B | Center for Technology Innovation at BROOKINGS

March 2015

Innovation and manufacturing labor: a value-chain perspective

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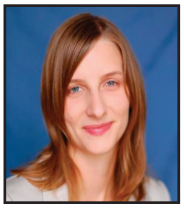
EXECUTIVE SUMMARY

Policies and initiatives to promote U.S. manufacturing would be well advised to take a value chain perspective of this economic sector. Currently, our economic statistics do not include pre-production services to manufacturing such as research and development or design or post-production services such as repair and maintenance or sales. Yet, manufacturing firms invest heavily in these services because they are critical to the success of their business. It is thus important for any collective efforts aimed at invigorating manufacturing to seize the opportunities throughout the entire value chain including upstream and downstream services to production.

Examining employment in manufacturing from a value chain perspective offers a fresh insight into the sector's labor composition and trends. In 2002, manufacturing narrowly defined had about 15.2 million workers but the entire value chain employed nearly 37.4 million; by 2010 employment had dropped to 11.5 million in production and 32.9 million across the value chain. The manufacturing value chain shrunk by more than 4 million workers from 2002 to 2010 and those who worked in factories took the heaviest toll. What is striking however is that during this same period, which included the last recession, employment in upstream services expanded 26 percent for market analysis, 13 percent for research and development, and 23 percent for design and technical services. What is more, average wages for these services increased over 10 percent in that period.

Certain occupations within the manufacturing value chain have also experienced job growth over the 2002-2010 period. Specifically, engineers, scientists, and computer programmers have seen a 20 percent increase in employment, while the ranks of production line workers lost 25 percent. Going forward, this pattern is likely to be repeated. Technical occupations, particularly in upstream segments are expected to have the largest increases in employment and wages.



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Based on these findings we offer the following recommendations:

Federal manufacturing policy: Under the President's Council of Advisors on Science and Technology an initiative called the Advanced Manufacturing Partnership has issued two reports in July 2012 and October 2014. These reports recommend the development of a national system of certifications for production skills and establishing a national apprenticeship program for skilled trades in manufacturing. Based on the analysis presented here it would be important to expand those programs to include jobs outside the factory such as those in research and development, design and technical services, and market analysis.

Higher education: Institutions of higher education should consider some adjustment to their curriculum with a long view of the coming changes to high-skill occupations, particularly with respect to problem identification and the management of uncertainty in highly automated work environments. Small changes to how existing courses are taught could make a meaningful difference. Specifically, technical courses could emphasize more open-ended problems—rather than problems with a single correct answer—where students learn the underlying concepts by applying them to real world applications. At the same time, technical courses should include problems where students learn to incorporate aesthetic, social, and financial considerations to technical ones. In addition, universities and colleges should disseminate information among prospect and current students about occupations where the largest gains of employment and higher wage premiums are expected.

Improve national statistics: Current sectoral statistics are obtained with NAICS; a remarkably useful tool of economic analysis. This survey should be supplemented with data that permits tracking the entire value chain. One initiative moving in that direction is the interagency effort (led by the Office of Management and Budget) to develop a demand-based classification system as a supplement to NAICS. This initiative could benefit from adding survey questions to replicate the data collection of countries with a Value Added Tax—without introducing the tax, that is—allowing in this manner a more accurate estimation of the value added by each participant in a production network.

I. INTRODUCTION

Manufacturing has increasingly received attention from policymakers and industry leaders. President Obama has placed manufacturing prominently in his speeches and his policies calling in the 2013 and 2014 State of the Union Addresses for the creation of a Nationwide Network of Manufacturing Innovation and in the 2015 SOTU Address announcing a plan to make community colleges tuition-free (The White House 2013, 2014, 2015). This attention has also come from the distinguished panels at the National Academies that have offered recommendations to strengthen U.S. manufacturing in a series of recent reports (NAE 2012, 2015; NRC 2013a, 2013b). An important part of this debate is the link between technical education and manufacturing jobs. That is implicit in the president's emphasis on access to community college education and is explicit in proposals coming from industry, advocating for example certification programs relevant to advanced manufacturing industries (US Chamber of Commerce 2014).

These calls for support, promotion, expansion, and modernization of U.S. manufacturing and employment in this economic sector are a clear indication that a consensus is forming among policymakers about the importance of manufacturing to the long-term health of the economy and to the creation of well-paid and stable jobs. But what jobs command stability and good salaries in manufacturing? And how are these jobs likely to change in the future? These are the questions that motivate this study where we take a closer look at labor data in manufacturing during the first decade of the new millennium, specifically from 2002 to 2010. We have two aims. First, we want to offer a fresh perspective to examine the changes in manufacturing employment during that period, by considering the full manufacturing value chain. As the National Academy of Engineering stated in a recent report on the future of U.S. manufacturing, “for business and policy leaders to take effective action in response to a changing manufacturing sector, it is important to start with a holistic understanding of the value chain” (NAE, 2015). Second, we want to place these changes in the larger context of the transformation of work in manufacturing over the past few decades to extrapolate some of the changes we can expect going forward and suggest some policies to better prepare the manufacturing workforce for those changes.[1]

The new approach we offer to analyze labor data takes a value chain perspective. Manufacturing is supported by a large array of services such as research and development, scientific testing, software development, and installation and repair services. However, U.S. labor data—and many policies that are informed by these data—do not fully recognize the ties between these services and manufacturing. Labor data is compiled in a typology called NAICS—the North American Industrial Classification System—that divides economic activity in sectors and sub-sectors and discerns between sectors by the similarity of their production processes. The conceptual foundation of this typology rests on the distinction that extractive industries (such as raw material recovery), manufacturing industries (such as fabricated metal or automotive manufacturing), and service industries (such as business and professional services) rely on essentially different production processes and establishments in each of these three categories have similar processes. Even setting aside the inherent difficulty of sorting economic activities into sectors this way, we can readily appreciate that NAICS groups industries based on how a good or service is produced independently of the value chain to which the establishment belongs. Therefore, a definition of manufacturing based on the NAICS typology excludes many services that are necessary to create and deliver physical products to consumers and support them throughout their life. Thus we submit that a more complete picture of U.S. manufacturing is to be obtained by examining the value chain of manufacturers. To this end we have reconstructed the labor data to approximate what would be the adequate accounting of the entire manufacturing value chain (further details of our methodology are offered in section 2).

What exactly are the insights that can be observed by analyzing manufacturing employment using a complete value chain perspective? One of the most important findings is the change in the demand for labor. We present below three trends in labor demand that are not captured in traditional sector-based analyses. First, while job losses are concentrated in factories, demand and compensation for *upstream services*, those that typically occur before production, are increasing. Specifically, services such as market research, design, and research and development are experiencing higher increases in demand and wages than either production or *downstream services* (services such as installation and repair that typically occur after production). Second, demand and compensation for higher skill occupations throughout the value chain are increasing, but the increase is skewed toward both upstream and downstream services. Third, the nature of work in those high-skill occupations is also changing, creating a premium for workers who can more effectively mix automation and real-time information systems with human judgment, who are more flexible to unexpected changes in the production process, and who are more sensitive to variations in work culture of the various international partners involved in production.

This new perspective is, we believe, of great significance for policy making. If the calls by the president, Congress, and captains of industry for renewed attention to strengthen U.S. manufacturing are to be taken seriously, we need to understand manufacturing in its full scope and consider the many services included in the value chain. We offer a more complete picture of the manufacturing labor demand, probe deeper into its nature, and consequently produce new perspectives for adjusting current policy. If manufacturing policy focuses on improving access to education and training for factory jobs but ignores the workforce demand for upstream services such as R&D and design, it risks not realizing the full potential of innovation as a driver of productivity gains and economic growth and as a mitigating factor of wage disparities.

