designers and Apparel Patternmakers • Textile Cutting Machine Operators • Mechanical Engineering Technician • Maintenance and Support Technicians • Other Technical Production Worker	• Chemical Technicians • Computer-Controlled Machine Tool Operator • Industrial Engineering Technician

Workforce Demand Projections

To better contextualize the growth trends implied by the survey, the research team developed a projection of expected positions and openings within the advanced fiber and fabrics (AFF) industry. This projection was based on three sources of data: forecasts for the overall economic activity within the U.S. AFF industry, estimates of worker intensity per dollar of economic activity within the represented sectors, and interview responses about specific staffing levels and anticipated growth in demand for specific occupations.

Estimates of economic activity within the U.S. AFF industry were assembled from two sources of market intelligence including the National Council on Textile Organization's *2019 State of the Textile Industry* report(Moran 2019) and the Bureau of Labor Statistics's *Projections Overview and Highlights, 2019-2029*(Weaver and Osterman 2017). From these sources of information, we estimate the AFF industry within the United States currently generates approximately $76B of revenue and is projected to grow at a rate of approximately 4% per year. (To be more conservative, we use this rate of growth only for the first five years of our analysis. For the latter five years, we assume 80% this rate of growth.) Estimates of workforce intensity (i.e. workers per dollar of revenue) are based on analysis of BLS data for the hybrid industry that is used here to represent AFF.

Note: in the balance of this section, in the interest of simplicity, we refer to technical middle-skilled and lower-skilled positions. As was detailed earlier in this document, our analysis includes only specific occupation types. For middle-skilled occupations, the primary omission is information technology positions. For lower-skilled occupations, we examine only four types of occupations that are particularly associated with this industry. As such, one would expect many additional lower-skilled openings beyond those we specifically analyze here.

As shown in Figure 3, we estimate that currently there are ~100,000 technical middle-skilled and lower-skilled positions in the U.S. AFF industry with that figure growing to just under 117,000 positions by the end of the decade (Figure 3a). About 18% (~18,700) of these positions are associated with middle-skilled technical positions. The expected growth coupled with expected departures from the existing workforce (i.e., retirements and separations into other occupations) would lead to an emergence of over 135,000 openings over that same time period including nearly 23,000 middle-skilled and 113,000 lower-skilled technical openings. This analysis projects nearly 4,800 openings for engineering technicians and patternmakers within the industry over the next decade. Demand for more generalized middle-skilled technical workers appears to remain strong as well, with more than 18,000 openings for maintenance technicians, other technical production workers (e.g., machinists), and CNC tool operators. The largest share of

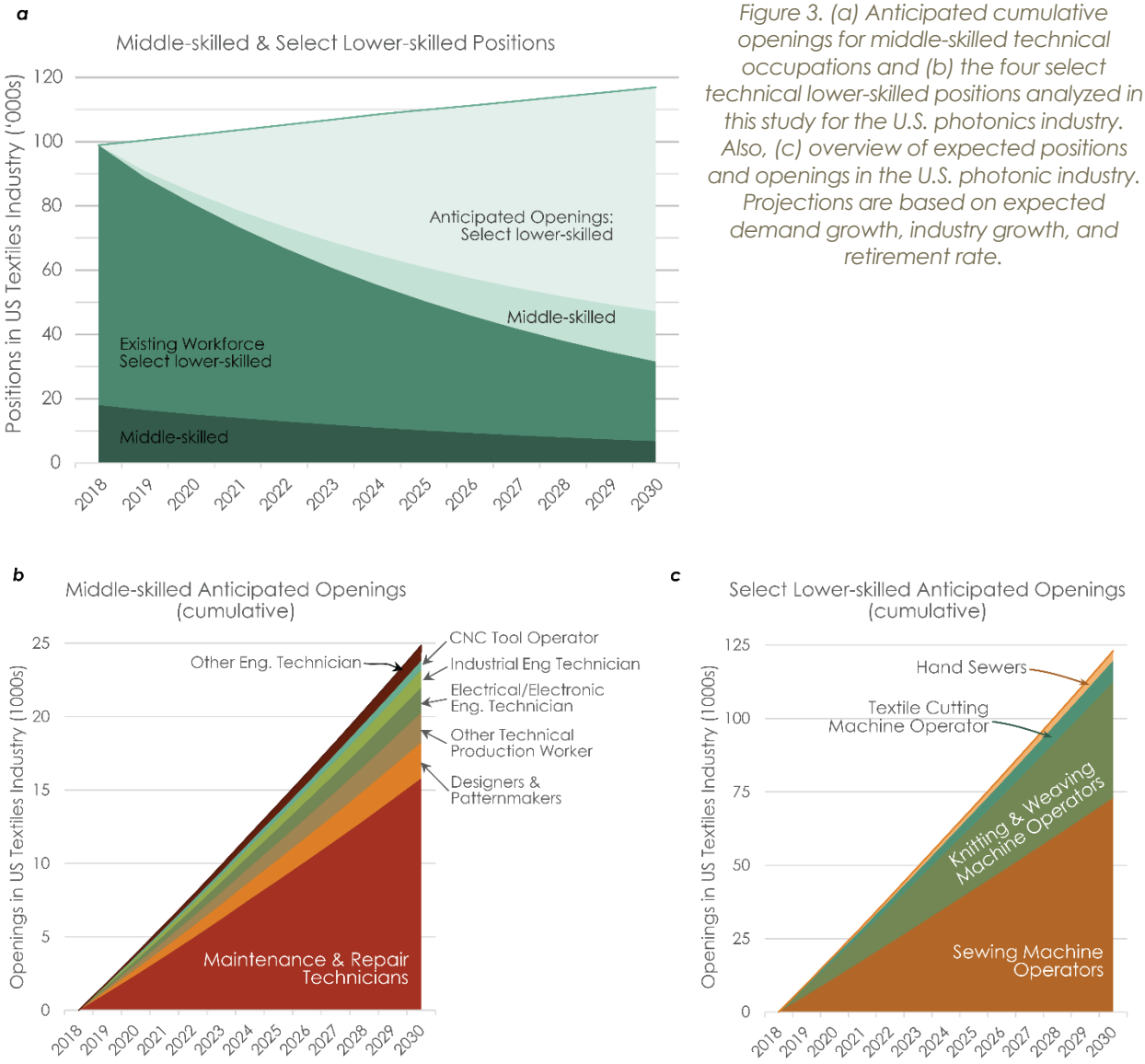

Figure 3. (a) Anticipated cumulative openings for middle-skilled technical occupations and (b) the four select technical lower-skilled positions analyzed in this study for the U.S. photonics industry. Also, (c) overview of expected positions and openings in the U.S. photonic industry. Projections are based on expected demand growth, industry growth, and retirement rate.

openings within the lower-skilled positions are found within the sew-machine operator and knitting and weaving machine operator occupations.

Considering all of the technical openings together, these estimates translate into a need of about 12,400 new workers per year including 2,100 middle-skilled and 10,300 lower-skilled workers. If a typical community college program graduates 15 middle-skilled learners with these skills per year, the country will more than 130 programs focused on the needs of the AFF industry to meet the expected industry demand for middle-skilled workers. Another clear recommendation that emerges from these numbers is the development of certificate or other short programs to provide the skills needed for the many lower-skilled workers that will be entering this industry. Assuming such programs could train 30 workers per year, at least 300 such programs would be needed nationally.

Mapping these number to a Massachusetts context, we estimate approximately 2,300 total openings in these positions for this sector within the state. This includes about 380 middle-skilled openings and 1,900 lower-skilled openings within the state. Following the national trends, these values translate into around 35 middle-skilled and 175 lower-skilled openings per year in the AFF industry, easily supporting two educational programs to train middle-skilled and six to train lower-skilled technical workers for the state's AFF industry.

Hiring Challenges

Question
Filling this type of position is ....

Figure 4 shows interview responses concern hiring challenges for each occupation. While demand for these positions is expected to grow moderately, hiring challenges are pervasive particularly for all engineering technicians and knitting and weaving machine operators. There was not a single position that could be classified as easy to hire. Respondents explained that the biggest challenge in the industry is: 1) finding workers to fill these positions and 2) retaining workers over time. Respondents were asked to classify the level of difficulty for hiring each of the positions as hard (>60 days to fill the position), average (30-60 days), or easy (<30 days). Few respondents indicated that it was easy to hire, particularly for many of the middle-skilled positions as shown in Figure 4.

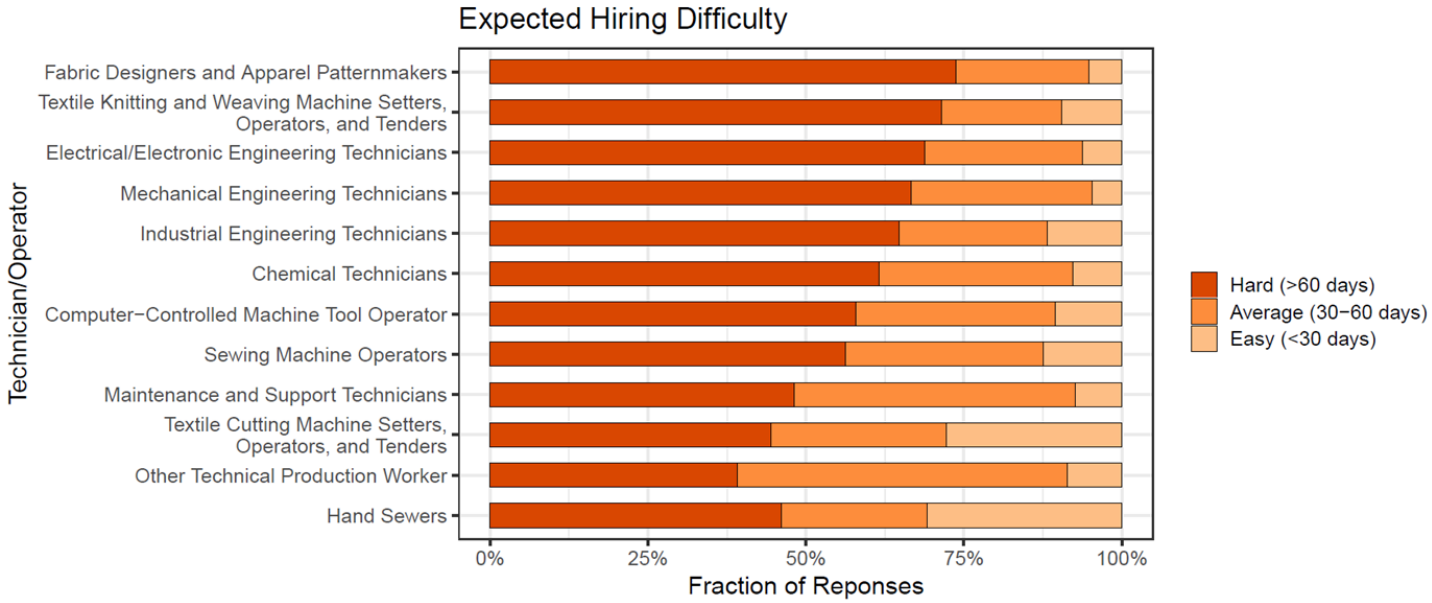

Figure 4 The difficulty of hiring the lower- and middle-skilled positions was assessed for the advanced fabrics and fibers industry (n=34). Many of the middle-skilled positions were found to be significantly difficult to hire, especially the Fabrics Designer and Patterns Maker position.

Respondents indicated that only two positions were somewhat easy to hire for (~25% of responses) including the Textile Cutting Machine Operator and the Hand Sewer position. For the Hand Sewer position, many of the respondents explained that there is a large

population in the Massachusetts region with hand sewing experience and they typically try to recruit workers from other AFF companies. The remaining positions were all classified as difficult to fill, suggesting a low supply of technical workers as well as a challenge of attracting workers to this industry. Another challenge in hiring is attracting diverse candidates. Firms mentioned that finding female workers was particularly difficult.

Many respondents explained that training is only one side of the equation; enticement and retainment of workers are equally, if not more important in this industry. There was discussion of raising wages, creating opportunities for professional development and promotion, and creating opportunities for feedback from workers to improve retainment over time.

> "Inherently, the fabrics and fibers industry is not viewed as a destination from a career standpoint."
>
> *New England Advanced Fabrics and Fibers Company Representative, February 2021*

The hiring difficulty for each position can be summarized as follows:

Considerable hiring effort	Moderate	Nominal
• Fabric Designers and Apparel Patternmakers • Textile Knitting & Weaving Machine Operators • Electrical/Electronic Engineering Technician • Mechanical Engineering Technician • Industrial Engineering Technician • Chemical Technician • Computer-Controlled Machine Tool Operator • Sewing Machine Operator	• Maintenance and Support Technicians • Textile Cutting Machine Operator • Other Technical Production Worker • Hand Sewer	

In comparing the demand and hiring results, maintenance and support technicians and other technical workers (e.g. machinists) are expected to have the largest growth, but are some of the easiest positions to fill in terms of hiring due to their non-specialized nature. Hand Sewers are the easiest to hire, yet are not in as high of demand. However, Mechanical Engineering and Electrical Engineering technicians are expected to have moderate demand growth, yet greater than 50% of respondents indicate they are difficult to hire.

Training Effort Required

Question
New hires typically require training that is …

Next, respondents were asked to assess the amount of on-the-job training required for new hires as extensive, some, or basic orientation only. Our findings indicate that more extensive training is required for middle-skilled technical workers than for lower-skilled operator workers (Figure 5). Many of the jobs in this industry are more specialized (e.g. Fabrics Designer and Apparel Patternmaker) and require on-the-job training because of the niche applications manufactured at each firm. A unique training challenge mentioned by a few respondents is addressing language barriers through the creation of non-English versions of training to eliminate more barriers to entry.

There are also position-specific training challenges. For instance, Fabric Designers and Apparel Patternmaker programs are largely centered around the fashion and apparel industry. However, respondents explained designers and patternmakers are in demand in other sectors of the industry and therefore more general training rather than apparel-specific training could increase the supply of qualified workers. For positions like Textile Knitting and Weaving Machine Operators, many firms currently send their workers to Europe or Asia because the training programs no longer exist in the U.S. To address these training challenges and help revive the workforce, several firms recommended a resurgence of apprenticeship programs between community colleges and AFF firms.

Figure 5 The training required for each position was assessed as extensive, some training, or basic orientation only (n=34). Most of the middle-skilled positions required extensive training (>50% of the responses) and the remaining positions required at least some training.

In comparing the training effort results to the hiring challenge results, we observe that many of the middle-skilled positions are difficult to hire and also require additional specialized training for new hires. Firms that were interviewed explained that it is often frustrating since it takes a long time to assess skillsets for hiring and they additionally need to invest time to train the worker. More often than not, after all of this effort to hire, the turnover rate for these positions is less than a year. Improved curricula to help reduce the training effort required would greatly benefit firms in the AFF industry.

> "Apprenticeships are very important. There are not apprenticeship opportunities available in manufacturing at all. Manufacturing is shrinking and apprenticeships only happen when there is industry growth."
>
> New England Advanced Fabrics and Fibers Company Representative, February 2021

The training challenges for each position can be summarized as follows:

Extensive training	Some training	Basic orientation only
• Mechanical Engineering Technician • Fabric Designers and Apparel Patternmakers • Chemical Technician • Industrial Engineering Technician • Electrical/Electronic Engineering Technician • Maintenance and Support Technicians • Computer-Controlled Machine Tool Operator	• Other Technical Production Worker • Textile Knitting & Weaving Machine Operators • Sewing Machine Operators • Textile Cutting Machine Operators • Hand Sewer	

Industry Recognized Certification Program

Question
How do you feel about the following statement: "Industry-Recognized Certifications and Credentials would be useful for the advanced fibers and fabrics industry."

Many organizations are promoting job-specific industry-recognized certifications and credentials to make it easier to identify qualified candidates and expand the pool of qualified workers. During the interviews, the firms were asked to rank how they felt about these programs to assist with hiring from strongly disagree to strongly agree (Figure 6). Specifically, they were asked if they agreed with a statement that industry specific credentials would be useful for the fiber and fabrics industry. Most respondents agreed or strongly agreed (58%). More importantly, this fraction was far larger than those that disagreed or strongly disagreed (16%). When asked to elaborate, respondents explained that a certification signals interest even if it doesn't necessarily equal more skills. Those that disagreed explained that it was another barrier to entry and sometimes was an incorrect signal that someone has more skills than they really have. If a credentialing or certification program was to be created for the advanced fabrics and fibers industry, it is recommended that the program be incentivized to ensure it is as accessible as possible for those interested.