II. EXAMINING MANUFACTURING USING A VALUE CHAIN PERSPECTIVE

2.1 Industry classification statistics

NAICS is the standard used by federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.[2] The US Office of Management and Budget (OMB) and the equivalent Canadian and Mexican governmental bodies developed the typology. These national economic statistics are derived from a complicated process of categorizing the economy into sectors, but in reality, the categories are not clear-cut. NAICS is based on a production-oriented conceptual framework, which means that establishments are grouped into economic sectors, such as manufacturing, information, or services, based on the similarity of their production processes. As a result, the manufacturing sector currently includes factories but excludes many other activities that manufacturers undertake in order to ensure the value of their products for their customers. For example, many manufacturers also have establishments classified by NAICS under research and other technical services, wholesale and retail trade, and repair and maintenance as shown by a sample of companies in Table 1.

To illustrate the problem of analyzing the manufacturing sector in isolation, consider Procter & Gamble. If all of the company's activities listed in Table 1 were housed in the same facility, they would all be counted as part of the manufacturing sector. But because they are housed in different buildings (some literally next door to each other), all the non-production activities are counted as part of the service sector. To get around this idiosyncrasy, this study looks at employment statistics using a different classification scheme based on the concept of the *value chain*, representing all activities that are performed in order to create and deliver a product that has value, including service-type activities such as product design, software development, and after-sale repair and maintenance.

TABLE 1.
MANUFACTURERS HAVE ESTABLISHMENTS ACROSS THE ENTIRE VALUE CHAIN

Company	Industry sector	Primary activity*	Location
General Electric	Manufacturing	Aircraft Engine and Engine Parts Manufacturing	Cincinnati, OH
	Professional, Scientific, and Technical Services	Research and Development in the Physical, Engineering, and Life Sciences	Bohemia, NY
		Marketing Consulting Services	Scottsdale, AZ
	Repair and Maintenance	Appliance Repair and Maintenance	Atlanta, GA
Ford Motor Company	Manufacturing	Automobile Manufacturing	Dearborn, MI
	Wholesale Trade	Automobile and Other Motor Vehicle Merchant Wholesalers	Livonia, MI
	Retail Trade	New Car Dealers	Dearborn, MI
	Professional, Scientific, and Technical Services	Engineering Services	Dearborn, MI
		Testing Laboratories	Dearborn, MI
		Custom Computer Programming Services	Farmington Hills, MI
		Research and Development in the Physical, Engineering, and Life Sciences	Dearborn, MI
		Marketing Research and Public Opinion Polling	Dearborn, MI
	Repair and Maintenance	General Automotive Repair	Wayne, MI
Procter & Gamble	Manufacturing	Sanitary Paper Product Manufacturing	Cincinnati, OH
	Wholesale Trade	Other Chemical and Allied Products Merchant Wholesalers	Cincinnati, OH
	Professional, Scientific, and Technical Services	Testing Laboratories	Cincinnati, OH
		Advertising Material Distribution Services	Cincinnati, OH

(*) As indicated by the North American Industry Classification System (NAICS)

2.2 Employment and economic data across the manufacturing value chain

This section briefly summarizes the process used to examine manufacturing employment and economic activity using a value-chain perspective. See details in Appendix 1.

The Quarterly Census of Employment and Wages (QCEW) and the Occupational Employment Statistics (OES), both maintained by the Bureau of Labor Statistics (BLS), are the primary datasets used in the analysis. The quarterly census data include more than 9 million establishments and 98 percent of all nonfarm wage and salary employment. OES produces employment and wage estimates for over 800 occupations based on a survey of 1.2 million establishments over a 3-year period.

In addition to these datasets, the BLS Occupational Projections Database was used to examine expected changes in employment demands by 2020. These projections are designed to reflect long-term trends in the economy based on extrapolations of industries' growth in outputs and intermediate inputs, labor supply, and occupational staffing patterns coupled with expert assessments of likely trends.

Economic activities were categorized as part of the manufacturing value chain based on the definition of the NAICS detailed industry classifications, which represents the self-reported primary activity of a business facility. Facilities were selected that either produce goods or generate services that are necessary for product development, production, delivery, or use of a manufactured good. For example, wholesale and retail facilities whose primary activity is selling physical goods are included in this analysis as are facilities engaged in product development activities for physical goods, such as engineering services, drafting, and testing laboratories. Facilities that primarily create or sell "pure services" (i.e. services that are not inputs to manufacturing product development or use) are excluded.

The list of facilities relevant to the manufacturing value chain is categorized in the following seven areas: market analysis, R&D, design and technical services, production, wholesale, retail, and after-market services (including software).[3] This categorization is meant to correspond to general stages of a manufacturing product development process and it allows for useful comparisons between trends in production and in other related areas of interest.

Following the heuristic of including all establishments that produce physical goods, facilities that publish books are included in the production category of the value chain and Internet or software publishers that provide content for manufactured goods are included in after-sale services for the purpose of this analysis. In contrast, NAICS groups book publishers along with Internet, software, and motion picture publishers in the information industry because their production processes are considered to be similar.

The analysis also includes an in-depth examination of particular occupations that are most relevant to the primary activities conducted along the manufacturing value chain, as opposed to administration or other support occupations. Occupations were selected from OES based on the knowledge requirement scores from O*NET.[4] These data are collected by surveying workers in each occupational category and asking them to rate the importance and level of knowledge in particular areas necessary to perform their job. Respondents rate the importance of a particular area of knowledge, such as production and processing, on a five point scale where 1 is not important and 5 is extremely important. This part of the analysis concentrates on occupations with average ratings of 3 or above in at least one of the following areas: production and processing, design, and engineering and technology.

The analysis examines changes in employment and wages from 2002, the first year that NAICS was used to categorize OES and QCEW statistics by industrial sectors, to 2010 and projections to 2020. Over this time period, the definitions of certain occupations changed in the OES surveys. High-level groupings of occupations are used to avoid mistaking any idiosyncrasies from these definitional changes as actual changes in employment. For instance, all engineering, science, and programming occupations are grouped together in our analysis so that, for example, the classification of a particular job as a systems software engineer in 2010 that would have been classified as a computer programmer in 2002, does not register as a change of employment demand.

2.3 Caveats and limitations of the analysis

There are a number of limitations of our analysis. Most notably, while we endeavor to provide a full value-chain analysis of manufacturing, the data available to analyze national employment and wages are based on an industrial sector perspective. Therefore, the analysis may include some inaccuracies associated with classifying activities outside the manufacturing sector as part of (or not part of) the manufacturing value chain. In particular, while every effort was made to exclude "pure" services—meaning services that are not produced as a necessary input to support the development, delivery, or use of a manufactured good—from the analysis, it was not always possible or practical given the available data. For example, the same marketing facility may provide consulting services to a manufacturing company and a hotel conglomerate. The data do not distinguish employment associated with these different types of activities. Therefore, the manufacturing value chain data likely include some data associated with pure services in the categories of market analysis, R&D, design and technical services, and after-market services.