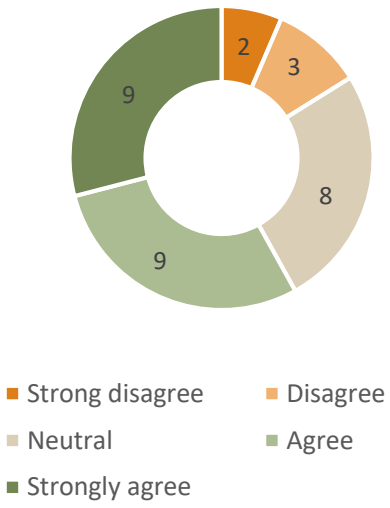

Figure 6 Reactions regarding certification and credentialing programs to improve hiring in the advanced fabrics and fibers industry.

Skills required for In-Demand Positions

The results from our firm interviews underscore the significant demand for middle-skilled and lower-skilled workers, hiring and retainment challenges, and training gaps for workers in the advanced fabrics and fibers industry. To better understand the training gaps, we asked respondents to evaluate which skills and technologies and tools are becoming more (or less) important over the next five years. Respondents evaluated the expected importance of specific work activities and tools and technologies (software) for three randomly selected middle- and lower-skilled technical positions. Expected importance was classified as grow significantly, grow somewhat, hold constant, or not important.

The research team used the overall set of responses to classify future importance for the individual work activities and tools and technologies as tending to grow significantly, grow, hold, diminish or diminish/regionally specific. The first four categories are generally self-explanatory. The final category "diminish/regionally-specific" was applied to items where many responses indicated a diminishing trend, but at least some responses were "grow" or "grow significantly." For these cases, the researchers felt that it was important to highlight that there are clearly some firms where this skill is important. As such, training programs should explore this topic with the firms that they serve locally to better understand its role for those firms.

There were a sufficient number of responses (n>=5) to characterize six positions including four middle-skilled positions and two lower-skilled positions. Since there are significant training gaps for these workers, we highlight opportunities to improve training programs for the future.

Table 2 Occupation descriptions for the six positions with a sufficient number of responses with four middle-skilled workers (blue) and two lower-skilled positions (green).

Occupation Title	Description
Mechanical Engineering Technicians (SOC Code 17-3027.00)	Apply theory and principles of mechanical engineering to modify, develop, test, or calibrate machinery and equipment
Industrial Engineering Technicians (SOC Code 17-3026.00)	Apply engineering theory and principles to problems of industrial layout or manufacturing production. May perform time and motion studies on worker operations in a variety of industries to establish standard production rates or improve efficiency
Fabric Designers and Patternmakers (SOC Code 51-6092.00)	Draw and construct sets of precision master fabric patterns or layouts. May also mark and cut fabrics and apparel.
CNC Tool Operators (SOC Code 9161.00)	Operate computer-controlled tools, machines, or robots to machine or process parts, tools, or other work pieces made of metal, plastic, wood, stone, or other materials. May also set up and maintain equipment.
Textile Knitting and Weaving Machine Setters, Operators, and Tenders (SOC Code 51-6063.00)	Set up, operate, or tend machines that knit, loop, weave, or draw in textiles.
Textile Cutting Machine Setters, Operators, and Tenders (SOC Code 51-6062.00)	Set up, operate, or tend machines that cut textiles.

Middle-Skilled Workers

Mechanical Engineering Technician

Survey responses for mechanical engineering technicians are shown in Figure 7. Recommendations for training of mechanical engineering technicians based on these results are summarized in Table 3.

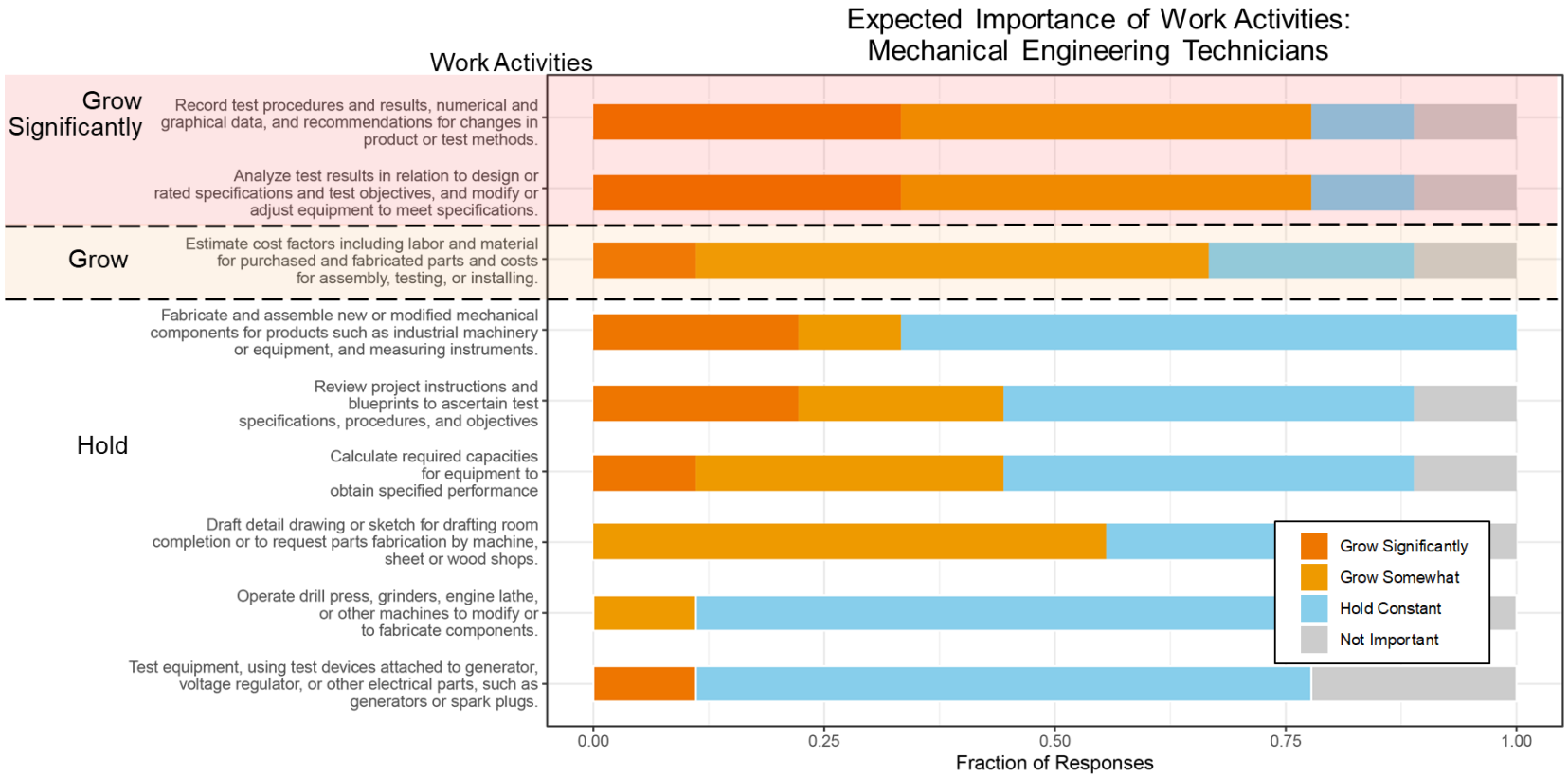

Figure 7. The expected importance of the work activities for mechanical engineering technicians are ranked from grow significantly to diminish and evaluate regionally.

Table 3. Recommended changes in the training of Mechanical Engineering Technicians in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Recommend changes in product or process design***	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.
	Analyze and respond to test data***	Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.
	Estimate process cost	Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.
Maintain training on …	Fabrication methods	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.
	Interpret process or test requirements	Review project instructions and blueprints to ascertain test specifications, procedures, and objectives
	Estimate equipment capabilities	Calculate required capacities for equipment to obtain specified performance
	Drafting for fabrication	Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.
	Electrical testing	Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.
	Operate specific equipment	Operate drill press, grinders, engine lathe, or other machines to modify parts tested or to fabricate experimental parts for testing.

Survey responses about expected importance of various tools and technologies for mechanical engineering technicians are summarized in Figure 8.

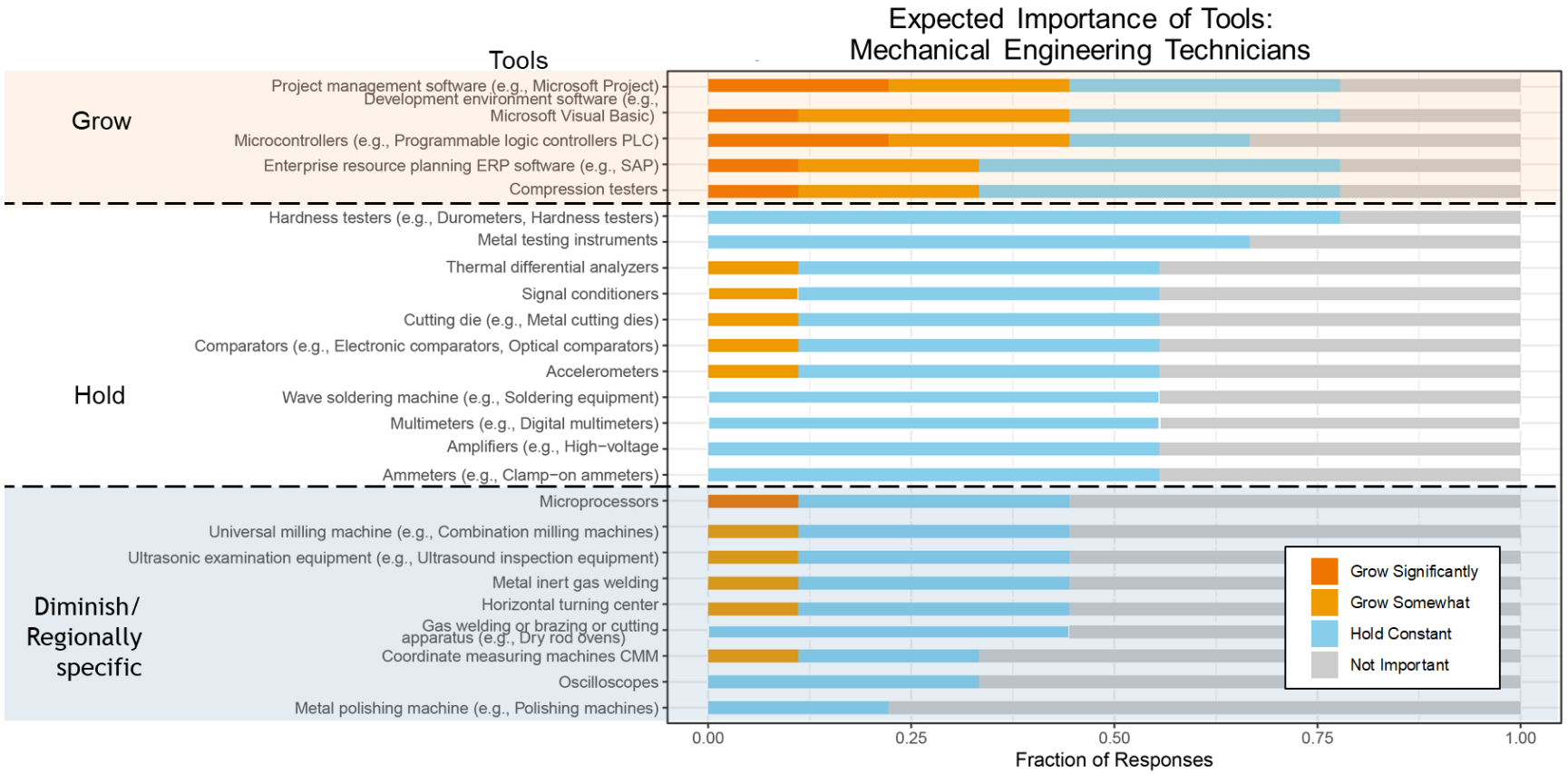

Figure 8 The expected importance of the tools and technologies for mechanical engineering technicians are ranked from grow significantly to diminish and evaluate regionally.

Industrial Engineering Technician

Survey responses for industrial engineering technicians are shown in Figure 9. Recommendations for training of industrial engineering technicians based on these results are summarized in Table 4.

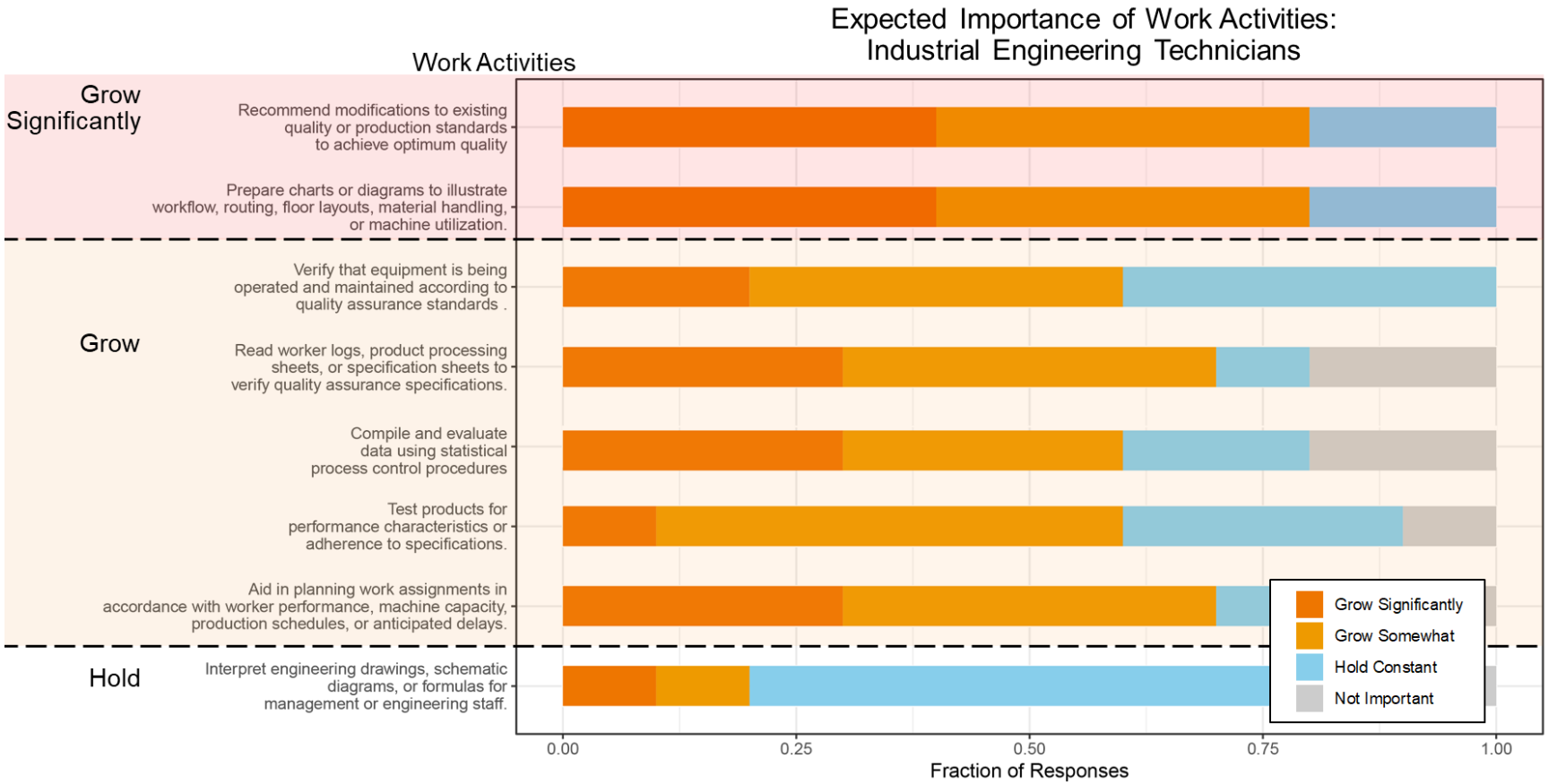

Figure 9 The expected importance of the work activities for industrial engineering technicians are ranked from grow significantly to diminish and evaluate regionally.

Table 4 Recommended changes in the training of Industrial Engineering Technicians in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Recommend operational & procedural changes***	Recommend modifications to existing quality or production standards to achieve optimum quality
	Communication with engineering and management***	Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.
	Maintain product and process quality assurance standards	Verify that equipment is being operated and maintained according to quality assurance standards.
		Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.
		Test products for performance characteristics or adherence to specifications.
	Analyze and respond to process data	Compile and evaluate statistical data to determine and maintain quality and reliability of products.
	Recommend operational & procedural changes	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.
Maintain training on…	Communication with engineering and management	Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.

Survey responses about expected importance of various tools and technologies for industrial engineering technicians are summarized in Figure 10.

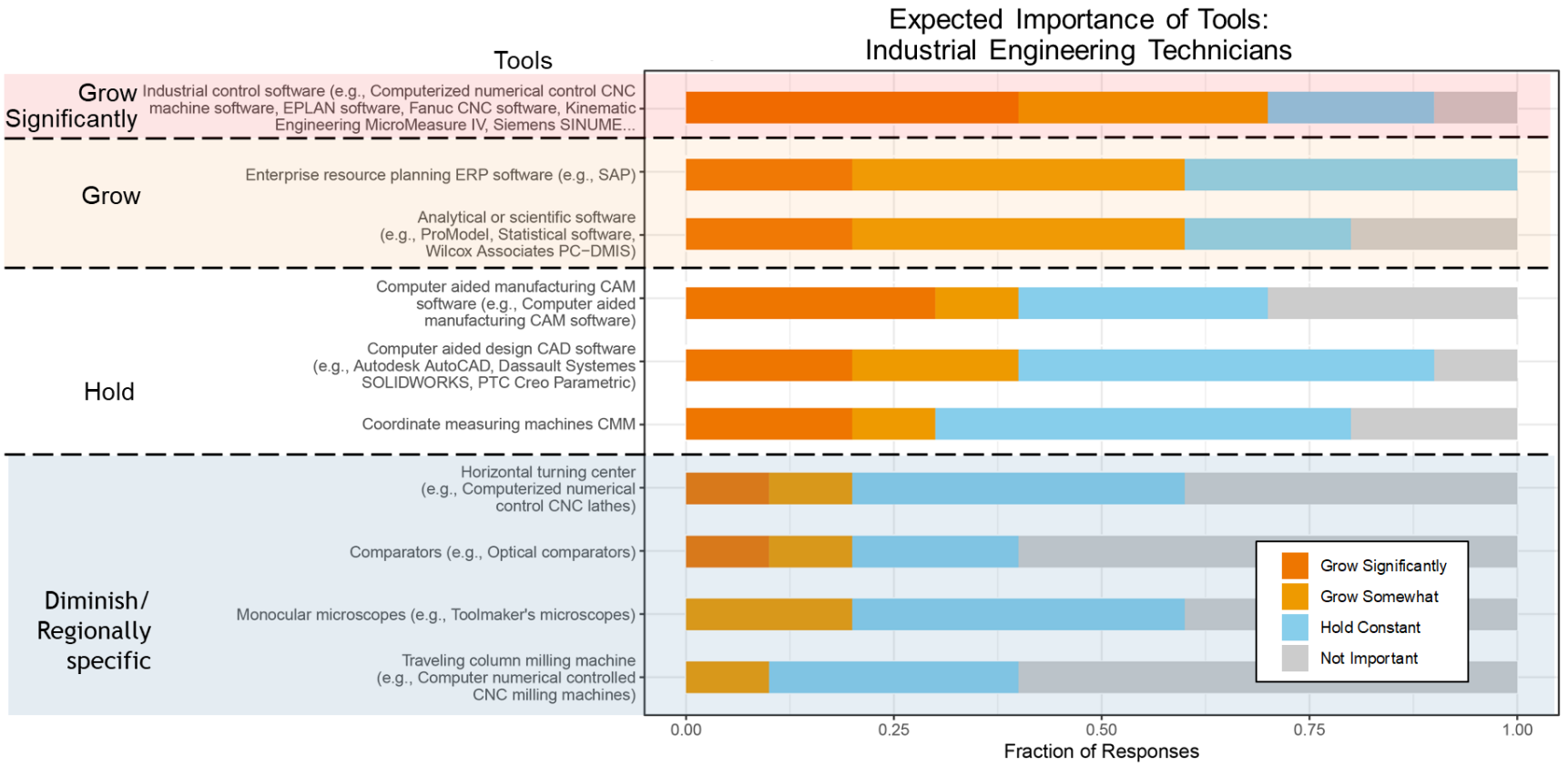

Figure 10 The expected importance of the tools and technologies for industrial engineering technicians are ranked from grow significantly to diminish and evaluate regionally.

Fabric Designer and Patternmaker

Survey responses for fabric designer and patternmaker shown in Figure 11. Recommendations for training of fabric designers and patternmakers based on these results are summarized in Table 5.

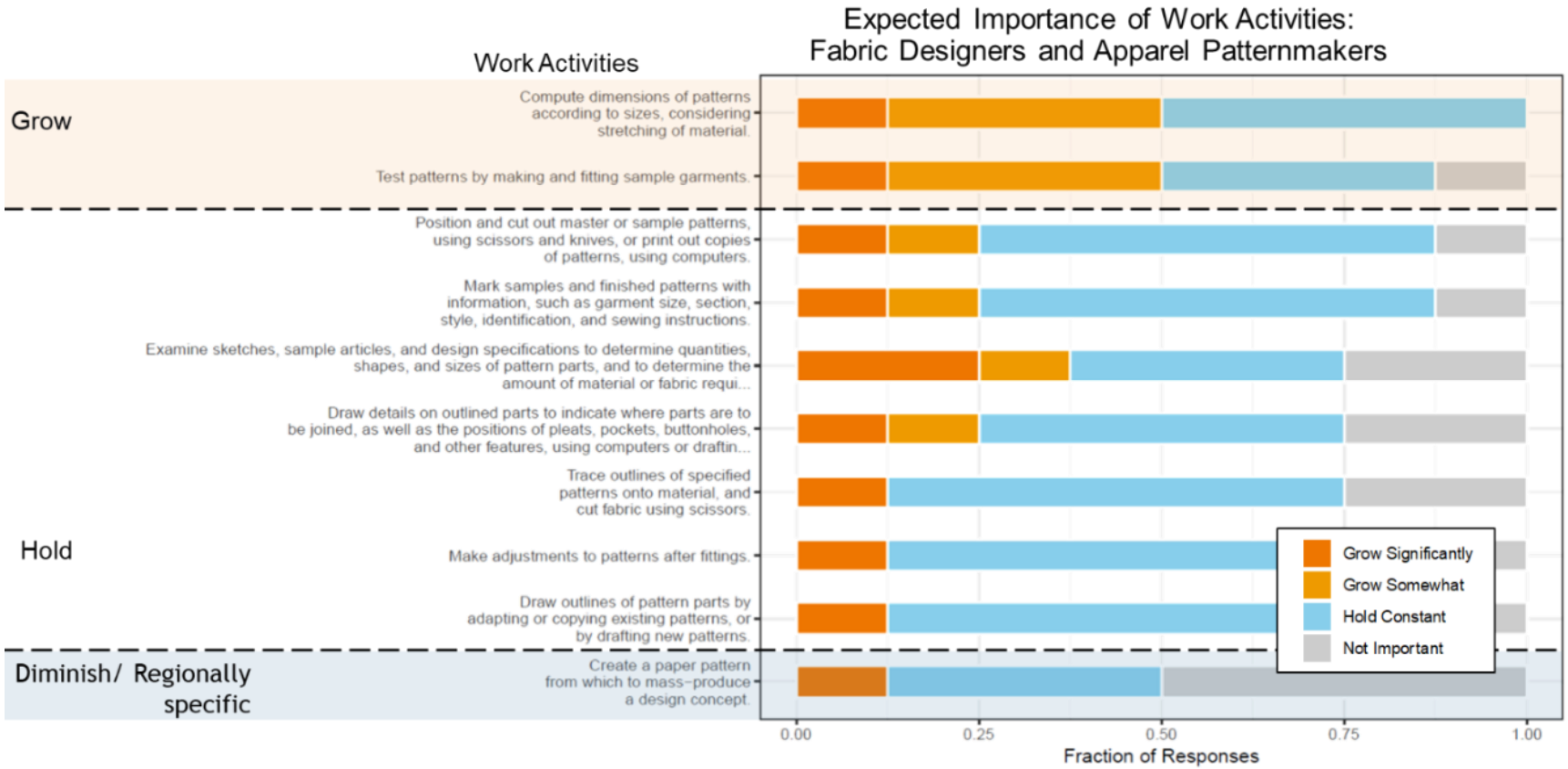

Figure 11 The expected importance of the work activities for fabric designers and patternmakers are ranked from grow significantly to diminish and evaluate regionally.

Table 5 Recommended changes in the training of fabric designers and patternmakers in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Compute dimensions	Compute dimensions of patterns according to sizes, considering stretching of material.
	Create samples	Test patterns by making and fitting sample garments.
Maintain training on…	Organize and make use of samples	Position and cut out master or sample patterns, using scissors and knives, or print out copies of patterns, using computers.
		Mark samples and finished patterns with information, such as garment size, section, style, identification, and sewing instructions.
	Estimate amount of material required	Examine sketches, sample articles, and design specifications to determine quantities, shapes, and sizes of pattern parts, and to determine the amount of material or fabric required to make a product.
	Draw pattern and product details	Draw details on outlined parts to indicate where parts are to be joined, as well as the positions of pleats, pockets, buttonholes, and other features, using computers or drafting instruments.
		Draw outlines of pattern parts by adapting or copying existing patterns, or by drafting new patterns.
	Trace and cut patterns	Trace outlines of specified patterns onto material, and cut fabric using scissors.
	Adjust patterns	Make adjustments to patterns after fittings.
Evaluate with their local industry the importance of…	Create paper patterns	Create a paper pattern from which to mass-produce a design concept.

Survey responses about expected importance of various tools and technologies for fabric designers and patternmakers are summarized in Figure 12.

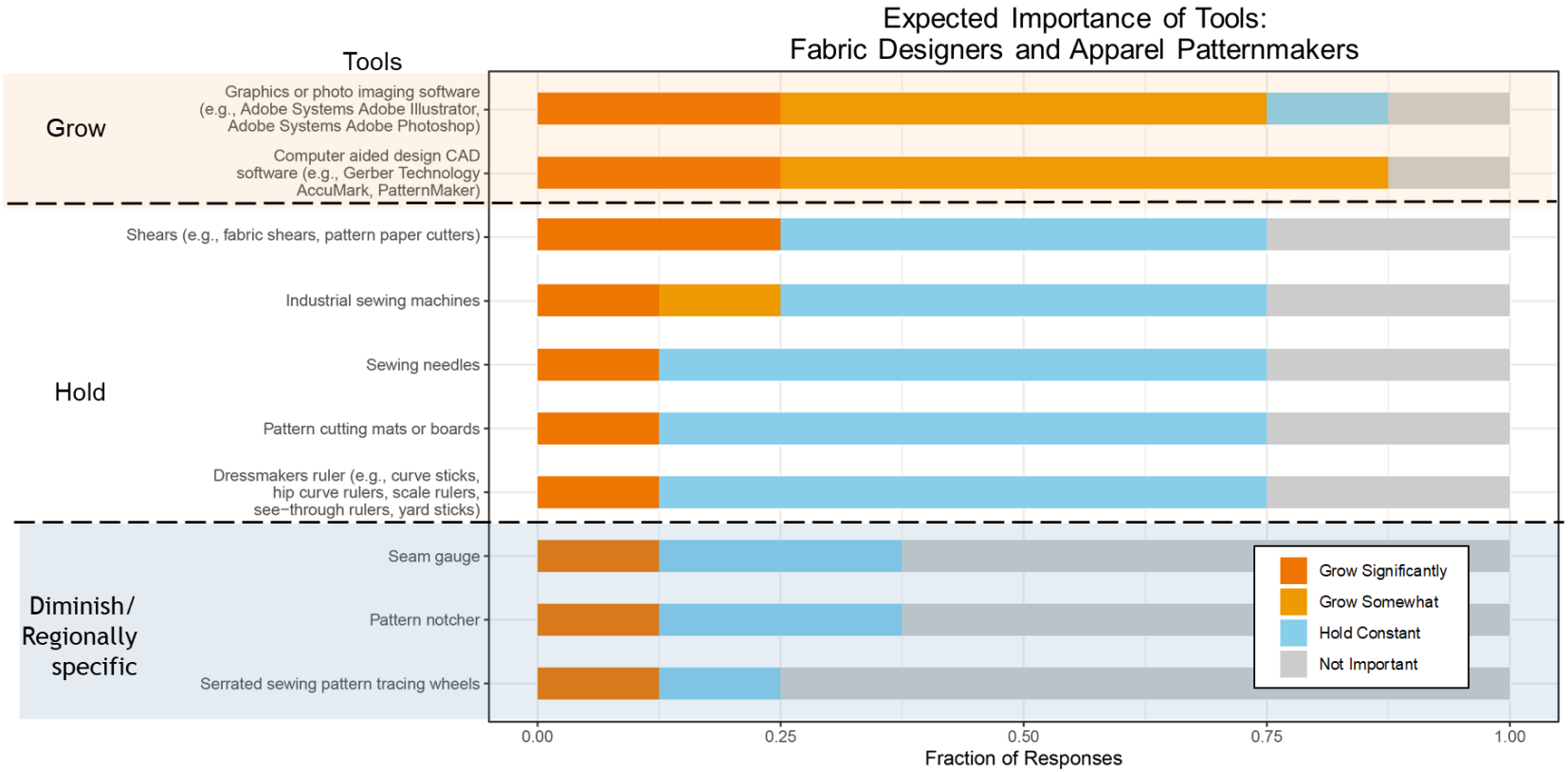

Figure 12 The expected importance of the tools and technologies for fabric designers and patternmakers are ranked from grow significantly to diminish and evaluate regionally.

CNC Tool Operator

Survey responses for textile knitting and machine operators shown in Figure 13. Recommendations for training of CNC tool operators based on these results are summarized in Table 6.

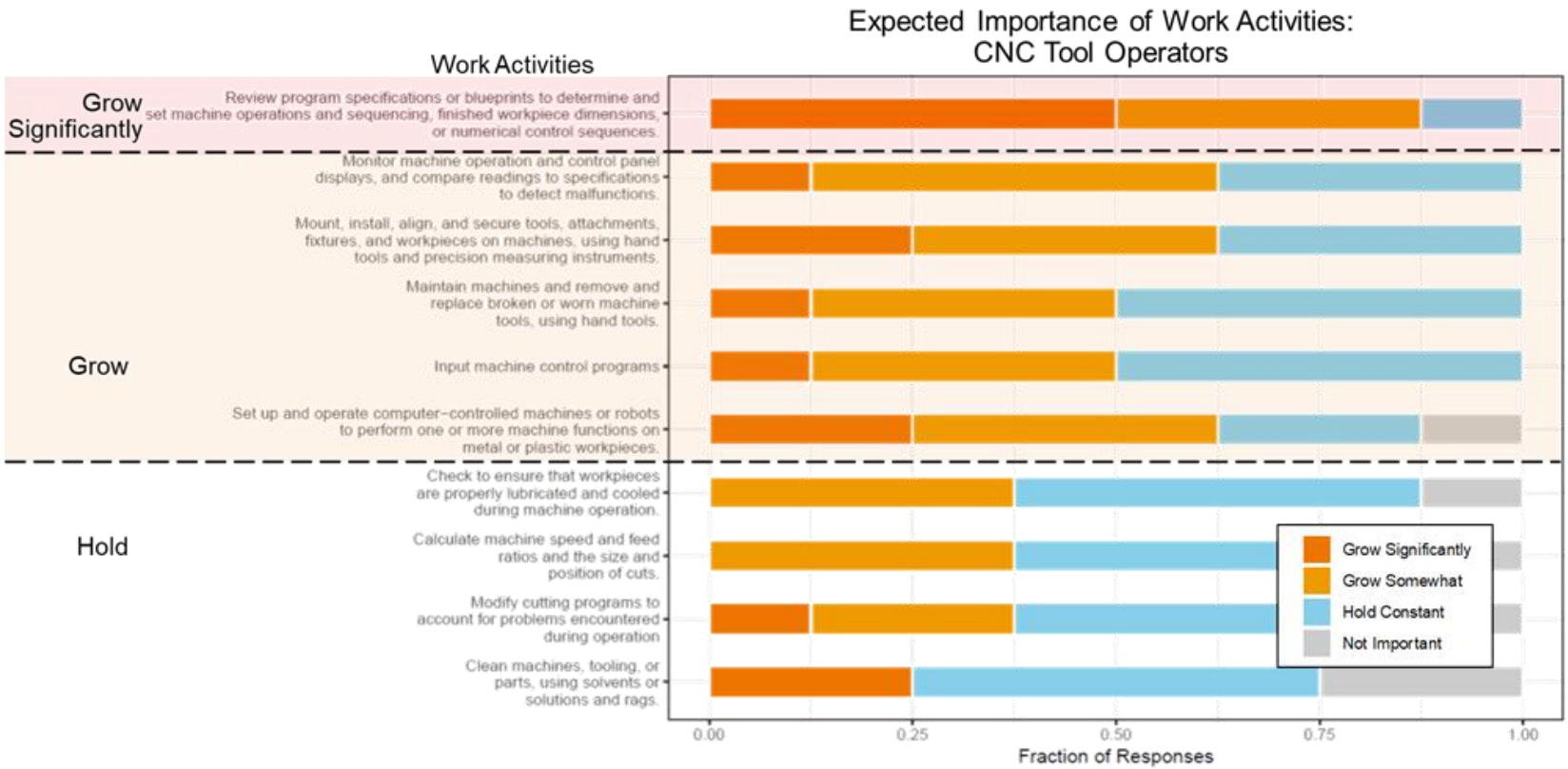

Figure 13 The expected importance of the work activities for CNC tool operators are ranked from grow significantly to diminish and evaluate regionally.