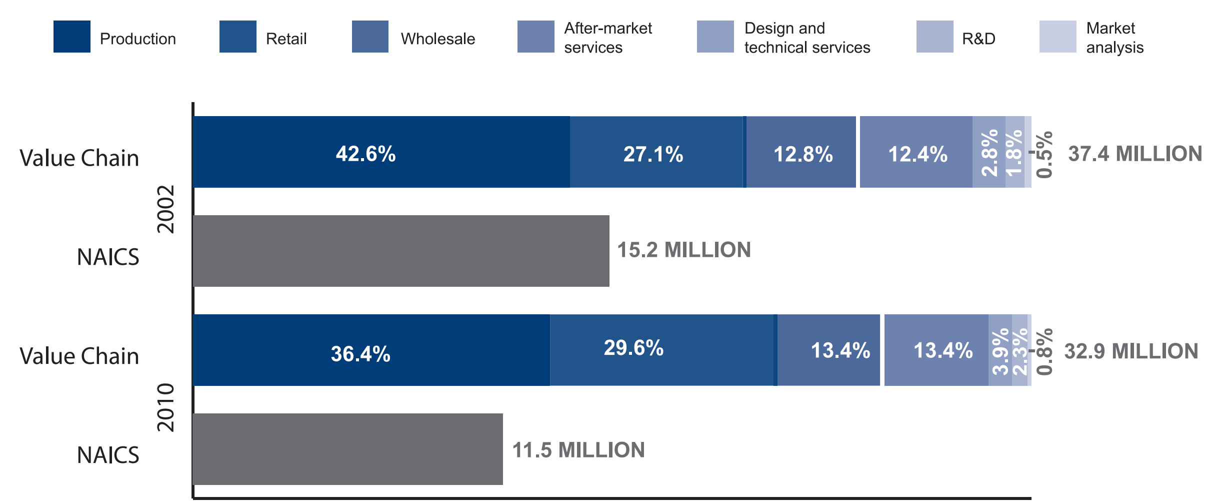
Additional caveats are associated with the limitations of the OES and QCEW datasets. OES and QCEW do not capture self-employed individuals and QCEW excludes organizations that had less than $25,000 annual revenue for three consecutive years. QCEW also counts employment based on filled jobs in each facility such that a multi-job holder will be counted more than once; therefore the employment numbers reported in the analysis should be most-precisely interpreted as approximations of the number of jobs rather than the number of people employed in the manufacturing value chain.

III. PATTERNS IN MANUFACTURING EMPLOYMENT

3.1 Employment losses were concentrated almost entirely on the factory floor

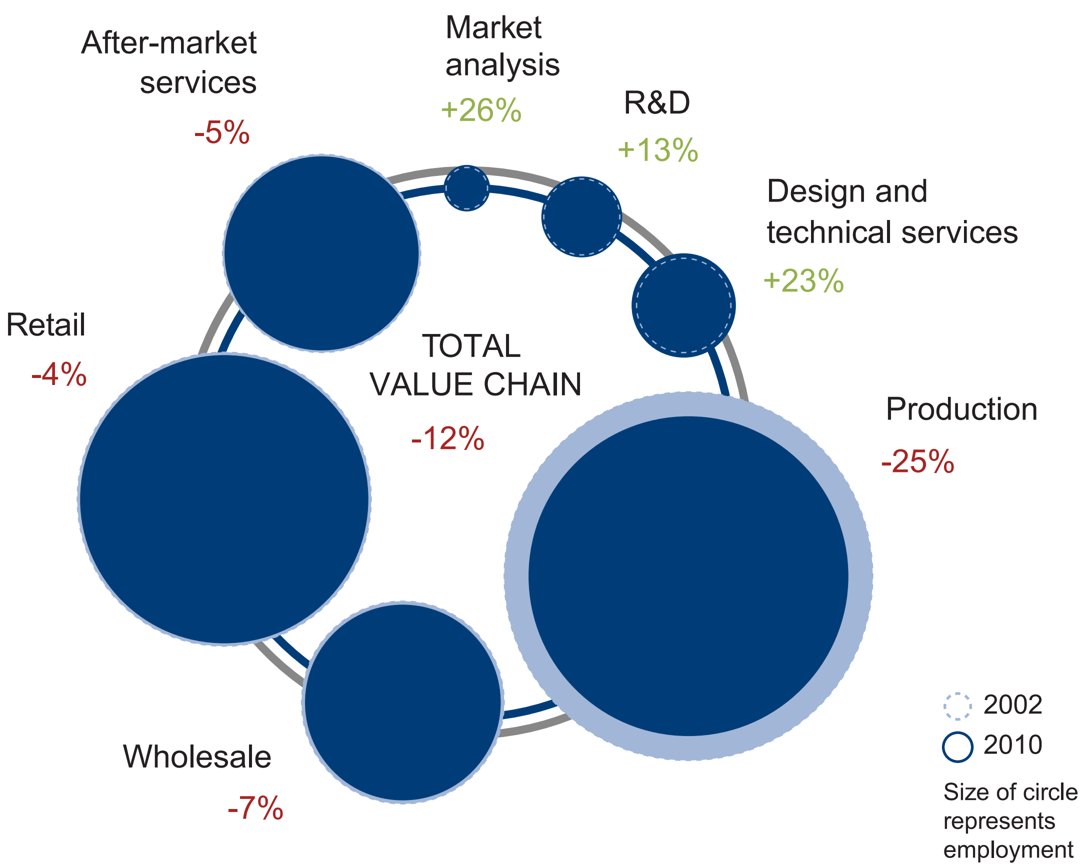
The analysis shows that, as of 2010, employment across the manufacturing value chain totals 32.9 million (25 percent of US employment), in comparison with only 11.5 million (9 percent of US employment) in production under the NAICS accounting (Figure 1). This employment shrunk from 37.4 million in 2002, but this decline is almost entirely due to the large employment decrease of 4 million in production (Figure 2).

FIGURE 1.
COMPARING JOB LOSSES FROM TWO PERSPECTIVES OF MANUFACTURING: VALUE CHAIN VS. NAICS*



*Production includes manufacturing as well as newspaper, books and other publishers.
Data Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages

FIGURE 2.
JOBS HAVE INCREASED IN EARLY STAGES OF THE VALUE CHAIN BUT HAVE NOT MADE UP FOR JOB LOSSES IN PRODUCTION

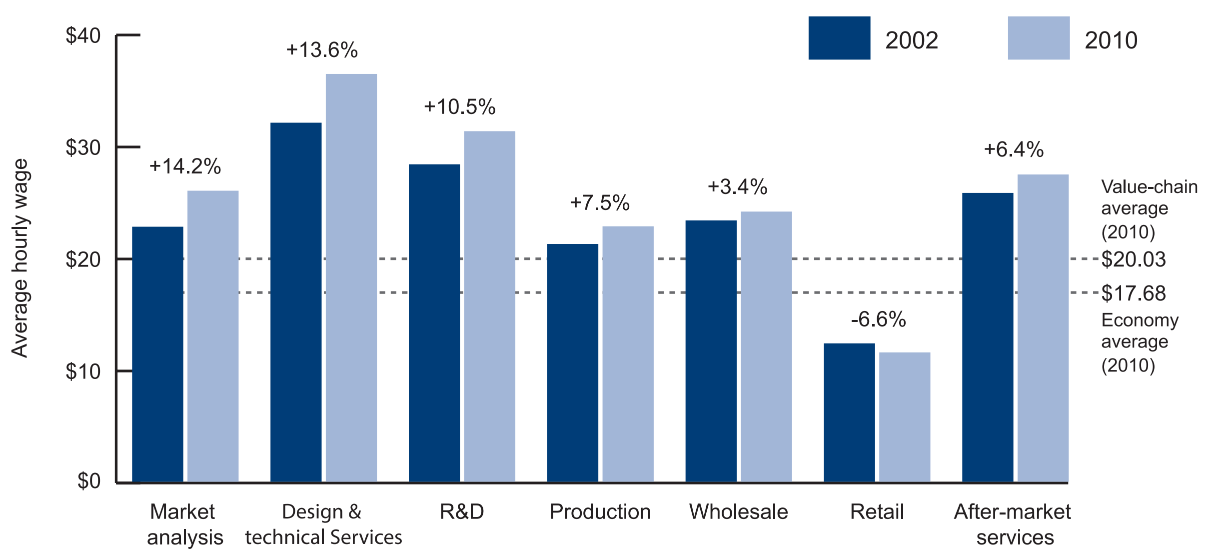


Data Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages

Other segments of the value chain—wholesale, retail, and after-market services—also experience a drop in employment from a total of 19.6 million to 18.5 million over the period observed. In contrast, upstream areas of the value chain saw employment growth. Market analysis, R&D, and design and technical services created 360,000 new jobs: design and technical services added 235,000 (up 23 percent), market analysis 53,000 (up 26 percent), and R&D approximately 88,000 (up 13 percent). While these employment increases do not offset the losses in production, they do offer higher-paying jobs, about $5 to $15 per hour more on average. Moreover, employment growth in these areas was paired with increasing wages: 14.2 percent wage growth for market analysis, 13.6 percent for design and technical services, and 10.5 percent for R&D (Figure 3). These increases are higher than those for the production (8 percent) and significantly exceed those for the entire value chain (4.4 percent).