Table 6 Recommended changes in the training of CNC tool operators in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Assess specifications or blueprints	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.
	Apply precision measuring instruments	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.
	Monitor and maintain machines	Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.
		Maintain machines and remove and replace broken or worn machine tools, using hand tools.
		Input machine control programs
		Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.
Maintain training on…	Inspect machines	Check to ensure that workpieces are properly lubricated and cooled during machine operation.
	Calculate machine speeds and feed ratios	Calculate machine speed and feed ratios and the size and position of cuts.
	Alter machine settings	Modify cutting programs to account for problems encountered during operation
	Clean	Clean machines, tooling, or parts, using solvents or solutions and rags.

Survey responses about expected importance of various tools and technologies for CNC tool operators are summarized in Figure 14.

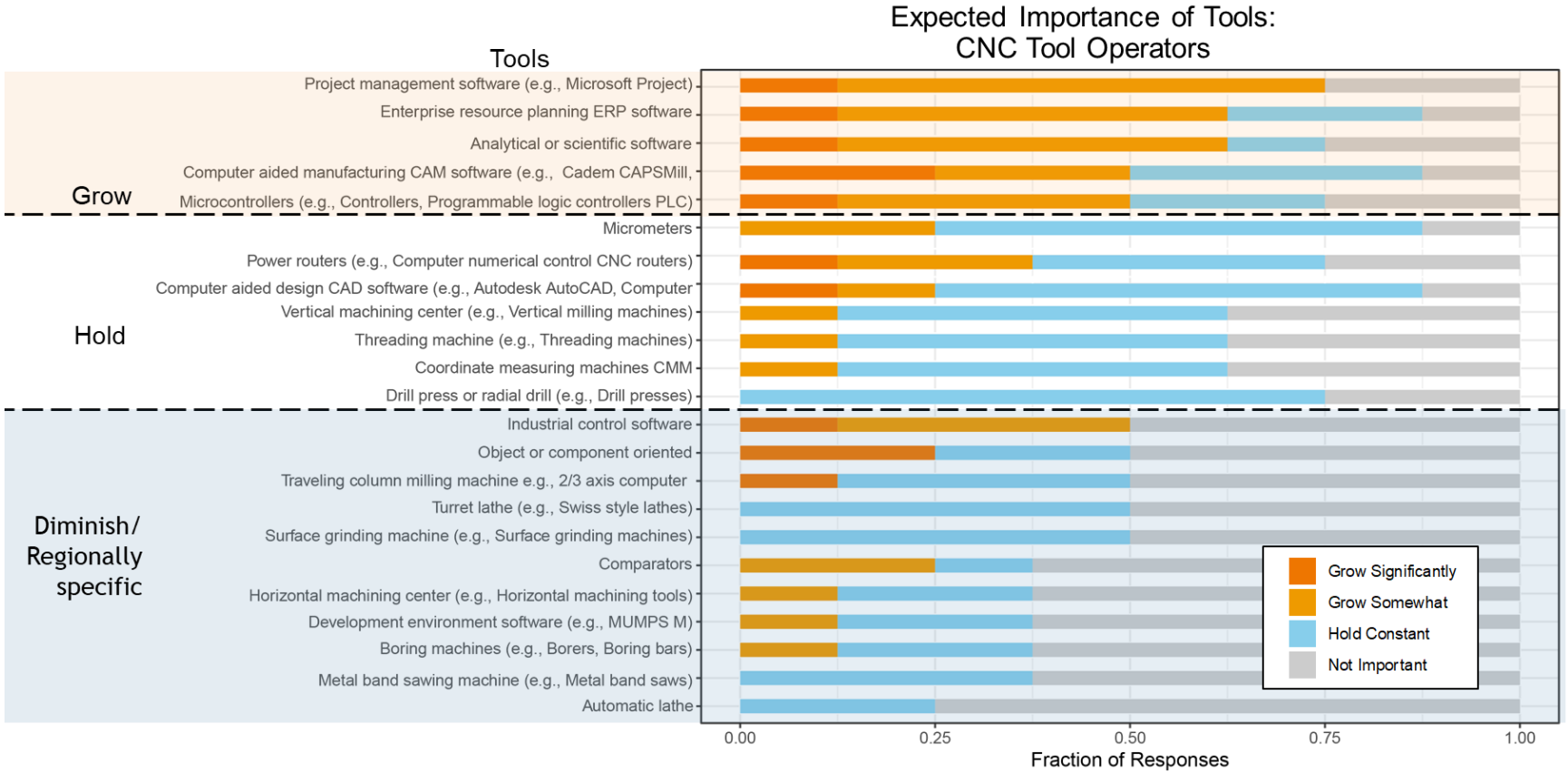

Figure 14 The expected importance of the tools and technologies for CNC tool operators are ranked from grow significantly to diminish and evaluate regionally.

Lower-Skilled Workers

Textile Knitting and Weaving Machine Operator

Survey responses for textile knitting and machine operators shown in Figure 15. Recommendations for training of textile knitting and weaving machine operators based on these results are summarized in Table 7.

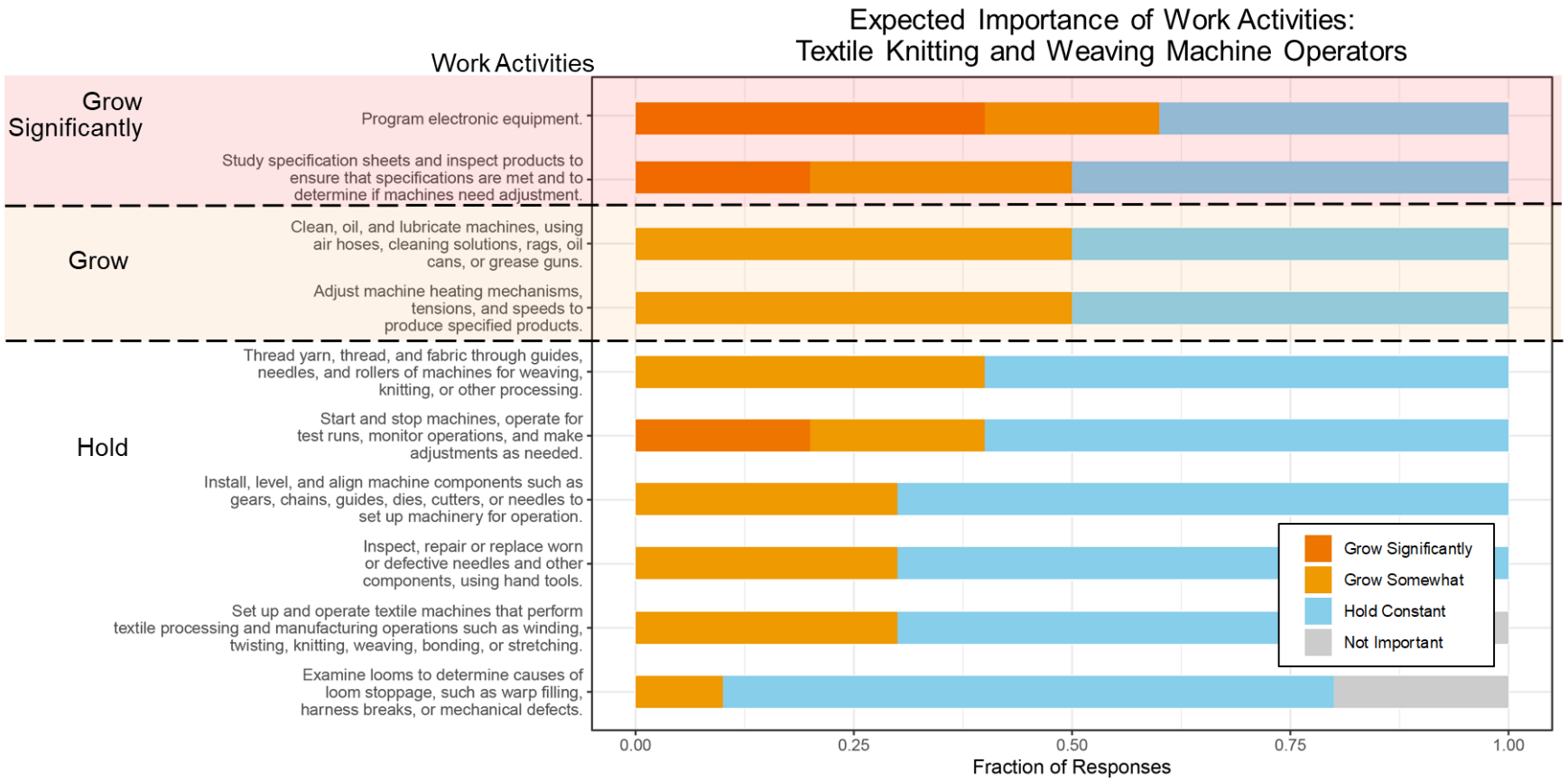

Figure 15 The expected importance of the work activities for textile knitting and weaving machine operators are ranked from grow significantly to diminish and evaluate regionally.

Table 7 Recommended changes in the training of textile knitting and weaving machine operators in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Program equipment	Program electronic equipment.
	Inspect products	Study specification sheets and inspect products to ensure that specifications are met and to determine if machines need adjustment.
	Maintain machines	Clean, oil, and lubricate machines, using air hoses, cleaning solutions, rags, oil cans, or grease guns.
	Adjust machine settings	Adjust machine heating mechanisms, tensions, and speeds to produce specified products.
Maintain training on…	Thread machines	Thread yarn, thread, and fabric through guides, needles, and rollers of machines for weaving, knitting, or other processing.
	Operate machines	Start and stop machines, operate for test runs, monitor operations, and make adjustments as needed.
		Set up and operate textile machines that perform textile processing and manufacturing operations such as winding, twisting, knitting, weaving, bonding, or stretching.
	Install components	Install, level, and align machine components such as gears, chains, guides, dies, cutters, or needles to set up machinery for operation.
	Inspect components	Inspect, repair or replace worn or defective needles and other components, using hand tools.
		Examine looms to determine causes of loom stoppage, such as warp filling, harness breaks, or mechanical defects.

Survey responses about expected importance of various tools and technologies for textile knitting and weaving machine operators are summarized in Figure 16.

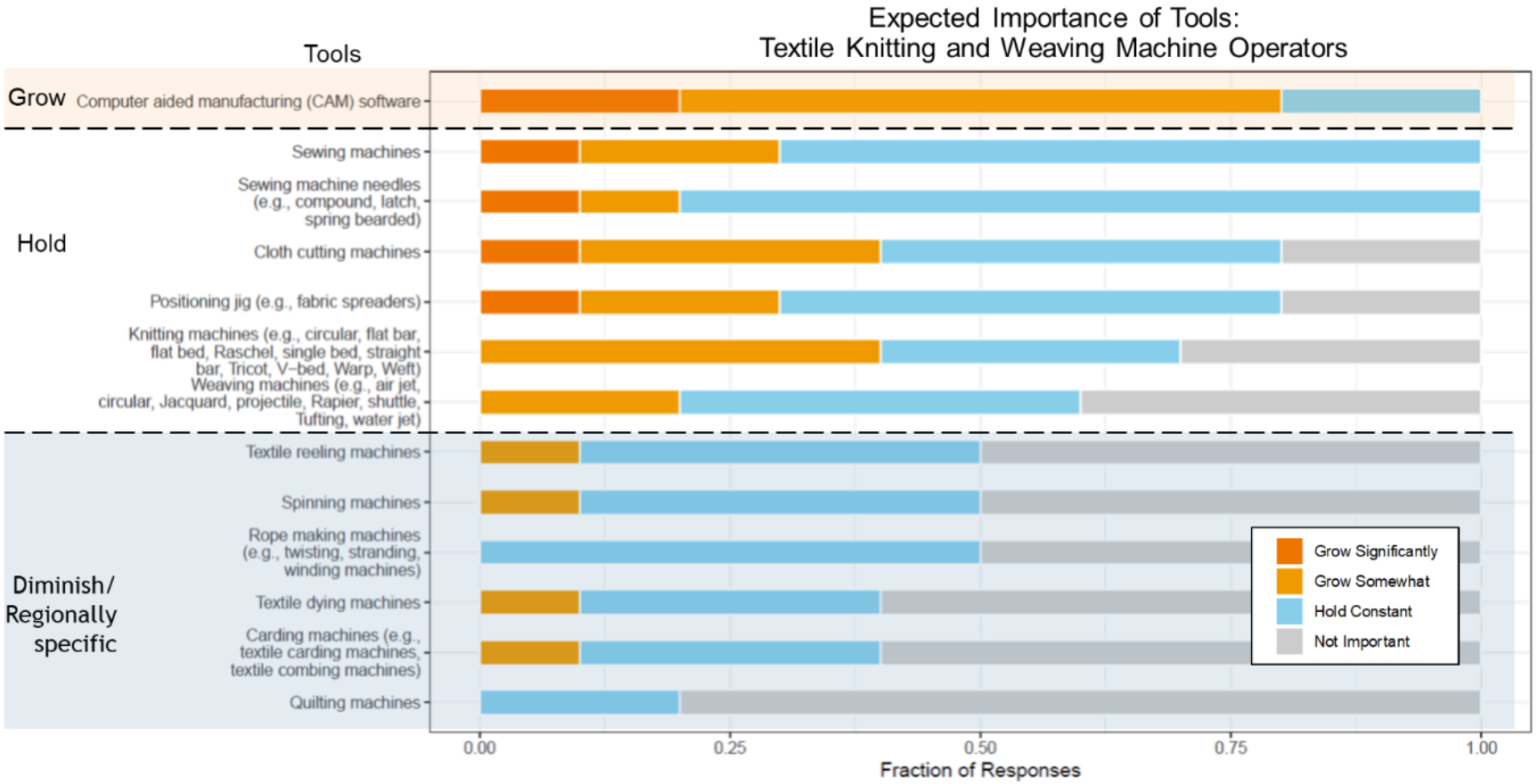

Figure 16 The expected importance of the tools and technologies for textile knitting and weaving machine operators are ranked from grow significantly to diminish and evaluate regionally.

Textile Cutting Machine Operator

Survey responses for textile cutting machine operators shown in Figure 17. Recommendations for training of textile cutting machine operators based on these results are summarized in Table 8.

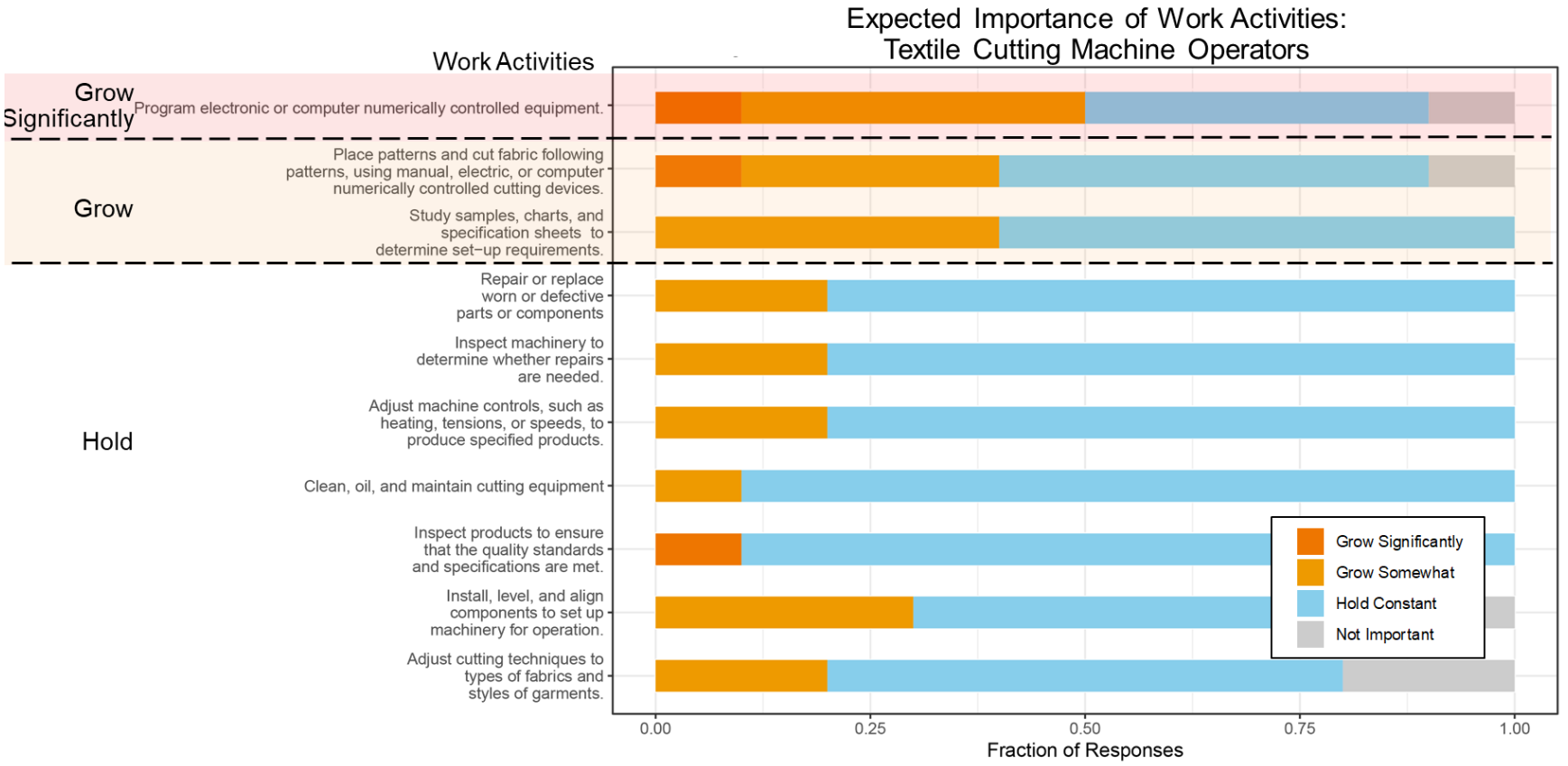

Figure 17 The expected importance of the work activities for textile cutting machine operators are ranked from grow significantly to diminish and evaluate regionally.

Table 8 Recommended changes in the training of textile cutting machine operators in the advanced fabrics and fibers industry.

Recommendation	Skill	Full Skill Description
Increase emphasis on…	Program equipment	Program electronic or computer numerically controlled equipment.
	Operate CNC device to cut fabrics	Place patterns and cut fabric following patterns, using manual, electric, or computer numerically controlled cutting devices.
	Assess set-up requirements	Study samples, charts, and specification sheets to determine set-up requirements.
Maintain training on…	Repair and inspect	Repair or replace worn or defective parts or components
		Inspect machinery to determine whether repairs are needed.
		Inspect products to ensure that the quality standards and specifications are met.
	Alter machine settings	Adjust machine controls, such as heating, tensions, or speeds, to produce specified products.
		Adjust cutting techniques to types of fabrics and styles of garments.
	Maintain equipment	Clean, oil, and maintain cutting equipment
	Install machinery	Install, level, and align components to set up machinery for operation.

Survey responses about expected importance of various tools and technologies for textile cutting machine operators are summarized in Figure 18.

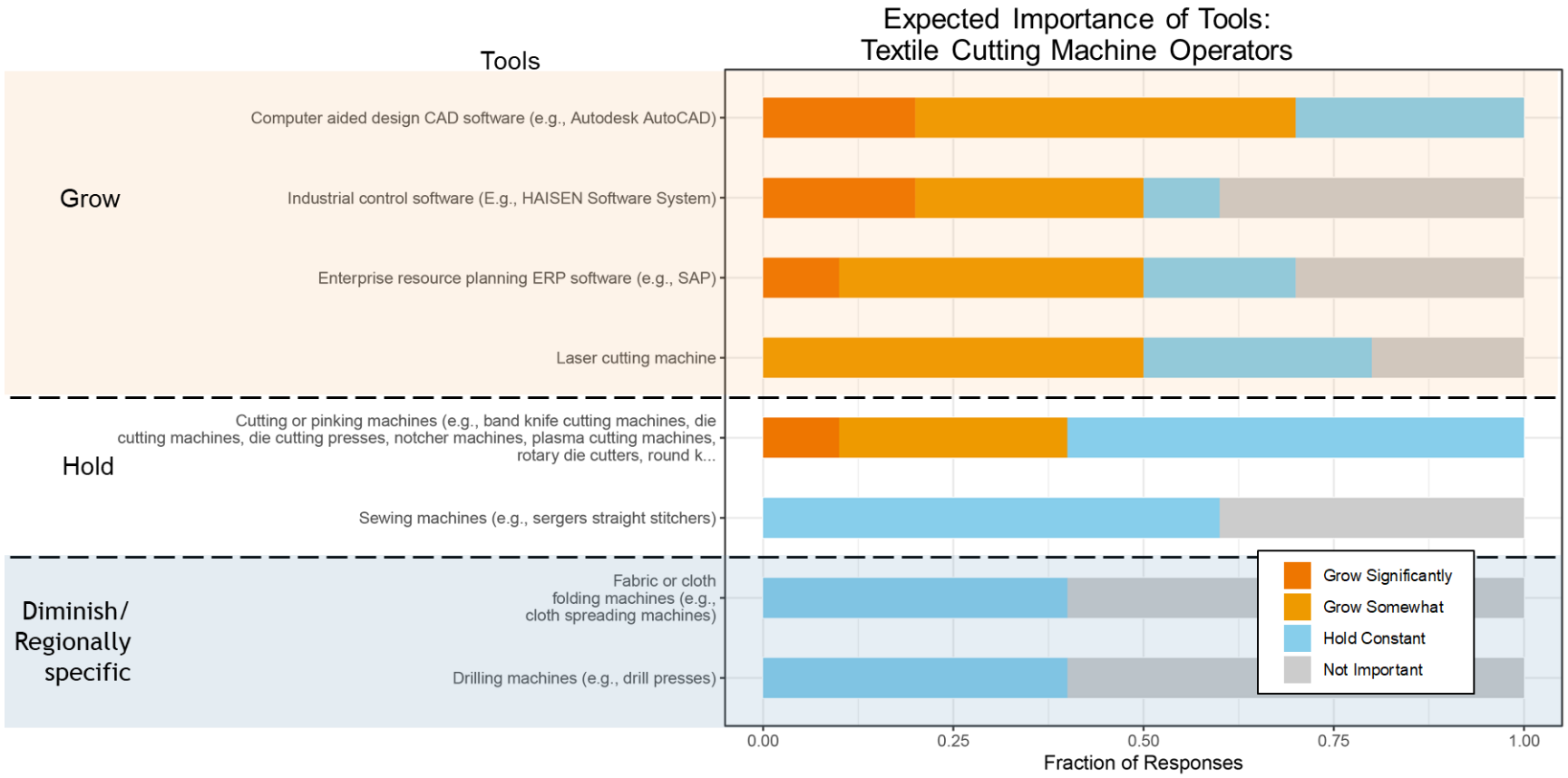

Figure 18 The expected importance of the tools and technologies for textile cutting machine operators are ranked from grow significantly to diminish and evaluate regionally.

Emerging skill needs

Along with assessing technical skills for each position, respondents also were asked to consider the importance of emerging skills over the next five years. This same set of skills was presented to respondents for each of the technical occupations. The importance of each of the emerging skills is shown for the operator and technician occupations (see Figure 24).

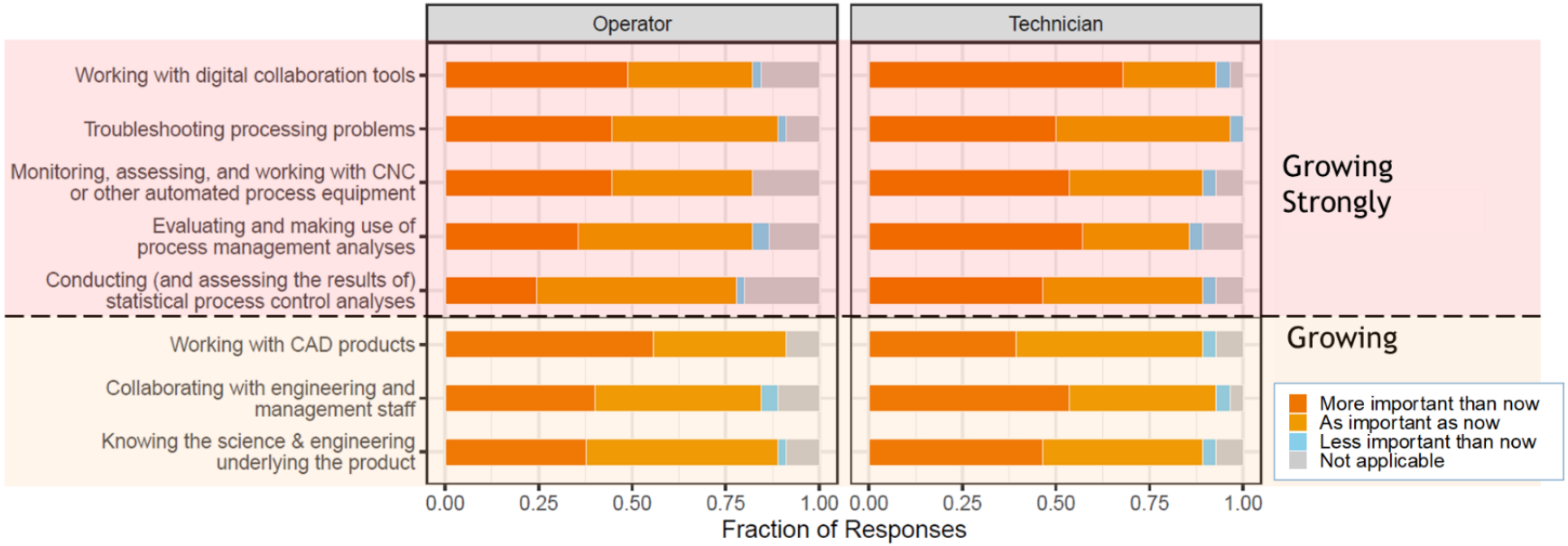

Figure 19 The expected importance of emerging skills is ranked as more important than now, as important as now, less important than now, and not applicable. The following skills are expected to grow strongly: 1) digital collaboration tools; 2) troubleshooting processing problems; and 3) monitoring, assessing, and working with automated process equipment (e.g. CNC).

The results demonstrate that these emerging skills are becoming increasingly important for technical workers. However, the future importance of a majority of these skills is stronger for technicians. For working with CAD products, the importance of this skill is stronger for lower-skilled, operator workers. These results indicate that training programs should put an emphasis on: 1) working with digital collaboration tools; 2) troubleshooting processing problems; and 3) working with automated process equipment (e.g. CNC). There is also a growing importance for evaluating and making use of process management analyses as well as conducting statistical process control analyses. The remaining emerging skills are already important and will likely remain important in the future.

Identifying Important Common Skills

In addition to understanding the detailed skills needs for each occupation, the research team has identified skills that are both important and shared (common) among multiple occupations. The purpose of this effort is to identify the skills needed broadly at the middle-skill occupation level to enable training programs to be relevant for companies across the advanced fabrics and fibers supply chain.

Figure 20 shows the ten highest weighted average importance scores for the general task/skill (GTS) level ranked from highest to lowest. The top three ranked common skills include documenting/recording data, getting information, and analyzing data or information, all which involve understanding and processing information and data. In addition, many of the remaining common skills (e.g. thinking creatively, making decisions and solving problems) involve critical thinking on the part of the worker. Table 9 to Table 11 provide details on the underlying specific skills associated with these GTS. Details for all GTS are provided in the appendix.

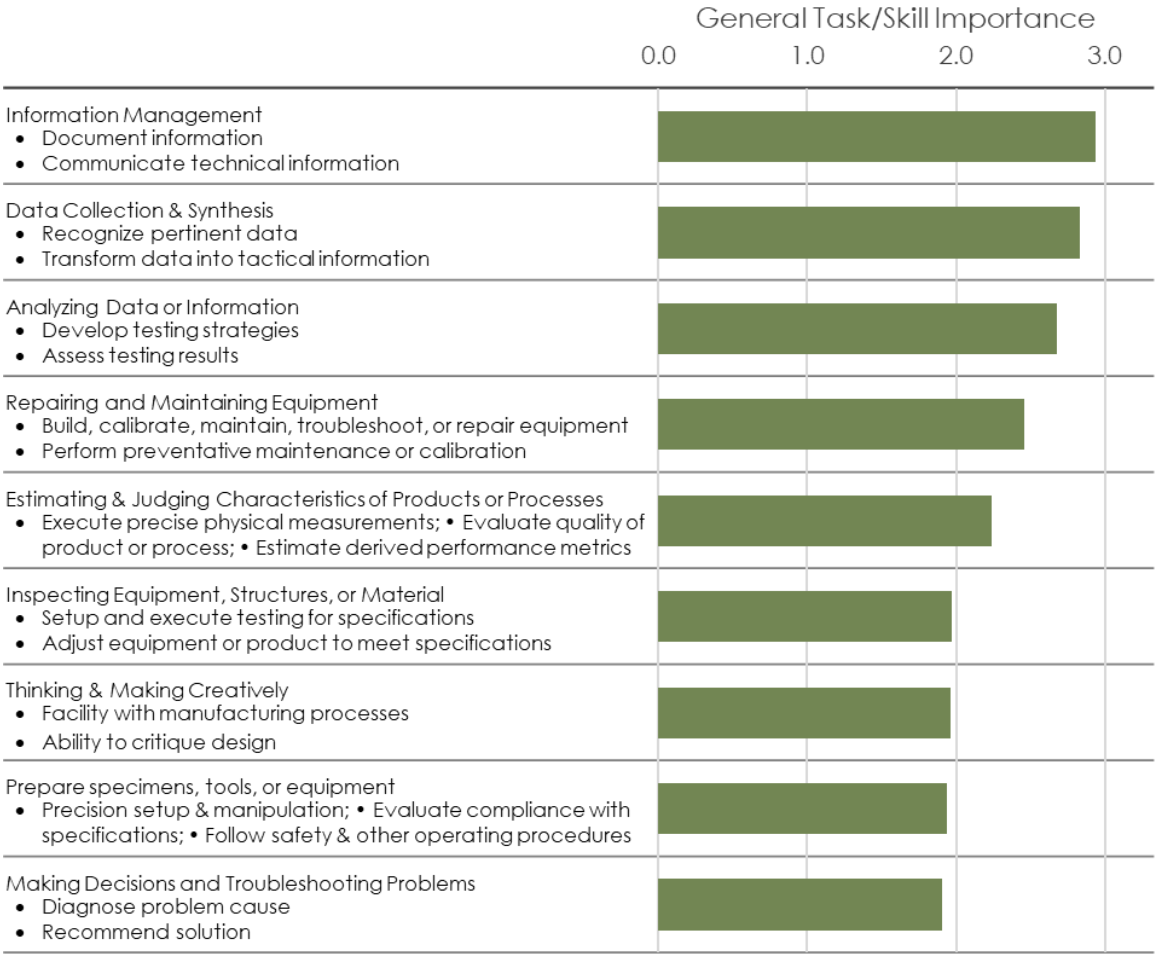

Figure 20 General Task or Skill ranked by weighted average importance of the skills within that class. Only GTS that are shared across at least three occupations are labeled as common and, therefore, included in this figure.