Notwithstanding the differences in employment and wages between production and non-production areas, their total output in 2010 was roughly similar. Production contributed 20 percent to the total US output while employing only 9 percent of the workforce. In contrast, the rest of the value chain had similar output, but employed nearly twice as many workers. This reflects on higher productivity for the production area, which increased by 44 percent from 2002 (to $360,000 per employee in 2010).[5] In contrast, the productivity of the upstream and downstream segments of the value chain increased by only 12 percent (to $180,000 per employee in 2010). This difference is consistent with the prediction from economic theory that higher productivity gains from innovation can be expected at the plant level where labor productivity is higher already than upstream/downstream services because automation and more efficient processes have already replaced more jobs there than in support services to manufacturing (Acemoglu 1998).

FIGURE 3.
EARLY-STAGE ACTIVITIES IN THE VALUE CHAIN HAVE HIGHER AND FASTER GROWING WAGES



Data Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages

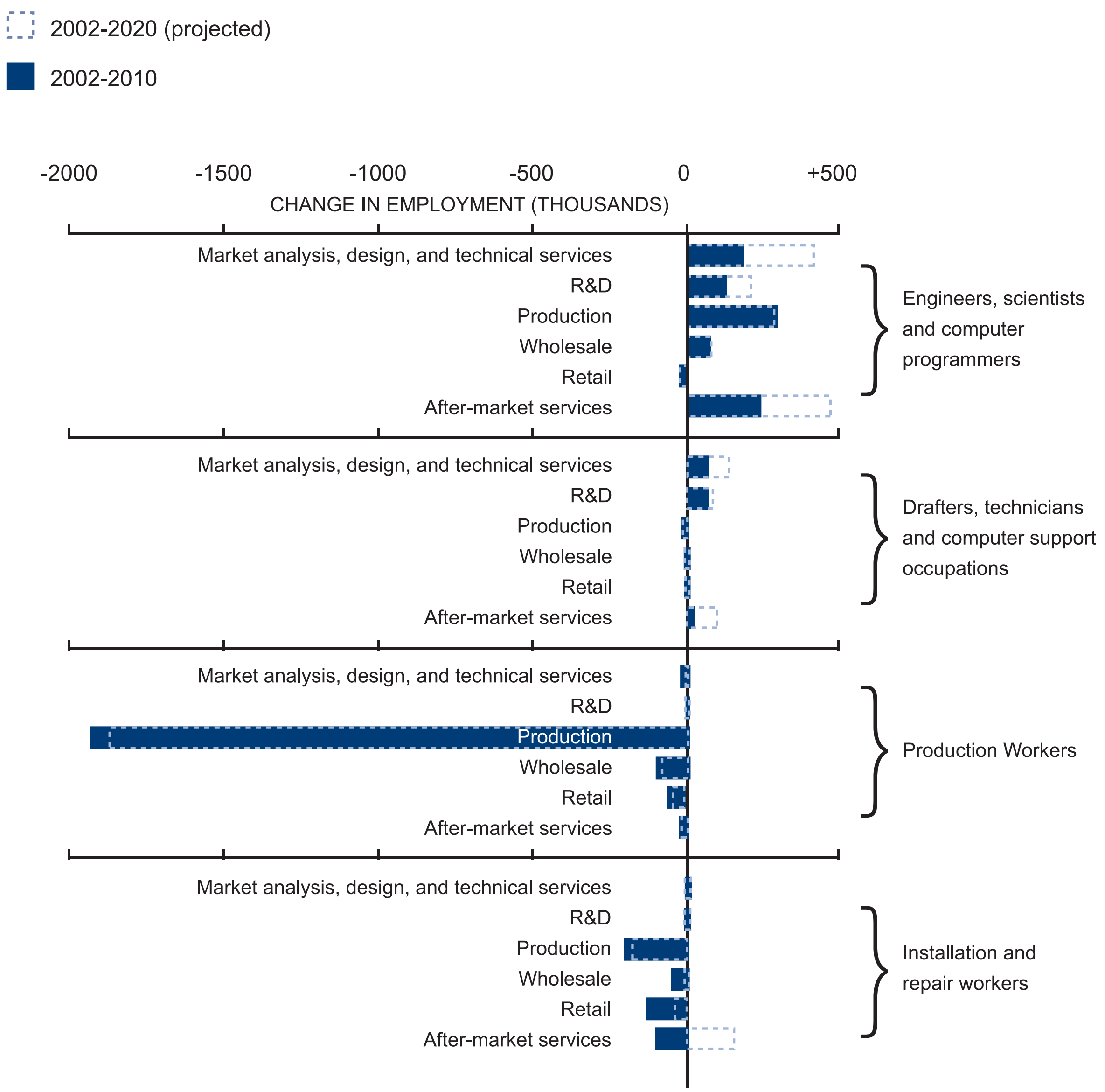
3.2 Demand is growing for higher skill occupations

The trends discussed above refer to total employment in all areas of the value chain, including support occupations such as administrative assistants and human resource specialists. But we can break down the data by occupational categories and take a closer look at those categories that have the greatest involvement in primary activities of the manufacturing value chain: production line workers; installation and repair workers; drafters and technicians; engineers, scientists and programmers; designers and technical writers; sales personnel; and managers and analysts (Porter 2008).

The relevant occupations were selected from the standard occupational classification (SOC) system based on the importance of an employee's knowledge in production and processing, design, and engineering and technology as reported in O*Net, and those involved in primary activities of the manufacturing value chain. This approach enabled analysis of employment trends among both traditional factory occupations (e.g., production line workers) and other occupations related to manufacturing (e.g., production managers, repairers of technical equipment, or sales representatives of technical products). See details in Appendix 2.

The comparative findings illustrate that in the value chain overall, engineering, science, and computer programming occupations increased by 20 percent from 2002 to 2010, while the number of production line workers dropped by 25 percent. The decrease of 2 million production line workers accounts for half of the 4 million factory jobs lost since 2002.[6] The employment of technicians and drafters increased by 50 percent in various stages of the value chain, such as R&D and design and technical services, but these occupations do not significantly impact overall employment because their numbers are small. The forecast to 2020—that we borrow from the BLS— show that the growth in engineering, science, and computer programming occupations is likely to continue, particularly so in upstream and downstream services. As we discuss below, this uptick in the demand for these occupations is likely linked to innovation, particularly increasing use of computing capacity.

FIGURE 5.
EMPLOYMENT GROWTH IS CONCENTRATED IN ACTIVITIES UPSTREAM AND DOWNSTREAM OF PRODUCTION WITH MANY MORE OPPORTUNITIES FOR ENGINEERS, SCIENTISTS, AND COMPUTER PROGRAMMERS



Data Source: Bureau of Labor Statistics, Occupational Employment Statistics.

3.3 The nature of work within occupations is changing

Our data analysis has shown better prospects for upstream segments of the manufacturing value chain and a particularly good outlook in terms of employment and wage for high-skill occupations such as computer programmers, scientists and engineers. These occupations are also likely to see increases in employment for downstream segments as well (Figure 5). In turn, factory workers have experienced significant declines in employment. These effects are likely the result of a greater degree of automation of manufacturing, the digitization of office work and communications, and the flattening of hierarchical structures, in other words, the result of technological and organizational innovation. These advances are not only changing the manufacturing value chain up and downstream, but also the nature of those occupations.