Details on Common Skills

Table 9 shows the underlying categorization and score detail for the two highest ranked GTS, "Information management" and "Data collection & synthesis." The specific skills in the information management category involve cognitive activities such as identifying context-relevant information and physical activities such as recording information. However, there are also cognitive activities that require critical thinking and communication skills such as "write technical reports…" or "prepare, review, or coordinate ongoing modifications…" The importance of these skills was identified for electrical engineering technicians, chemical technicians, and mechanical engineering technicians. For data collection & synthesis, cognitive processing of specifications and blueprints is necessary as well as an understanding of underlying "knowledge of electronic theory and components." This skillset was particularly important for electrical engineering technicians, mechanical engineering technicians, and CNC tool operators.

Table 9. Details of skill importance for General Task/Skill "Information Management" and "Data Collection & Synthesis" and their sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Information Management	2.9	Document technical designs, procedures, or activities.	3.1	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.	3.1				X		
				Write procedures for the commissioning of electrical installations.	-nr-		X				
				Write reports or record data on testing techniques, laboratory equipment, or specifications to assist engineers.	-nr-		X				
		Present research or technical information.	3.0	Write technical reports or prepare graphs or charts to document experimental results.	-nr-			X			
		Prepare documentation for contracts, applications, or permits.	2.0	Prepare, review, or coordinate ongoing modifications to electrical system specifications or plans.	-nr-		X				
Data Collection & Synthesis	2.8	Read documents or materials to inform work processes.	2.8	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.	3.8					X	
				Review project instructions and blueprints to ascertain test specifications, procedures, and objectives	2.2				X		
				Read blueprints, wiring diagrams, schematic drawings, or engineering instructions for assembling electronics units, applying knowledge of electronic theory and components.	-nr-		X				

Figure 10 shows the details of the scoring for the third and fourth highest ranked GTS, "Analyzing data or information" and "Repairing and maintaining equipment." For analyzing data or information, all the engineering technicians had skills of this type included in the interviews as well as the chemical technician. In all cases, these skills involve both executing diagnostic tests, analyzing the data that comes from those, and interpreting that data to guide some product or process decision. The GTS of repairing and maintaining equipment was found in the electrical engineering technicians,

chemical technicians, and CNC tool operator position. Most of these skills require the physical workmanship to maintain and service equipment, the cognitive understanding of how the machine functions, and troubleshooting skills to understand how to address malfunctions.

Table 10. Details of skill importance for General Task/Skill "Analyzing Data or Information" and "Repairing and Maintaining Equipment" and its sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Analyzing Data or Information	2.7	Analyze performance of systems or equipment.	2.8	Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.	3.1				X		
				Compile and evaluate data using statistical process control procedures	2.6	X					
				Interpret test information to resolve design-related problems.	-nr-		X				
		Analyze biological or chemical substances or related data.	2.3	Conduct chemical or physical laboratory tests to assist scientists in making qualitative or quantitative analyses of solids, liquids, or gaseous materials.	-nr-			X			
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-			X			
Repairing and Maintaining Equipment	2.5	Maintain electronic, computer, or other technical equipment.	3.0	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	-nr-		X				
				Maintain, clean, or sterilize laboratory instruments or equipment.	-nr-			X			
				Perform preventative maintenance or calibration of electronic equipment or systems.	-nr-		X				
				Adjust or replace defective or improperly functioning circuitry or electronics components, using hand tools or soldering iron.	-nr-		X				
		Maintain tools or equipment.	2.3	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	2.3					X	

Table 11 details a final important common skill, "Estimating and judging the characteristics of products or processes." This skill involves critical thinking on the part of the worker. For instance, the worker must be able to know what information is needed in a specific context and how to make decisions using that information.

Table 11. Details of skill importance for General Task/Skill "Estimating and Judging the Characteristics of Products or Processes" and its sub classes and skills. (-nr- indicates insufficient responses to report a meaningful average).

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Estimating and Judging the Characteristics of Products or Processes	2.2	Evaluate production inputs or outputs.	4.0	Monitor product quality to ensure compliance with standards and specifications.	-nr-			X			
		Estimate project development or operational costs.	2.4	Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.	2.4				X		
				Prepare electrical project cost or work-time estimates.	-nr-		X				
		Measure physical characteristics of materials, products, or equipment.	2.3	Compute dimensions of patterns according to sizes, considering stretching of material.	2.3						X
		Mark materials or objects for identification.	1.6	Mark samples and finished patterns with information, such as garment size, section, style, identification, and sewing instructions.	1.6						X

Results Summary

The results from the semi-structured interviews with fabric and fiber firms demonstrate a growing demand for technical workers at the middle-skilled level. Specifically, our projections underscore the growing demand where we estimate middle-skilled and our focal lower-skilled positions within this industry to grow from around 100,000 today to 117,000 by the end of the decade. Accounting for expected retirement and separations, nearly 23,000 cumulative middle-skilled technical openings are expected over the next decade or around 2,100 new middle-skilled technical workers per year. If we assume that a typical training program produces about 15 graduates per year, this suggests that the US needs around 130 training programs to meet the growing needs of the industry. In addition to middle-skilled openings, we project 113,000 cumulative openings or around 10,000 openings per year for the focal lower-skilled occupations in this study.

Training for technical workers in advanced fabrics and fibers should increase emphasis on

- Information management
- Analysis of data or information
- Repairing and maintaining mechanical equipment
- Working with digital collaboration tools
- Troubleshooting processing problems

Mapping these number to a Massachusetts context, we estimate about 35 middle-skilled and 175 lower-skilled openings per year in the fiber and fabrics industry in the state; easily supporting two programs for training technical middle-skilled workers and suggesting a need for certificate programs to train lower-skilled workers.

Interview respondents identified growing demand for a majority of the occupations included in this study. In particular, there is stronger growth expected for the ubiquitous positions (present in more than 75% of interviewed firms) of maintenance and support technicians as well as other technical production workers (e.g., CNC operators). Of those occupations common (present in more than 50% of interviewed firms) across the industry, electrical/electronic engineering technicians and sewing machine operators are expected to have the largest growth. Nearly all occupations studied have significant hiring challenges as well as extensive on-the-job training required for new hires. There are five occupations that were both notable training gaps and hiring challenges including:

- Fabric Designers and Apparel Patternmakers
- Mechanical Engineering Technicians
- Electrical/Electronic engineering Technicians
- Industrial Engineering Technicians
- Textile Knitting and Weaving Machine Operators (lower-skilled position)

Because of specific implementation issues, we did not receive sufficient responses to comment on the technical skill needs for all occupations. Nevertheless, we did receive feedback on the importance of specific technical skills for mechanical engineering

technicians, industrial engineering technicians, fabric designers and apparel patternmakers, CNC tool operators, textile knitting and machine operators, and textile cutting machine operators. The results demonstrate both real opportunities for technical careers within the advanced fabric and fiber industry and improvements in training for these occupations.

These detailed results should prove useful for shaping specific elements of the curriculum for these positions, however, they also provide insights into trends across the fiber and fabrics workforce. Because the interviews focused on skills derived from work activities described in the Bureau of Labor Statistics O*Net dataset, it was possible to use the hierarchy within that dataset to aggregate survey responses to more generalized classes of skills (referred to as General Task/Skill, GTS). Looking across all positions, the top five general tasks that are expected to be the most important for middle-skilled workers include:

- Information Management
- Data Collection & Synthesis
- Analyzing Data or Information
- Repairing and Maintaining Equipment
- Estimating and Judging Characteristics of Products or Processes

Information management skills include identifying context-pertinent information, documenting that information in an appropriate manner, and developing the information into written or oral communication. Data collection and synthesis involve gathering and measuring relevant data and summarizing the data for others (or yourself) to analyze. Analyze data or information, skills include assessing, cleaning, testing, and transforming the data into a useable product to inform decision making. Beyond data and information processing, repairing and maintaining equipment is a common, important skill across all positions. This skill entails building, calibrating, and troubleshooting equipment malfunctions to minimize downtime. Finally, estimating and judging characteristics of products or processes involves quality assurance functions such as precise measurement, assessment of and suggestions for process or product improvement, and comparison against performance quality metrics. These overall results make clear the growing importance of information management and data analysis for middle-skilled workers in the advanced fabric and fiber industry.

In this study, the focus was on understanding and evaluating technical skills gaps. We explicitly did not ask respondents to evaluate soft skills; however, we did explore the importance of some broadly discussed, emerging tools and skills. From this, we found that survey respondents expect increasing importance for technical workers to be skilled in

- Working with digital collaboration tools
- Troubleshooting processing problems
- Monitoring, assessing, and working with automated process equipment (e.g. CNC)

The increasing importance of these emerging technical skills is consistent with survey responses about the importance of generalized skills such as communication and troubleshooting.

Overall, the results presented here demonstrate both the growing opportunities for technical careers in the advanced fabric and fiber industry as well as the key opportunities to improve the training and skills development of those pursuing these occupations.

Appendix

Literature review and gap analysis

Past efforts to characterize skills gaps and fulfill workforce needs have been successful in increasing employment opportunities specifically for middle-skilled workers. In Pennsylvania, a National Science Foundation (NSF) grant provided funding to develop community college programs in the area of nanofabrication (Hallacher, Fenwick, and Fonash 2002) through professional development workshops for educators and new curricula for students. Through these efforts, community college graduates from targeted nanofabrication programs received more than seven job offers on average upon graduation. There were also regional benefits of new nanofabrication facilities locating to Pennsylvania as a result of the increased workforce and skill development of Pennsylvania community college graduates. In an NSF funded workshop for additive manufacturing (AM), stakeholders evaluated the current state, workforce needs, and future trends to inform research and education and training for the upcoming workforce (Huang et al. 2015) . Their findings suggest the university-community college partnership model can enable a well-trained AM workforce through sharing of lectures, knowledge via educator workshops, web resources, and laboratory spaces for hands-on training. Participants in the workshop recommended future funding opportunities through America Makes, the NSF, and other federal agencies for AM education and curricula development. With support for feeder programs, a stable workforce of well-trained, low-cost, entry-level technicians will continue to grow (Foy and Iwaszek 1996). In addition to curricula development, internship opportunities will also be necessary for the up-and-coming workforce to obtain the on-the-job experience necessary to fill these critical gaps (Hardcastle and Waterman-Hoey 2010).

While curricula have been developed for emerging manufacturing areas in the past (e.g. nanofabrication), this is the first development of a roadmap method to assess workforce gaps and needs across several advanced manufacturing industries. This research provides a method to classify emerging advanced manufacturing industries, identify companies within the industry, and leverage industry expertise to inform workforce development needs. In BLS, these emerging manufacturing industries are organized broadly, and as a result, the industries are not immediately apparent. To address these limitations, we've developed a systematic, data-driven method for classifying advanced manufacturing industries and an industry stakeholder informed education roadmap on current priority and future accelerating jobs and training needs. The education roadmap will provide recommendations for community college, certificate programs, and instructors on how to upgrade their photonics curricula and matriculate more competitive technician candidates, for targeted hiring in photonics industry clusters across the US. This method is performed in four steps: 1) classification of emerging advanced manufacturing industries, 2) survey development leveraging industry expertise, 3) survey assessment by experts, and 4) survey distribution, response analysis

and recommendations. To demonstrate the method for classifying and assessing employment needs for an advanced manufacturing industry, the method is applied to a case study of the photonics industry.

Detailed Methods

To characterize workforce needs within advanced manufacturing industries we have relied primarily on interviewing firms within that industry. Development and deployment of the semi-structured interview followed a process involving four major steps.

Discern emerging advanced manufacturing industries

The discernment process aims to identify a sufficiently large sample of firms that are representative of the advanced manufacturing sector of interest and to identify how these firms are currently classified in some relevant industrial classification system. This classification system will be referred to as the discernment system. This information will play two roles in subsequent analyses. First these firms will be the target of surveys and interviews. Second, the classifiers associated with these firms will be used to estimate employment intensity from BLS databases.

The first step in this classification process was to identify firms that are representative for the industry of interest. We refer to these firms as archetypes. This is an inherently manual, expert-based process. For the advanced fabric and fiber industry, archetype firms were identified through a number of methods, including querying member listing from relevant professional associations[5] and expert elicitation. Once archetypes were identified, they were queried within the discernment system. The most common economic activity type (EAT) codes associated with those firms within the discernment system were cataloged. This set of codes serves as one definition of our industry of interest and were used to identify a larger set of similar firms.

[5] In this case, we specifically queried the membership roster of AFFOA (Advanced Functional Fabrics of America) a Manufacturing USA institute based in Cambridge, MA.

To leverage data catalogued by the US BLS, firms must be identified using the North American Industrial Classification System (NAICS) (Dalziel 2007). If the discernment system is not NAICS (as it was not in our case study here), then it is necessary to create an empirical mapping between the two systems. Here we do this by using the discernment system to identify a larger set of firms of the same type as the archetypes and then identifying the prevailing NAICS codes used to characterize those firms.

The North American Industrial Classification Systems (NAICS)

Industry classification systems reflect a country's economic output, trade, and employment (Dalziel 2007). The NAICS is a framework that is used widely for firm classification. NAICS was developed in 1997. It captures a large number of business types including those in the service industry (BLS). In the NAICS system, firms are identified using their production processes and the codes are updated every five years to reflect changes in industry titles and descriptions. The industries and sectors are classified with two to six digits, where the higher number of digits represents a greater detailed classification of the industry.

While the NAICS system may be more representative than its predecessor, the SIC system, many researchers have found limitations in classifying industries based on their production processes (Kile and Phillips 2009). For instance, Dalziel (2007) explains that eight non-diversified communications equipment manufacturers are classified in four separate industries and two separate sectors despite being major competitors. Other limitations include addressing the rapid changes in technology advancements. While there are many different types of software companies, all firms that develop software are classified with the same code, 511210, Software Publishers (Dalziel 2007). In classifying emerging industries, such as those in the advanced manufacturing space, it can be challenging to identify the boundaries of the industry and assign a NAICS code that is accurately representative of a firm's activities. For example, when searching the NAICS database for "photonics", the NAICS code assigned is 541715, Research and Development in the Physical, Engineering, and Life Sciences (except Nanotechnology and Biotechnology). Although photonics can be classified under this code, botany and agricultural research also share this classification. This shows yet another limitation of the NAICS system; the NAICS codes are often too broad to capture the specifics of an emerging industry. As a result, it can be difficult to capture the current employment statistics for an advanced manufacturing industry and understand the existing workforce gaps.

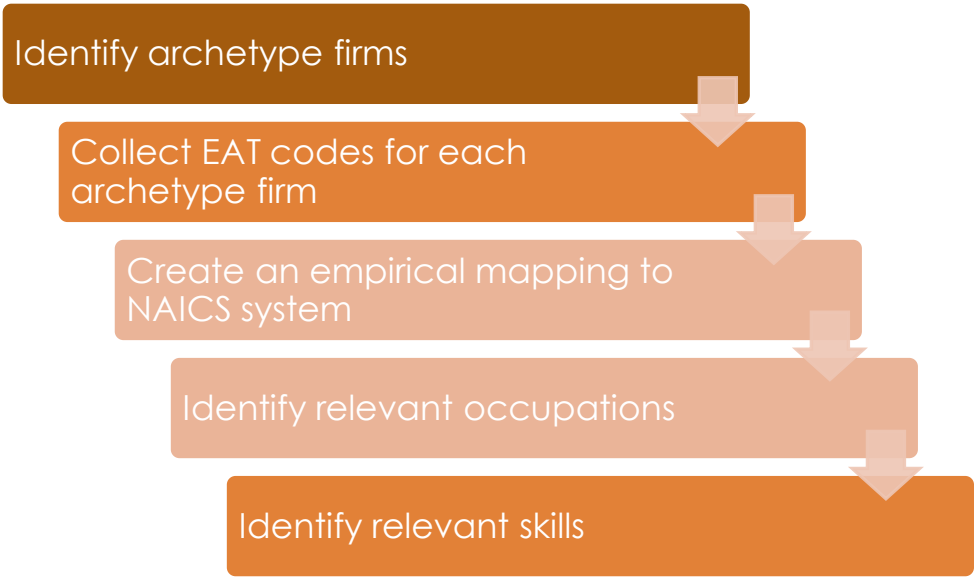

Figure 21 5-step process for discerning emerging advanced manufacturing industries.

The United States fabric and fiber industry is growing at a solid pace and is projected to generate revenues in excess of $90B by 2025. Table 12 lists eleven companies that were identified as archetypes for the advanced fiber and fabric industry.

EAT codes for several industrial classification systems were collected for each archetype firm using the D&B Hoovers business database (Dun and Bradstreet 2020). Here we elected to use the D&B Hoovers Proprietary SIC 8-digit Code (SIC8) classification system (Cramer 2017), an expansion of the original SIC system, to discern the industry. Table 12 shows the SIC8 and NAICS EAT codes for the archetype firms. If a primary and secondary code are provided, both codes are listed. This process was repeated for all the archetype companies for the industry to help develop a description of the firms based on the industrial classification codes.

Table 12 Fabric and fiber industry classification archetype examples

Company	US Standard Industrial Classification – DB Hoovers Expanded Version (SIC8)	North American Industrial Classification System (NAICS)
New Balance Athletics, Inc.	23210200 Men's and boys' sports and polo shirts 23290205 Jackets (suede, leatherette, etc.), sport: men's and boys'	315220 Men's and Boys' Cut and Sew Apparel Manufacturing
Haartz Corp	22950201 Resin or plastic-coated fabrics	313320 Fabric Coating Mills
99 Degrees Custom	39990000 Manufacturing industries, nec	339999 All other miscellaneous manufacturing
Warwick Mills	22210400 Manmade and synthetic broadwoven fabrics	313210 Broadwoven Fabric Mills
Gentex Corporation	38120500 Defense systems and equipment	334511 Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing
Auburn Manufacturing	22620203 Fire resistance finishing: manmade and silk broadwoven 22210000	313310 Textile and Fabric Finishing Mills
Otex	22410000 Narrow fabric milks	313220 Narrow Fabric Mills and Schiffli Machine Embroidery
Fabreeka	30691006 Molded rubber products	423840 Industrial Supplies Merchant Wholesalers
Teufelberger Fiber Rope Corp	22980000 Cordage and twine	314994 Rope, Cordage, Twine, Tire Cord, and Tire Fabric Mills
Fall River Apparel, Inc.	23920000 Household furnishings	314120 Curtain and Linen Mills
Unwrapped, Inc.	23930000 Textile bags	314910 Textile bag and canvas mills

Using the D&B Hoovers companies database, we identified the 137 unique firms with more than 20 employees that are classified by one or both of the 14 SIC8 codes. These firms are classified into one of eleven NAICS codes. These eleven codes are listed in Table

13. Occupation data available from the BLS is organized in a truncated version of NAICS, with most industries organized at the three- or four-digit level. As such, Table 13 also lists the six BLS equivalent codes that capture this same scope for the fabric and fiber industry.

Table 13. Most common NAICS codes for firms identified as in the optical fiber cabling industry. These codes capture 90% of firms identified.

NAICS Code	NAICS Description	BLS Equivalent Code
313210	Broadwoven Fabric Mills	313000
313220	Narrow Fabric Mills and Schiffli Machine Embroidery	"
313310	Textile and Fabric Finishing Mills	"
313320	Fabric Coating Mills	"
314120	Curtain and Linen Mills	"
314910	Textile bag and canvas mills	314000
314994	Rope, Cordage, Twine, Tire Cord, and Tire Fabric Mills	"
315220	Men's and Boys' Cut and Sew Apparel Manufacturing	315000
326299	All Other Rubber Product Manufacturing	326000
334511	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical System and Instrument Manufacturing	334000
339999	All Other Miscellaneous Manufacturing	339000

In summary, we discern the advanced fabric and fiber industry as firms classified as one of the 14 codes within the SIC8 system which maps to the six BLS equivalent industrial classification codes 313000, 314000, 315000, 326000, 334000, 339000. Effectively, we are defining the industry of interest as a hybrid of these six industries. This hybrid industry description, will be used to identify relevant occupations.

Posit Relevant Occupations and Skills

Identify Relevant Occupations

To leverage the extensive surveying knowledge embedded within the O*NET database(U.S. Department of Labor 2020), we use the BLS equivalent NAICS codes to identify a relevant set of occupations for our industry of interest.

Specifically, occupation codes were identified using a combination of the 2018 National Employment Matrix (NEM) (U.S. Bureau of Labor Statistics 2018) and the O*NET database. Using this dataset, we identified occupations that met the following criteria:

- Associated with the industry of interest (as defined by the codes identified previously)
- Technical in nature (see next paragraph)
- Primarily held by middle-skilled workers (see two paragraphs down)
- Represented more than 0.1% of the workforce across the defined industry

The definition of technical work is inherently subjective. For our purposes here, we limit our search to jobs associated with the Standard Occupational Classification (SOC) codes listed in Table 14. That includes occupations involved in mathematics, architecture, engineering, life, physical, and social sciences, installation, maintenance, repair, and production. Computer related positions were excluded because in early test interviews we learned that skills for those positions would not be influenced by the specific industry.

Table 14. Standard Occupational Classification codes considered in this study.

Standard Occupation Classification Code (2-digit level)	Class Name
15-0000	Computer and mathematical occupations (excluding 15-1: Computer occupations)
17-0000	Architecture and engineering occupations
19-0000	Life, physical, and social science occupations
49-0000	Installation, maintenance, and repair occupations
51-0000	Production occupations

Middle-skilled workers are often defined as those with an education level that is greater than a high school diploma and less than a Bachelor's degree (Fuller and Raman 2017). Occupations are always held by workers with a range of education. For this research, we define middle-skilled occupations to be those for which both greater than 30% of the workforce is middle skilled and less than 50% of the workforce is either lower-skilled or upper-skilled.

Based on these definitions, we identified 28 relevant middle-skilled positions associated with the advanced fabrics and fibers industry. To facilitate survey data collection, these were grouped into twelve representative positions, as shown in bold in

Table 15. This set includes five types of engineering technicians – electrical / electronic, industrial, mechanical, and chemical– as well as technical maintenance personnel (e.g., mechanics, electricians), computer-numerical-controlled machine operators, fabrics designers and patternmakers, and machinists.

Additionally, four lower-skilled (i.e. positions where most workers highest level of education is high-school or less) were selected to better understand firm needs and trends. These were: sewing machine operators, hand sewers, textile cutting machine operators, and textile knitting and weaving machine operators. These lower-skilled positions were selected because they each were highly concentrated in some portion of the advanced fabrics and fibers supply chain.

Table 15. Focal occupations that were evaluated in this study. Bold titles represent representative occupations that were served as proxy for the subsequent specific occupations.

Occupation	Standard Occupation Classification Code
Middle-skilled	
Electrical and electronics engineering technicians(representing)	
Electrical and electronics engineering technicians	17-3023
Electro-mechanical technicians	17-3024
Electrical and electronics drafters	17-3012
Industrial engineering technicians(representing)	
Industrial engineering technicians	17-3026
Aerospace engineering and operations technicians	17-3021
Mechanical engineering technicians(representing)	
Mechanical engineering technicians	17-3027
Mechanical drafters	17-3013
Chemical technicians	19-4031
Maintenance and Support Technicians (representing)	
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
Heating, air conditioning, and refrigeration mechanics and installers	49-9021
Mobile heavy equipment mechanics, except engines	49-3042
Electrical and electronics repairers, comm. and ind. equipment	49-2094
Computer-controlled machine tool operators(representing)	
Computer-controlled machine tool operators	51-4011
Computer numerically controlled machine tool programmers	51-4012
Other Technical Production Worker (representing)	
Machinists	51-4041
Tool and die makers	51-4111
Fabrics Designers and Patternmakers	51-6092
Lower-skilled	
Sewing Machine Operators	51-6031
Hand Sewers (representing)	
Hand Sewers	51-6051
Upholsterers	51-6051
Fabric menders, except garment	49-9093
Tailors, dressmakers, and custom sewers	51-6052
Textile Cutting Machine Operators	51-6062
Textile Knitting and Weaving Machine Operators	51-6063

Identify Relevant Skills

For each identified occupation, an associated set of competencies (skills) and tools was developed from the U.S. Department of Labor O*Net database, an online tool for career exploration and job analysis (U.S. Department of Labor 2020). The O*Net database uses a hierarchical taxonomic approach to organize tasks and skills. (Peterson et al. 2001). The database was originally developed through survey methods to create a relational database of occupation attributes for the U.S. economy (Peterson et al. 2001)and helps create a common language for job descriptors. An example of tools and competencies collected is shown in Figure 22 for an Electrical Engineering Technician.

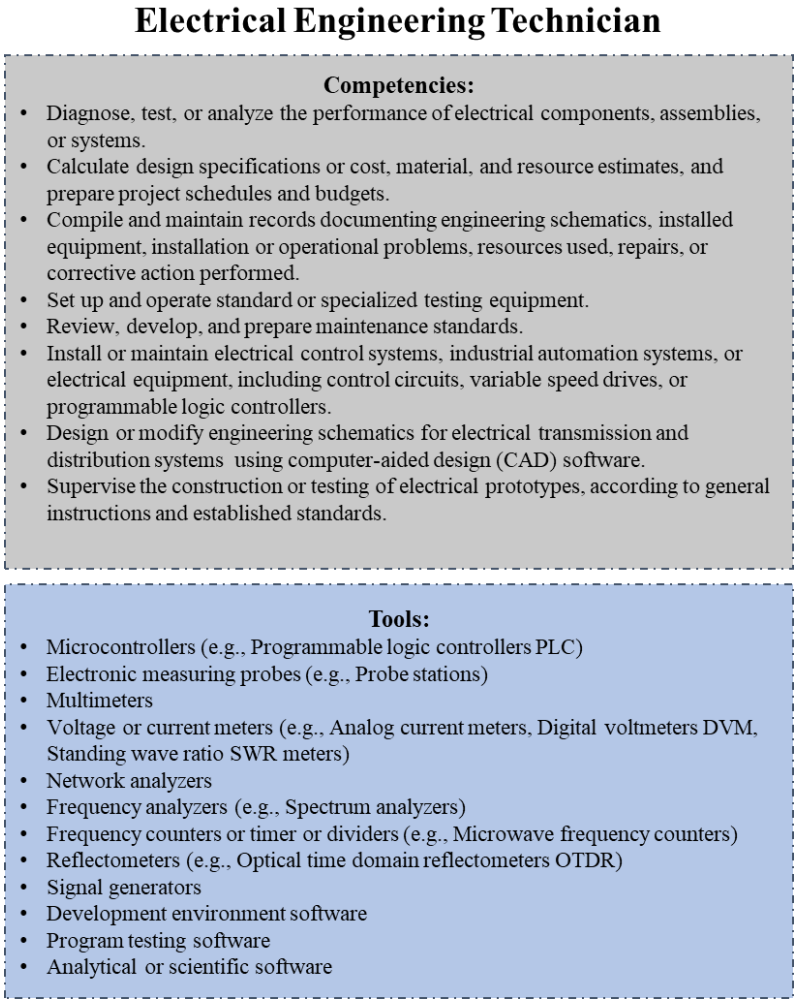

Figure 22 Competencies and tools associated with the job title electrical engineering technician.

What about "Soft" skills?

The focus of this study was to assess the training gaps associated with specific applied skills for technical workers. This focus in no way implies that the research team believes

that such technical skills are more important than other non-technical skills (also known as "soft" or human skills). Research was focused on technical skills for two reasons. First, our primary goal was to develop insights to shape training programs aimed to support the photonics industry. Such programs themselves focus on technical skills and, therefore, require feedback on the same. Secondly, the survey tool applied in this research was already of a scale that taxed most respondents. As such, tradeoffs had to be made to limit its scope and content.

Emerging Skills

While the O*NET database gives a sense of the current skills needed for these occupations, we also wanted to get a sense of what kinds of skills would be expected to become important in the coming years. Considerable work has been invested into exploring what might be the consequences of the changing technological composition of manufacturing work, and we sought to leverage some of that learning into devising a set of questions that would explore how the survey respondents imagined the skills required for these occupations would change.

Much of the work in this area has centered upon the ways in which occupations will increasingly require extended problem-solving skills, building upon increased basic technological knowledge and more interpersonal, soft skills (see, for example, Weaver and Osterman 2017). These skills are also sometimes referred to as essential skills (Government of Canada 2015), skills that are necessary to be successful in the workplace and community. For instance, as manufacturing jobs become much less solitary than before, collaborative skills are increasingly important (Yoo, Boland, and Lyytinen 2006) . Similarly, the concurrent rise of technologically-centered and technologically-enabled production environments require problem-solving and process evaluating skills that require new kinds of competencies and tools.

Because the literature speaks in terms of relatively high levels of abstraction when speaking of these emerging skills, we elected to construct a set of job skills for the survey that would reflect the ideas of these emerging skills. The expectation was that a more concrete set of skills would be less taxing for the survey respondents to evaluate in terms of their future importance. Table 16 illustrates one such mapping of these abstractions to the "essential skills" framework that is used by the Canadian government. This table is illustrative of the kinds of abstract skills whose importance we were trying to understand better.

Table 16 The essential skills framework maps essential skill types to specific emerging skills identified for the photonics industry.

Essential Skill Types	Survey Skills Inquiry	Comment
• Reading • Document Use • Numeracy	• Conducting (and assessing the results of statistical process control analyses) • Evaluating and making use of process management analyses	With increased computer control comes increased opportunity to measure and track process performance, hence a rise in the importance of SPC and related tools. Such evaluations depend upon numerical literacy and problem-solving skills
• Working with Others • Writing • Oral Communication	• Collaborating with engineering and management staff • Working with digital collaboration tools	While collaboration, per se, is not a particularly novel skill, the ability to employ emerging digital tools will lead to
• Thinking	• Knowing the science & engineering underlying the product • Troubleshooting processing problems	General problem-solving skills will depend upon employees able to frame their understanding of process / product problems within a commonly-held scientific and technological context, particularly since collaboration will be key
• Computer Use	• Working with CAD products • Monitoring, assessing, and working with CNC or other automated process equipment	Formal ability to work with advanced engineering programming, as well as process control tools
• Continuous Learning	-	-

Realistically, of course, there are many ways of mapping these statements to the emerging skills. This family of skills were tested with subjects before wider deployment to ensure that they met our goals of being future-looking as well as approachable by the survey respondents.

Identifying Important, Common Skills

While it is valuable to understand the skills trends within individual occupations, in many cases, training programs or courses will need to be more broadly applicable, serving the needs of multiple types of learners. To that end, the research team has attempted to identify those skills that are both important and shared (common) among multiple occupations.

This was accomplished by making use of the hierarchical nature of the O*NET dataset from which occupation-specific skills were identified. To create the survey administered for this project, the research team identified occupation-specific skills from the list of Tasks within the O*NET dataset. In that context, Tasks are the most specific representation of occupation requirements. Tasks are related to more generalized classifications of skills as represented in Figure 23. Specifically, Tasks can be associated with many Detailed Work Activities which are each associated with only one Intermediate Work Activity which are themselves associated with only one General Work Activity. (To maintain a more consistent terminology in this report, we will refer to these classifications as Detailed Tasks/Skills (DTS), Intermediate Tasks/Skill (ITS), and General Tasks/Skills (GTS), respectively.)

Because of this hierarchical relationship, it was possible to compute an average skill importance at any level of aggregation. To do this, a weighting was assigned to each level of response for each specific skill (Importance will Grow Significantly = 5, Grow= 3, Hold = 1, Not important = 0). Then weighted averages of these importance levels were computed for each specific task or skill and the corresponding DTS, ITS, and GTS. For this set of occupations, the DTS level of aggregation did not provide useful insights. As such, it is not discussed further in the results section.

These weighted importance scores were then used to identify the most important GTS and ITS across all of the occupations considered in this survey. From these important skills we identify those that are shared by at least three occupations and refer to this set as important, common (as in shared) skills.

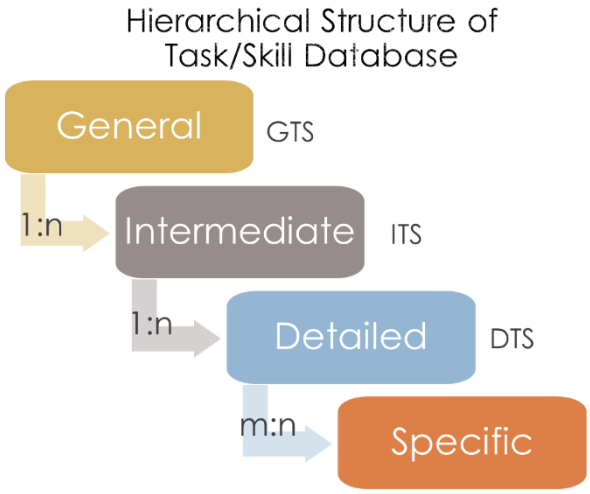

Figure 23. Hierarchical structure of the task/skill database used in this study. Survey respondents were asked about occupation specific (orange level) tasks or skill. 1:n indicates a one (parent) to many (child) relationship. m:n indicates a many to many relationship. The hierarchies are defined within the O*NET database.