Well publicized successes of automation include the victory of IBM's Deep Blue over the world chess champion Garry Kasparov in 1997 and IBM's Watson winning the TV trivia game Jeopardy! in 2010. Other more mundane examples include the ubiquity of software automating tax preparation and filing and performing small business bookkeeping. Corresponding accomplishments in automation have occurred in manufacturing. For example, the creation of Computer Aided Design (commonly refer to as CAD), which manufacturers and design firms started adopting in the 1970s has replaced armies of drafters who used to prepare technical drawings by hand. The advent of robotic engineering paired with *precise assembly-line sequencing* has also displaced technicians who prepared line-side inventory buffers.

David Autor and his colleagues pointed out in a seminal paper that computers are good substitutes of routine tasks—repetitive tasks that follow a well-determined algorithm—and complements for non-routine tasks requiring analytic skills and interpersonal communications (Autor, Levy, Murnane 2003). Nevertheless, when considering the progress made in automated systems such as Google's self-driving car, it is easy to see how automation could displace even some non-routine tasks. Taking this possibility seriously, Carl Frey and Michael Osborne examined routine and non-routine tasks for their likelihood of automation and estimated that as many as 47 percent of U.S. employment is at high risk of being automated within two decades—high risk defined as having a probability of 70 percent or higher (Frey and Osborne 2013, see Figure III, p. 37). They used the O*Net database to identify the content of occupations in terms of the tasks they entail. These tasks were then assigned a likelihood of automation that could be aggregated into an overall score for each occupation.

What's more, almost 45 percent of the 702 occupations considered were classified as high risk of automation. Applying their methodology exclusively to the manufacturing value chain, the result is similar. Using their tabulation of probability, we identified about 50 percent of O*Net occupations in the manufacturing value chain to be at high risk, with the majority of them in production (e.g. technicians, operators, machine setters, helpers) and downstream services (e.g. machinery installation, maintenance, repair, and sales) and only a few upstream (e.g. mechanical drafters and mathematical technicians). The occupations that we identified as having the better demand prospects seem therefore to be somewhat sheltered from automation.

Nevertheless, these high-skill occupations will still be transformed by automation, even if not displaced by it, because the workers holding these positions are likely to need to leverage the power of computers and robots to provide creative solutions. With ever more sophisticated machines not only the scope of complementarity with automated systems will change, but also the tasks themselves will change. For instance, in design occupations employers have placed a premium on hard-to-automate tasks that combine technical competencies with the ability to assess commercial feasibility and customers' expectations. Another example is in the managing of uncertainty throughout the value chain because this skill is particularly difficult to automate; in turn, adequate use of computation capacity improves the quality of human judgment under uncertainty (see discussion in Rotman 2013).

Since Deep Blue's victory, computers have gotten better at beating humans at chess but not at poker. The reason, suggests Tyler Cowen, is that "computers don't know how to psych out the opponent, bluff, or read the 'tells' from the guy sitting across the table" (Cowen 2013, p. 49). The occupations sheltered from displacement will thus put a premium on the ability to combine a sensibility for reading the subtle cues from other humans, effect sound judgment, all the while using effectively computing knowledge and capabilities. In-person negotiation with co-workers, with partners down the value chain, and with competitors is likely to be a complementary skill to automated systems. Likewise, the ability to identify and resolve dilemmas such as efficiency versus safety or short versus long view in planning, will continue to be in demand. These changes have taken place in the recent past. Product design already depends on computing power but business success is reserved to those with the ability to deploy design tools in the service of an aesthetic sensibility that meets (or creates) a demand for the product, much in the way Apple fashioned the "look" of the MacBook or iPhone to suit the preferences of young adults that became a critical mass of early adopters.

We can also observe this kind of transformation in the emergence of new complex tasks in manufacturing over the last couple of decades such as tracking the movement of the parts along the global supply chain or system design for real-time monitoring of the manufacturing process. These tasks demand use of computer and information systems as intensely as they demand the ability to communicate effectively around the globe and to negotiate non-standard solutions with international partners.

IV. POLICY IMPLICATIONS

The foregoing analysis and discussion not only suggests challenges for increasing the adaptability of manufacturing labor, but it also hints at a policy problem: If the federal government wishes to reinvigorate American manufacturing, it would be well advised to extend its current policies for the sector (as defined by the NAICS typology) onto upstream and downstream segments of the manufacturing value chain. Moreover, demand for labor in upstream services appears to be increasing at a much faster rate than that for labor on the shop floor, and occupations in these areas may be less susceptible to automation. If manufacturing policy focuses on improving access to education and training for production jobs but ignores the workforce pipeline for upstream services such as R&D and design, it risks distorting the labor market. Designing policy with an expansive view of manufacturing including all services involved will help to avoid these consequences and improve the competitiveness of U.S. manufacturers.

4.1 Federal Manufacturing Policy

Take for instance President Obama's manufacturing initiative. Organized under the President's Council of Advisors on Science and Technology (PCAST), the Advanced Manufacturing Partnership—now on its second iteration for which the suffix 2.0 is added to its name—has issued two reports, the first in July of 2012 and the second on October 2014 (AMP 2012; AMP-2.0 2014). These reports contain a collection of policy recommendations to strengthen U.S. manufacturing and the pipeline of manufacturing talent, sixteen in the first and twelve in the second, including developing a national system of certifications and accreditation for production skills and establishing a national apprenticeship program for skilled trades in manufacturing. If the administration wishes to connect more Americans with the skills needed for successful manufacturing careers, it should consider the skills needed for non-production jobs that are critical to manufacturing and are growing in demand, such as industrial engineers, computer programmers, and operations research analysts, in addition to production jobs. These jobs require knowledge of production processes as well as a facility with analytic and scientific software, mathematical reasoning, and data analysis. Allowing more American students and displaced workers to improve their skills in these areas will help them qualify for manufacturing jobs that have higher wages and faster-growing prospects than most production jobs.

The last recommendation of the AMP 2.0 report tasks the National Economic Council and the Office of Science and Technology Policy with presenting the president with an implementation plan by year's end. It would be appropriate to include consideration of manufacturing services and software in that plan, something that could be accomplished without substantial modification, by recognizing as beneficiaries of this strategy all businesses in the advanced manufacturing value chain.

4.2 Higher education

A second area of policy focus is education. Our analysis illustrates two important and differentiated effects in labor demand that should inform manufacturing education and career guidance. First, employment and wages for high skill occupations in the value chain are growing, as one might expect since higher skills are more likely to complement advanced technologies that are being introduced. This trend suggests a need to improve the education of the manufacturing workforce to keep pace with technological change. While factory workers will experience the slowest growth and will be the most vulnerable to the business cycle, higher skill jobs in the manufacturing value chain will experience better employment prospects and higher wages. This is an argument for employees to continuously update their skills and for business to provide them with opportunities to do so.

Moreover, as described in section 2, increases in employment and wages seem to be particularly concentrated in upstream services; that is, in favor of R&D, design, and technical services supporting manufacturing. High-school and college students interested in pursuing careers in manufacturing should have access to this information and should be aware that their knowledge of production processes can be of use in R&D and manufacturing-related professional services as well as production facilities. Disseminating this kind of information is a public service that universities and community colleges could undertake.