Semi-Structured Interview

Interview design

The interview is structured into four main sections:

5) firm characterization,
6) hiring and training challenges
7) workforce scaling, and
8) emerging skill needs.

In the first section of the interview, respondents were asked to identify the primary role that their firm plays in the advanced fabric and fiber supply chain. Additionally, respondents were asked to estimate the firm's annual revenues and overall employment levels.

In the second section, respondents were asked to identify which of the focal occupations were relevant for their firm. Then for each relevant occupation they were asked whether

- Demand for that position would (Hold, Grow Somewhat, or Grow Significantly)?
- Filling an open position was (Easy, Average, or Hard)?
- In house training for new hires tends to be (Basic, Moderate, or Extensive training)?

In the third section of the survey, respondents were asked to quantify how many individuals were employed at their firm for each type of relevant occupation.

In the final section of the survey, respondents were randomly assigned three relevant occupations. For each of these, they were asked to rank the importance of specific skills and tools for the future.

Semi-Structured Interview Process

The interview responses were captured in the Qualtrics online platform (Qualtrics XM 2021) and interviews were conducted with advanced fabrics and fibers firms located in the New England area. Thirty-five responses where the respondent completed more than 50% of the survey were received and incorporated into the following results.

Respondent Demographics

Survey respondents came from a broad array of firms. As shown in Figure 24a, a majority of the respondents came from Massachusetts, with a few firms from other New England states. Firms ranged in size from as few as three employees to as many as 1,2000. The median firm size was 142 employees. Annual revenue ranged from $0.3M to $200M with a median of $7M per year (Figure 24b).

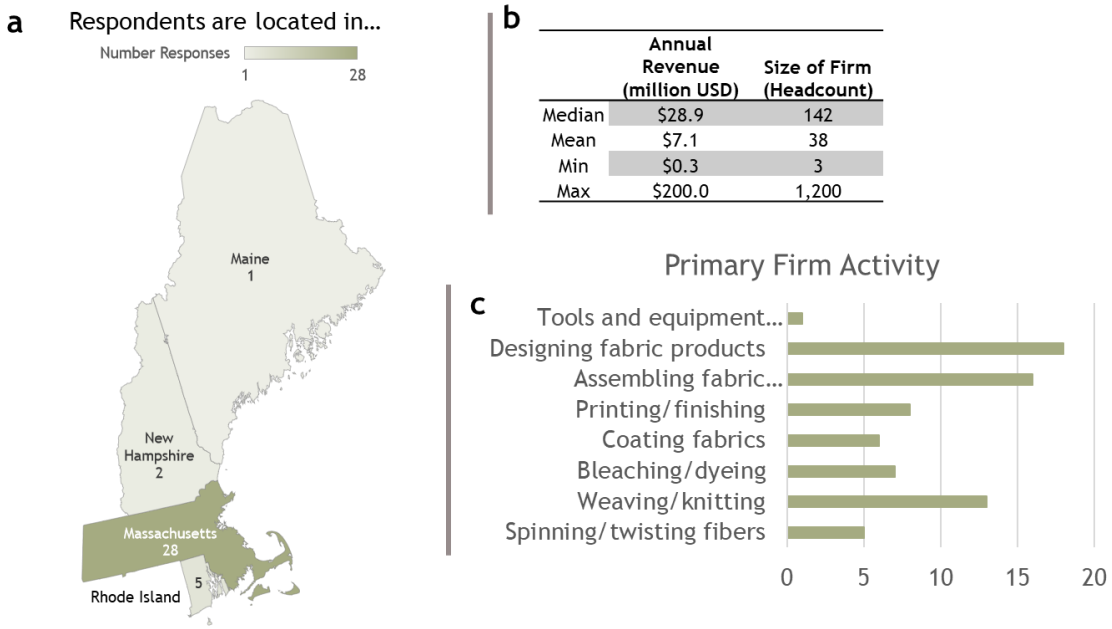

Figure 24. Distribution of respondent location, size, revenue, and primary supply chain activity.

Firms were asked to identify their role in the supply chain. There was a range of primary activities for each firm (see Figure 24c) with a majority focused on designing fabric products and assembling fabric products.

Finally, firms were asked about whether or not they currently, plan to, or do not use smart textiles. A majority of firms interviewed (62%) are either currently using or planning to use smart textiles. Thirty-eight percent (38%) of firms interviewed did not have any immediate plans to use smart textiles (Figure 25).

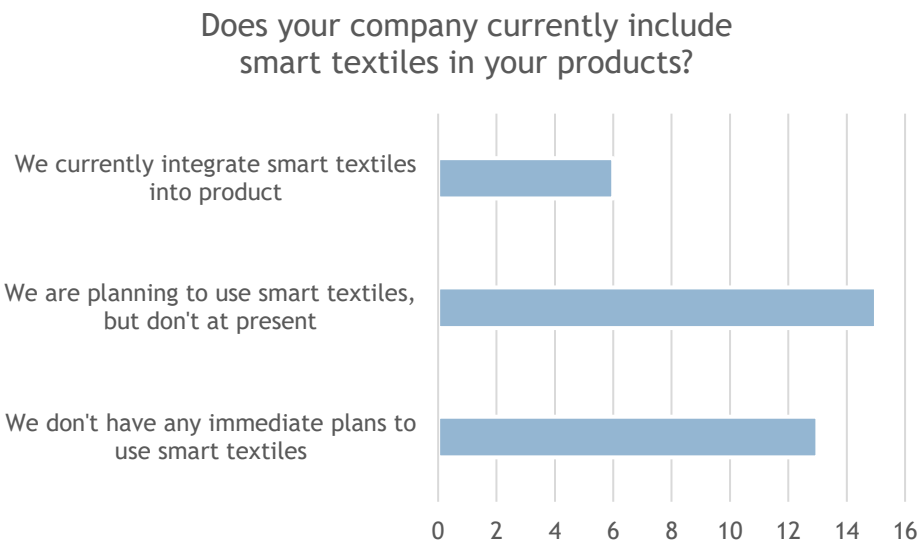

Figure 25. Distribution of responses of firm participation with smart textiles.

Common Important Skills

The following pages contain the details of survey responses for each specific skill organized by Intermediate Task/Skill (ITS) and by General Task/Skill (GTS). In the subsequent tables, occupation titles are abbreviated as listed in Table 17.

Table 17. Focal occupations that were evaluated in this study and abbreviated title used in GTS / ITS tables

Occupation	Abbreviation
Industrial engineering technicians	Ind Eng T
Electrical and electronics engineering technicians	ElecEng T
Mechanical engineering technicians	MechEng T
Chemical technicians	Chemical T
Computer-controlled machine tool operators	CNC Oper
Fabric and apparel patternmaker	Patternmaker

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Information Management	2.9	Document technical designs, procedures, or activities.	3.1	Record test procedures and results, numerical and graphical data, and recommendations for changes in product or test methods.	3.1				X		
				Write procedures for the commissioning of electrical installations.	-nr-		X				
				Write reports or record data on testing techniques, laboratory equipment, or specifications to assist engineers.	-nr-		X				
		Present research or technical information.	3.0	Write technical reports or prepare graphs or charts to document experimental results.	-nr-			X			
		Prepare documentation for contracts, applications, or permits.	2.0	Prepare, review, or coordinate ongoing modifications to electrical system specifications or plans.	-nr-		X				
Data Collection & Synthesis	2.8	Read documents or materials to inform work processes.	2.8	Review program specifications or blueprints to determine and set machine operations and sequencing, finished workpiece dimensions, or numerical control sequences.	3.8					X	
				Review project instructions and blueprints to ascertain test specifications, procedures, and objectives	2.2				X		
				Read blueprints, wiring diagrams, schematic drawings, or engineering instructions for assembling electronics units, applying knowledge of electronic theory and components.	-nr-		X				

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Analyzing Data or Information	2.7	Analyze performance of systems or equipment.	2.8	Analyze test results in relation to design or rated specifications and test objectives, and modify or adjust equipment to meet specifications.	3.1				X		
				Compile and evaluate data using statistical process control procedures	2.6	X					
				Interpret test information to resolve design-related problems.	-nr-		X				
		Analyze biological or chemical substances or related data.	2.3	Conduct chemical or physical laboratory tests to assist scientists in making qualitative or quantitative analyses of solids, liquids, or gaseous materials.	-nr-			X			
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-			X			
Repairing and Maintaining Equipment	2.5	Maintain electronic, computer, or other technical equipment.	3.0	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	-nr-		X				
				Maintain, clean, or sterilize laboratory instruments or equipment.	-nr-			X			
				Perform preventative maintenance or calibration of electronic equipment or systems.	-nr-		X				
				Adjust or replace defective or improperly functioning circuitry or electronics components, using hand tools or soldering iron.	-nr-		X				
		Maintain tools or equipment.	2.3	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	2.3					X	

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Estimating and Judging the Characteristics of Products or Processes	2.2	Evaluate production inputs or outputs.	4.0	Monitor product quality to ensure compliance with standards and specifications.	-nr-			X			
		Estimate project development or operational costs.	2.4	Estimate cost factors including labor and material for purchased and fabricated parts and costs for assembly, testing, or installing.	2.4				X		
				Prepare electrical project cost or work-time estimates.	-nr-		X				
		Measure physical characteristics of materials, products, or equipment.	2.3	Compute dimensions of patterns according to sizes, considering stretching of material.	2.3						X
		Mark materials or objects for identification.	1.6	Mark samples and finished patterns with information, such as garment size, section, style, identification, and sewing instructions.	1.6						X

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Inspecting Equipment, Structures, or Material	2.0	Test characteristics of materials or products.	2.3	Test products for performance characteristics or adherence to specifications.	2.3	X					
		Inspect completed work or finished products.	2.0	Examine sketches, sample articles, and design specifications to determine quantities, shapes, and sizes of pattern parts, and to determine the amount of material or fabric required to make a product.	2.0						X
				Inspect electrical project work for quality control and assurance.	-nr-		X				
		Test performance of equipment or systems.	1.7	Test equipment, using test devices attached to generator, voltage regulator, or other electrical parts, such as generators or spark plugs.	1.2				X		
				Set up or operate test equipment to evaluate performance of developmental parts, assemblies, or systems under simulated operating conditions.	-nr-		X				
				Test electronics units, using standard test equipment, and analyze results to evaluate performance and determine need for adjustment.	-nr-		X				

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Thinking & Making Creatively	2.0	Develop research plans or methodologies.	3.0	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	-nr-		X				
		Create visual designs or displays.	2.7	Prepare charts or diagrams to illustrate workflow, routing, floor layouts, material handling, or machine utilization.	3.4	X					
				Draft detail drawing or sketch for drafting room completion or to request parts fabrication by machine, sheet or wood shops.	2.0				X		
				Design basic circuitry and design documentation under engineers' direction, using drafting instruments or computer-aided design (CAD) equipment.	-nr-		X				
		Design industrial systems or equipment.	2.1	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.1				X		
		Design materials or devices.	1.1	Draw outlines of pattern parts by adapting or copying existing patterns, or by drafting new patterns.	1.3						X
				Create a paper pattern from which to mass-produce a design concept.	1.0						X
		Develop models of systems, processes, or products.	1.0	Build prototypes from rough sketches or plans.	-nr-		X				
		Design electrical or electronic systems or equipment.	0.5	Modify electrical prototypes, parts, assemblies, or systems to correct functional deviations.	-nr-		X				

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Prepare Specimens, Tools, or Equipment	1.9	Adjust equipment to ensure adequate performance.	3.0	Perform preventative maintenance or calibration of electronic equipment or systems.	-nr-		X				
		Prepare specimens or materials for testing.	3.0	Prepare chemical solutions for products or processes, following standardized formulas, or create experimental formulas.	-nr-			X			
		Set up equipment.	2.6	Mount, install, align, and secure tools, attachments, fixtures, and workpieces on machines, using hand tools and precision measuring instruments.	2.8					X	
				Set up and conduct chemical experiments, tests, and analyses, using techniques such as chromatography, spectroscopy, physical or chemical separation techniques, or microscopy.	-nr-			X			
		Disassemble equipment.	2.3	Maintain machines and remove and replace broken or worn machine tools, using hand tools.	2.3					X	
		Position workpieces or materials on equipment.	2.3	Make adjustments to patterns after fittings.	1.3						X
		Assemble equipment or components.	2.0	Build, calibrate, maintain, troubleshoot, or repair electrical instruments or testing equipment.	-nr-		X				
		Clean workpieces, finished products, or other objects.	2.0	Maintain, clean, or sterilize laboratory instruments or equipment.	-nr-			X			
		Clean tools, equipment, facilities, or work areas.	1.8	Clean machines, tooling, or parts, using solvents or solutions and rags.	1.8					X	

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Prepare Specimens, Tools, or Equipment (cont.)		Assemble products or work aids.	1.7	Test patterns by making and fitting sample garments.	2.1						X
				Trace outlines of specified patterns onto material, and cut fabric using scissors.	1.3						X
		Position tools or equipment.	1.6	Position and cut out master or sample patterns, using scissors and knives, or print out copies of patterns, using computers.	1.6						X
		Position materials or components for assembly.	1.3	Draw details on outlined parts to indicate where parts are to be joined, as well as the positions of pleats, pockets, buttonholes, and other features, using computers or drafting instruments.	1.5						X
				Draw outlines of pattern parts by adapting or copying existing patterns, or by drafting new patterns.	1.3						X

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Making Decisions and Troubleshooting Problems	1.9	Determine operational methods or procedures.	3.0	Plan method or sequence of operations for developing or testing experimental electronic or electrical equipment.	-nr-		X				
		Determine resource needs of projects or operations.	1.8	Calculate required capacities for equipment to obtain specified performance	2.0				X		
				Calculate machine speed and feed ratios and the size and position of cuts.	1.5					X	
				Prepare electrical project cost or work-time estimates.	-nr-		X				
Organizing, Planning, and Prioritizing Work	2.9	Develop operational or technical procedures or standards.	3.0	Develop or upgrade preventative maintenance procedures for components, equipment, parts, or systems.	-nr-		X				
		Plan work activities.	2.9	Aid in planning work assignments in accordance with worker performance, machine capacity, production schedules, or anticipated delays.	2.9	X					

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Provide Consultation and Advice to Others	2.6	Advise others on business or operational matters.	3.4	Recommend modifications to existing quality or production standards to achieve optimum quality	3.4	X					
		Advise others on products or services.	3.0	Provide user applications or engineering support or recommendations for new or existing equipment with regard to installation, upgrades, or enhancements.	-nr-		X				
		Advise others on the design or use of technologies.	3.0	Provide technical assistance in resolving electrical engineering problems encountered before, during, or after construction.	-nr-		X				
		Coordinate with others to resolve problems.	3.0	Collaborate with electrical engineers or other personnel to identify, define, or solve developmental problems.	-nr-		X				
		Explain technical details of products or services.	1.5	Interpret engineering drawings, schematic diagrams, or formulas for management or engineering staff.	1.5	X					

General Task / Skill	GTS Import	Intermediate Task / Skill	ITS Import	Specific Task or Skill	Task Import	Ind Eng T	ElecEng T	Chemical T	MechEng T	CNC Oper	Patternmaker
Monitor Processes, Materials, or Surroundings	2.4	Monitor operations to ensure compliance with regulations or standards.	2.8	Read worker logs, product processing sheets, or specification sheets to verify quality assurance specifications.	2.8	X					
		Monitor operations to ensure adequate performance.	2.6	Verify that equipment is being operated and maintained according to quality assurance standards .	2.6	X					
		Monitor equipment operation.	2.1	Monitor machine operation and control panel displays, and compare readings to specifications to detect malfunctions.	2.5					X	
				Check to ensure that workpieces are properly lubricated and cooled during machine operation.	1.6					X	
Interacting With Computers	2.2	Program computer systems or production equipment.	2.2	Set up and operate computer-controlled machines or robots to perform one or more machine functions on metal or plastic workpieces.	2.6					X	
				Input machine control programs	2.3					X	
				Modify cutting programs to account for problems encountered during operation	1.8					X	
Controlling Machines and Processes	1.8	Operate industrial processing or production equipment.	2.1	Fabricate and assemble new or modified mechanical components for products such as industrial machinery or equipment, and measuring instruments.	2.1				X		
		Fabricate devices or components.	1.6	Operate drill press, grinders, engine lathe, or other machines to modify or to fabricate components.	1.1				X		

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