The second effect on the labor demand is on the nature and character of the tasks required for high-skill occupations. As advanced technologies and production processes are adopted, production workers, engineers, and other technical staff are seeing their job requirements change. These jobs use to require a command of a complex set of well-determined procedures, in other words, to find the correct sequence of choices in a complex decision tree. Now, with increasing computing capabilities to program even very complex decision trees, new job descriptions will entail identifying abnormalities in automated systems, determining the cause, and reprogramming the system to avoid future errors. These conditions place a premium on mastery of problem-solving approaches rather than command of following prescribed procedures. Likewise, increasing work in teams formed from various locations around the globe, will place a premium on the kind of leadership that is flexible, effective, and sensitive to different work cultures.

This all implies that the education system needs to adjust their curriculum in STEM and other fields relevant to manufacturing with a long view of the coming changes to high-skill occupations. System automation will increase demand for workers with a high level of problem identification and uncertainty management abilities. Modifying the curriculum by adding course requirements can add to the costs of education and ancillary courses add sometimes little more than cosmetic value; we recommend instead making small but important changes to how existing courses are taught. For instance, the content of technical courses could emphasize more open-ended problems where students learn the underlying concepts by applying them to real world applications rather than the standard approach of teaching students to apply the concepts to find a single correct answer to every problem—regularly by having them follow a prescribed sequence of operations.

Another example of the kind of curriculum change we are here advocating is teaching students to manage uncertainty and to use their judgment in problems where their technical knowledge is necessary but not sufficient to come up with a sensible solution. All technical courses could include problems that capture the value trade-offs of real-life situations; problems that can only be resolved by means of balancing competing values such as balancing safety versus privacy, or reconcile design-redundancies versus budget constraints, or favor robust and flexible user interfaces versus simple but more constraining interfaces. In other words, technical training should involve an education that helps workers incorporate in addition to technical considerations other relevant aspects to a decision, in particular value dilemmas and trade-offs.

Expanding the set of relevant considerations in technical fields also implies a robust training in entrepreneurial skills, from recognizing commercial opportunities to addressing prospect funders to product development, to social and regulatory implications. Even for students who remain in the lab for their careers, a better understanding of the complexities of how an idea is taken into a commercial product can help them improve the way they ask research questions or the way they choose business partners who will develop their inventions in a manner consonant with the values that inspired those inventions. We are proposing to expand technical training from its traditional focus on an advanced toolkit for problem-solving to a skill-set for problem-identification—that precedes the selection (or creation) of tools to solve problems. We believe that there will be a high demand and a wage premium for individuals able to integrate adequately technical, social, and economic considerations in the design of new products and production processes.

4.3 Improve the conceptual framework of sectoral labor statistics.

From the outset we said that a better understanding of the changes in labor demand in manufacturing is to be attained by looking at the entire value chain. We believe that our analysis offers a fresh look at the changes that have occurred to U.S. manufacturing labor over the last few years and the challenges going forward. But this too has an implication for the way we do national accounting of sectoral activity. NAICS is a tremendously useful tool but alternative methods of classifying economic activity should be considered as supplemental information, particularly approaches that allow us to recognize the close ties between manufacturing and services.

One possible method of organizing economic statistics could be based on value-added. Countries with value added tax (VAT) have, in their sales tax record, an account of inputs and outputs at the company level. While the Office of Management and Budget is coordinating an interagency effort to develop a demand-based classification system as a supplement to NAICS (OMB 2014), it is worthwhile considering a type of data collection that simulates the VAT data collection structure, without of course the tax. Businesses themselves invest in understanding and managing their value chain and it may not be too difficult to convince them that sharing that kind of information for national statistics purposes—that ought to be made public only in aggregates—will help policymakers understand how to best support national manufacturing.

V. CONCLUSIONS

There is currently an intense public debate about the future of the U.S. manufacturing labor force, changes in labor demand, and the challenges that the institutions training our workforce must meet. The long-term benefits of innovation come with short-term costs particularly for workers that are displaced by new technological platforms. Much ink is devoted to the question of job creation and too little to the more important but complex questions of what kinds of jobs are to be created? What will be the content of those new jobs? How will that content impact job security? How should our education system adjust to the evolving job requirements as we described in this paper? The first task in tackling these difficult questions, we believe, is to better understand the manufacturing sector. Above we have sought to make a contribution to that understanding by focusing on the value chain of manufacturing, its labor and its composition. We have found that the changes of employment in manufactures are underestimated by the standard way of accounting for its activity and we have proposed an alternative approach.

Looking at the value chain of manufacturing for a period that included the Great Recession, we have estimated a larger job loss tally in manufacturing than NAICS based estimates—which is not surprising given our expansive definition of manufacturing. We have shown as well that facilities performing services supporting manufacturing experienced job losses during the financial crisis but the bulk of employment declines were concentrated in production facilities. What is more, it appears that occupations that are more prevalent in upstream and downstream services are less likely to be displaced by advances in automation. The analysis also shows that high skill occupations such as engineers, computer programmers, and scientists, are faring particularly well— these occupations saw increased demand over the financial crisis and are much less likely to be at risk for automation in the future.

We offer several policy recommendations from these observed trends. In particular, policies aimed at revitalizing manufacturing should consider its entire value chain and not simply focus on the production segment of it; our discussion suggests plenty of opportunities for industry and higher education to partner in easing the costs of transition to new technological platforms, for instance, industry could play a leading role in training their workers to use automated systems. Likewise, the education system and particularly college and vocational programs in manufacturing have an opportunity to expand their offerings and adjust their pedagogies to meet the challenges of an increased premium to skill as well as higher demand for competencies associated with computer programming, problem identification, and data analysis. Lastly, we have touched on an old but persistent epistemic problem: policy makers can only imagine solutions to the problems they see, and a critical part of their vision is our system of economic statistics. We advocate for creating a supplement to the standard NAICS system that allows a value chain approach, so that we begin to conceive policy that benefits the entire productive chain and not only segments of it.

A final note on inequality: we are aware that our analysis can be taken as further evidence of an increasing asymmetry of employment opportunities and wages in the manufacturing sector. In fact, we are not simply confirming this effect, but observing that it is more wide-ranging than previously believed. High skill jobs appear to have increasingly better prospects in manufacturing than positions requiring fewer qualifications. In turn, jobs at the base of the pyramid are experiencing both a disappearance—by means of automation of plant processes—and a diaspora—by means of offshoring. Sensible policy will therefore seize the opportunities of new technological platforms at the same time it mitigates the pain to vulnerable workers. Policies to foment manufacturing should thus entail the strengthening of the safety net, particularly unemployment benefits tied to the condition that workers undertake re-training, and the vigorous introduction of new opportunities for education and training for displaced workers. These opportunities must be relevant to growing industries such as those we identified as upstream services in the manufacturing value chain. In the long term, the transition also means a whole new cohort of workers, children who are today in grade school and who will enter in ten to twenty years all levels of the labor pyramid. This is the second prong of a sensible strategy, that is, to educate this new cohort with the skills necessary to earn a decent living. Industry, government, and students will need to assume shared responsibility to ensure the American workforce can gain the skills needed for future jobs. We think greater collaboration of private enterprise and universities and community colleges should be highly encouraged. Cooperating in this area, companies and universities and colleges will accomplish far more than acting individually. Sensible coordination can indeed improve the working conditions in all segments of the manufacturing value chain.

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ENDNOTES

All findings, conclusions, and recommendations are those of the authors and do not necessarily represent the views of the National Academies or any of its constituent units.

1 This second exercise is one of anticipation rather than forecasting. To clarify, we contrast forecast or a rigorous guessing of the future based on historic data with anticipation or a reflection about the future that examines more critically the same data and looks into actions that may help us better prepare for uncertain futures. While we discern from forecasting and anticipation, we find them both complementary and in fact we use existing forecasts—by the Bureau of Labor Statistics—for our anticipatory analysis.

2 *North American Industry Classification System* (*NAICS)* http://www.census.gov/eos/www/naics/

3 These areas of the value chain include only industries related to creating or adding value for a physical good. They have specific meaning in this report and should not be confused with the industry sectors represented in national statistics. Appendix 1 lists the NAICS-defined industries included in these areas.

4 Occupational Information Network (O*Net) database, available at www.onetonline.org

5 Productivity was calculated as the total output of the sector (inflation adjusted dollars) divided by the total number of employees in the sector

6 About 1.5 million jobs were lost in support occupations, mainly administration. An additional 0.2 million lost jobs were in occupations such as sales, and installation, repair, and maintenance.

APPENDIX 1

Industries selected for the manufacturing value chain analysis, based on descriptions from the North American Industry Classification System (NAICS). Facilities were selected that either produce goods or generate services that are necessary for product development, production, delivery, or use of a manufactured good.

AREA IN THE VALUE CHAIN	NAICS CODE	NAICS DESCRIPTION
Understanding customers	54191	Marketing Research and public opinion polling
	541613	Marketing consulting services
Research + Development	54138	Testing laboratories
	5417	Scientific research and development service
Design	54133	Engineering services
	54134	Drafting services
	54142	Industrial design services
	54143	Graphic design services
	541614	Process, physical distribution and logistics consulting services
	54162	Environmental Consulting Services
Manufacturing	31-33	Manufacturing
	5111	Newspaper, book, and directory publishers
Sales Wholesales	423	Merchant Wholesalers, Durable Goods
	4241	Paper and Paper product Merchant Wholesalers
	4242	Drugs Merchant Wholesalers
	4243	Apparel, piece goods and notions Merchant Wholesalers
	4244	Grocery and Related product merchant
	4246	Chemical and Allied Products Merchant Wholesalers
	4248	Beer, wine and distilled beverages Merchant Wholesalers
	4249	Miscellaneous Merchant Wholesalers (books, flower, tobacco, paint, varnish, etc.)
Retail	441	Motor vehicle and parts
	442	Furniture
	443	Electronics and appliances
	444	Building material and garden equipment
	445	Food and beverage stores
	446	Health and personal care stores
	448	Clothing stores
	451	Sporting goods
	4541	Electronic shopping and mail-order houses
Services	5112	Software publishers
	516	Internet publishing and broadcasting
	517	Telecommunications
	518	Data processing, hosting and related activities
	5415	Computer system design and programming
	56142	Telephone Call centers

APPENDIX 2

Occupations selected for the manufacturing value chain analysis based on the involvement of activities that directly add to the value of the product as perceived by the customer (Standard Occupational Classification System, available at www.bls.gov/SOC/) and the importance of an employee's knowledge in production and processing, design, and engineering and technology (Occupational Information Network database, available at www.onetonline.org).

2010 NATIONAL EMPLOYMENT MATRIX DESCRIPTION (SOC)	CODE
Total, all occupations	00-0000
Managers and analysts	
Advertising and promotions managers	11-2011
Marketing managers	11-2021
Sales managers	11-2022
Computer and information systems managers	11-3021
Industrial production managers	11-3051
Architectural and engineering managers	11-9041
Natural sciences managers	11-9121
Cost estimators	13-1051
Logisticians	13-1081
Market research analysts and marketing specialists	13-1161
Engineers, computer and natural scientists and programmers and developers, designers	
Computer and information research scientists	15-1111
Computer systems analysts	15-1121
Computer programmers	15-1131
Software developers, applications	15-1132
Software developers, systems software	15-1133
Database administrators	15-1141
Network and computer systems administrators	15-1142
Information security analysts, web developers, network architects	15-1179
Computer occupations, all other	15-1799
Actuaries	15-2011
Mathematicians	15-2021
Operations research analysts	15-2031
Statisticians	15-2041
Miscellaneous mathematical science occupations	15-2090
Aerospace engineers	17-2011
Agricultural engineers	17-2021
Biomedical engineers	17-2031
Chemical engineers	17-2041
Civil engineers	17-2051
Computer hardware engineers	17-2061
Electrical engineers	17-2071
Electronics engineers, except computer	17-2072
Environmental engineers	17-2081
Health and safety engineers, except mining safety engineers / inspectors	17-2111

Industrial engineers	17-2112
Marine engineers and naval architects	17-2121
Materials engineers	17-2131
Mechanical engineers	17-2141
Nuclear engineers	17-2161
Petroleum engineers	17-2171
Engineers, all other	17-2199
Animal scientists	19-1011
Food scientists and technologists	19-1012
Soil and plant scientists	19-1013
Biochemists and biophysicists	19-1021
Microbiologists	19-1022
Zoologists and wildlife biologists	19-1023
Biological scientists, all other	19-1029
Conservation scientists	19-1031
Foresters	19-1032
Epidemiologists	19-1041
Medical scientists, except epidemiologists	19-1042
Life scientists, all other	19-1099
Astronomers	19-2011
Physicists	19-2012
Atmospheric and space scientists	19-2021
Chemists	19-2031
Materials scientists	19-2032
Environmental scientists and specialists, including health	19-2041
Geoscientists, except hydrologists and geographers	19-2042
Hydrologists	19-2043
Physical scientists, all other	19-2099
Survey researchers	19-3022
Drafters, technicians and computer support specialists	
Electrical and electronics drafters	17-3012
Mechanical drafters	17-3013
Drafters, all other	17-3019
Computer support specialists	15-1150
Aerospace engineering and operations technicians	17-3021
Electrical and electronics engineering technicians	17-3023
Electro-mechanical technicians	17-3024
Environmental engineering technicians	17-3025
Industrial engineering technicians	17-3026
Mechanical engineering technicians	17-3027
Engineering technicians, except drafters, all other	17-3029
Agricultural and food science technicians	19-4011
Biological technicians	19-4021
Chemical technicians	19-4031
Environmental science and protection technicians, including health	19-4091
Forest and conservation technicians	19-4093

Life, physical, and social science technicians, all other	19-4099
Designers and technical writers	
Commercial and industrial designers	27-1021
Graphic designers	27-1024
Technical writers	27-3042
Sales occupations	
First-line supervisors of retail sales workers	41-1011
First-line supervisors of non-retail sales workers	41-1012
Cashiers	41-2011
Gaming change persons and booth cashiers	41-2012
Counter and rental clerks	41-2021
Parts salespersons	41-2022
Retail salespersons	41-2031
Sales representatives, wholesale and manufacturing, technical and scientific products	41-4011
Sales representatives, wholesale and manufacturing, except technical and scientific products	41-4012
Models, demonstrators, and product promoters	41-9010
Demonstrators and product promoters	41-9011
Sales engineers	41-9031
Installation, production and repair	
First-line supervisors of mechanics, installers, and repairers	49-1011
Computer, automated teller, and office machine repairers	49-2011
Radio and telecommunications equipment installers and repairers	49-2020
Radio, cellular, and tower equipment installers and repairs	49-2021
Telecommunications equipment installers and repairers, except line installers	49-2022
Avionics technicians	49-2091
Electric motor, power tool, and related repairers	49-2092
Electrical and electronics installers and repairers, transportation equipment	49-2093
Electrical and electronics repairers, commercial and industrial equipment	49-2094
Electrical and electronics repairers, powerhouse, substation, and relay	49-2095
Electronic equipment installers and repairers, motor vehicles	49-2096
Electronic home entertainment equipment installers and repairers	49-2097
Security and fire alarm systems installers	49-2098
Aircraft mechanics and service technicians	49-3011
Automotive technicians and repairers	49-3020
Automotive body and related repairers	49-3021
Automotive glass installers and repairers	49-3022
Automotive service technicians and mechanics	49-3023
Bus and truck mechanics and diesel engine specialists	49-3031
Heavy vehicle and mobile equipment service technicians and mechanics	49-3040
Farm equipment mechanics and service technicians	49-3041
Mobile heavy equipment mechanics, except engines	49-3042
Rail car repairers	49-3043

Small engine mechanics	49-3050
Motorboat mechanics and service technicians	49-3051
Motorcycle mechanics	49-3052
Outdoor power equipment and other small engine mechanics	49-3053
Miscellaneous vehicle and mobile equipment mechanics, installers, and repairers	49-3090
Bicycle repairers	49-3091
Recreational vehicle service technicians	49-3092
Tire repairers and changers	49-3093
Control and valve installers and repairers	49-9010
Mechanical door repairers	49-9011
Control and valve installers and repairers, except mechanical door	49-9012
Heating, air conditioning, and refrigeration mechanics and installers	49-9021
Home appliance repairers	49-9031
Industrial machinery installation, repair, and maintenance workers	49-9040
Industrial machinery mechanics	49-9041
Maintenance workers, machinery	49-9043
Millwrights	49-9044
Refractory materials repairers, except brick masons	49-9045
Line installers and repairers	49-9050
Electrical power-line installers and repairers	49-9051
Telecommunications line installers and repairers	49-9052
Precision instrument and equipment repairers	49-9060
Camera and photographic equipment repairers	49-9061
Medical equipment repairers	49-9062
Musical instrument repairers and tuners	49-9063
Watch repairers	49-9064
Precision instrument and equipment repairers, all other	49-9069
Maintenance and repair workers, general	49-9071
Miscellaneous installation, maintenance, and repair workers	49-9090
Coin, vending, and amusement machine servicers and repairers	49-9091
Commercial divers	49-9092
Fabric menders, except garment	49-9093
Locksmiths and safe repairers	49-9094
Manufactured building and mobile home installers	49-9095
Riggers	49-9096
Signal and track switch repairers	49-9097
Helpers--installation, maintenance, and repair workers	49-9098
Installation, maintenance, and repair workers, all other	49-9799
First-line supervisors of production and operating workers	51-1011
Aircraft structure, surfaces, rigging, and systems assemblers	51-2011
Electrical, electronics, and electromechanical assemblers	51-2020
Coil winders, tapers, and finishers	51-2021
Electrical and electronic equipment assemblers	51-2022
Electromechanical equipment assemblers	51-2023

Engine and other machine assemblers	51-2031
Structural metal fabricators and fitters	51-2041
Miscellaneous assemblers and fabricators	51-2090
Fiberglass laminators and fabricators	51-2091
Team assemblers	51-2092
Timing device assemblers and adjusters	51-2093
Assemblers and fabricators, all other	51-2099
Bakers	51-3011
Butchers and other meat, poultry, and fish processing workers	51-3020
Butchers and meat cutters	51-3021
Meat, poultry, and fish cutters and trimmers	51-3022
Slaughterers and meat packers	51-3023
Miscellaneous food processing workers	51-3090
Food and tobacco roasting, baking, and drying machine operators and tenders	51-3091
Food batch makers	51-3092
Food cooking machine operators and tenders	51-3093
Computer-controlled machine tool operators, metal and plastic	51-4011
Computer numerically controlled machine tool programmers, metal and plastic	51-4012
Extruding and drawing machine setters, operators, and tenders, metal and plastic	51-4021
Forging machine setters, operators, and tenders, metal and plastic	51-4022
Rolling machine setters, operators, and tenders, metal and plastic	51-4023
Cutting, punching, and press machine setters, operators, and tenders, metal and plastic	51-4031
Drilling and boring machine tool setters, operators, and tenders, metal and plastic	51-4032
Grinding, lapping, polishing, and buffing machine tool setters, operators, and tenders, metal and plastic	51-4033
Lathe and turning machine tool setters, operators, and tenders, metal and plastic	51-4034
Milling and planning machine setters, operators, and tenders, metal and plastic	51-4035
Machinists	51-4041
Metal-refining furnace operators and tenders	51-4051
Pourers and casters, metal	51-4052
Model makers, metal and plastic	51-4061
Patternmakers, metal and plastic	51-4062
Foundry mold and core makers	51-4071
Molding, core making, and casting machine setters, operators, and tenders, metal and plastic	51-4072
Multiple machine tool setters, operators, and tenders, metal and plastic	51-4081
Tool and die makers	51-4111
Welding, soldering, and brazing workers	51-4120
Welders, cutters, solderers, and brazers	51-4121
Welding, soldering, and brazing machine setters, operators, and tenders	51-4122
Heat treating equipment setters, operators, and tenders, metal and plastic	51-4191
Layout workers, metal and plastic	51-4192
Plating and coating machine setters, operators, and tenders, metal and plastic	51-4193
Tool grinders, filers, and sharpeners	51-4194
Metal workers and plastic workers, all other	51-4199
Prepress technicians and workers	51-5111

Printing press operators	51-5112
Print binding and finishing workers	51-5113
Laundry and dry-cleaning workers	51-6011
Pressers, textile, garment, and related materials	51-6021
Sewing machine operators	51-6031
Shoe and leather workers and repairers	51-6041
Shoe machine operators and tenders	51-6042
Sewers, hand	51-6051
Tailors, dressmakers, and custom sewers	51-6052
Textile bleaching and dyeing machine operators and tenders	51-6061
Textile cutting machine setters, operators, and tenders	51-6062
Textile knitting and weaving machine setters, operators, and tenders	51-6063
Textile winding, twisting, and drawing out machine setters, operators, and tenders	51-6064
Extruding and forming machine setters, operators, and tenders, synthetic and glass fibers	51-6091
Fabric and apparel patternmakers	51-6092
Upholsterers	51-6093
Textile, apparel, and furnishings workers, all other	51-6099
Cabinetmakers and bench carpenters	51-7011
Furniture finishers	51-7021
Model makers, wood	51-7031
Patternmakers, wood	51-7032
Sawing machine setters, operators, and tenders, wood	51-7041
Woodworking machine setters, operators, and tenders, except sawing	51-7042
Woodworkers, all other	51-7099
Nuclear power reactor operators	51-8011
Power distributors and dispatchers	51-8012
Power plant operators	51-8013
Stationary engineers and boiler operators	51-8021
Water and wastewater treatment plant and system operators	51-8031
Chemical plant and system operators	51-8091
Gas plant operators	51-8092
Petroleum pump system operators, refinery operators, and gaugers	51-8093
Plant and system operators, all other	51-8099
Chemical equipment operators and tenders	51-9011
Separating, filtering, clarifying, precipitating, and still machine setters, operators, and tenders	51-9012
Crushing, grinding, and polishing machine setters, operators, and tenders	51-9021
Grinding and polishing workers, hand	51-9022
Mixing and blending machine setters, operators, and tenders	51-9023
Cutters and trimmers, hand	51-9031
Cutting and slicing machine setters, operators, and tenders	51-9032
Extruding, forming, pressing, and compacting machine setters, operators, and tenders	51-9041
Furnace, kiln, oven, drier, and kettle operators and tenders	51-9051
Inspectors, testers, sorters, samplers, and weighers	51-9061
Jewelers and precious stone and metal workers	51-9071

Dental laboratory technicians	51-9081
Medical appliance technicians	51-9082
Ophthalmic laboratory technicians	51-9083
Packaging and filling machine operators and tenders	51-9111
Coating, painting, and spraying machine setters, operators, and tenders	51-9121
Painters, transportation equipment	51-9122
Painting, coating, and decorating workers	51-9123
Semiconductor processors	51-9141
Photographic process workers and processing machine operators	51-9151
Adhesive bonding machine operators and tenders	51-9191
Cleaning, washing, and metal pickling equipment operators and tenders	51-9192
Cooling and freezing equipment operators and tenders	51-9193
Etchers and engravers	51-9194
Molders, shapers, and casters, except metal and plastic	51-9195
Paper goods machine setters, operators, and tenders	51-9196
Tire builders	51-9197
Helpers--production workers	51-9198
Production workers, all other	51-9399

Governance Studies
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