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Skill-sets and Their Impact on Long-term Employment in Manufacturing

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Abstract

The skill-sets necessary for employment in a modern manufacturing environment are quite varied. Technology has shifted the burden of monotonous tasks away from humans and that of higher-level creative processing to humans. Nine occupations in the state of Indiana, were found using the Frey and Osborne (2013, 2017) model, four of which are non-susceptible to automation. The most important tasks of each non-susceptible job were identified and classified based on skill-set required. Susceptibility referred to the presence of factors related to worker and job-oriented characteristics that were more prone to be automated in the future, while non-susceptibility was the opposite. A better understanding of mathematical skill-sets and their relation to product design and process operations are crucial for working modern manufacturing environments. This paper acts as starting point for the upgrading of manufacturing programs, here in Indiana, in the preparation of undergraduate students for the workforce.

Introduction

Technology acts as both an augmenter and a replacement for skills, possessed by humans, by modifying their nature. It does this by mastery of a codified task within a job, ultimately shifting the distribution of tasks from the human to itself (Autor, 2013). During its adoption, technology can have a profound impact on the social norms of an organization, forcing its workforce to acquire skills that are more creative, adaptable and collaborative. Gone are the days in which education garnered in college led to a semi-permanent job. Today's view of an occupation is one in which a more specialized on-demand type of education is required (National Academies of Sciences, Engineering, & Medicine, 2017a). Since the Great Recession, which ended in 2009, the fastest growing occupational categories have been in the professional fields of management, STEM and healthcare. A majority of these jobs had at a minimum, a Bachelor's degree requirement with earnings in the upper third of all occupational median wages. On the other hand, occupational categories in the lower third of all occupational median wages, considered low-wage, entailed food, personal services, sales and office support, and blue-collar jobs. These jobs were mostly held by workers with some college or an Associate degree holder (61% of these jobs) (Carnevale, Jayasundera, & Gulish, 2015).

The nature of the skill-sets needed for jobs in these occupational categories are not well understood (Autor, 2013). In particular, manufacturing related occupations are of particular concern as the skill-sets necessary for undertaking these jobs have changed over the past fifty years. During this period, the adoption of automated and robotic machinery has enabled many manufacturers to become more price competitive, due to increases in productivity and quality. Automated machinery has allowed efficiencies to be extracted via improved quality and reliability on tasks that are routine and structured. These technical systems have had a profound effect on the nature of work, which has resulted in a reduction in the sector's employment numbers over the past 50 years. In 1970, 28% of US private sector employment was in manufacturing. Today the sector employs 11% of the private sector workforce (U.S. Bureau of Labor Statistics, 2019). The next phase of manufacturing productivity will come from a boon in the usage of technical systems that are able to overcome difficulties with operating in unstructured environments (Mckinsey Global Institute, 2017). Robotic systems, unlike automated systems, emphasize intelligence and adaptability in an effort to cope with unstructured environments enabling further cost reductions and faster delivery times (Computing Community Consortium & Computing Research Association, 2009). The addition of robotic systems in manufacturing environments has, by some estimates, led to a reduction of direct employment in the sector by about 6.2 workers per robot, between 1993 to 2007 (Acemoglu & Restrepo, 2017). The impact of the adoption of new technologies on productivity can take several decades as new business practices; infrastructure and other complementary social and economic mechanisms are fulfilled. Once adoption has taken hold they have the added impact of an acceleration in productivity growth which also supports the theory of reduced need for human effort (Syverson, 2013).

Purpose

Robotic systems are increasingly being used in manufacturing environments to complement or substitute human labor in tasks considered routine or repetitive in unstructured settings. As these systems become more widely adopted and utilized, workers will be force to acquire skills that accentuate creativity, adaptability and collaboration, if they desire to be in the upper median of wage earners in the future. The exact nature of these skill-sets are not well understood, as are the details of what should be taught and how. This paper seeks to identify skill-sets needed for future employment in the manufacturing field, in the state of Indiana, by reviewing the likelihood of an occupation's demise through the use automated or robotic systems. As a starting point, the skill-sets that will be impaired by continued robotic system adoption must be understood with a content model. By utilizing the Occupational Information Network (O*NET) as the source of job information requirements the necessary skill-sets for a particular occupation was determined. To determine the occupations most likely to be impacted by automation and robotics the Frey and Osborne (2013) task model was employed to identify 71 occupations in the manufacturing sector, in the state of Indiana. The task model provided a probability for the utilization of automated and robotic systems to replace entire occupations within the sector. It is with this basic piece of information that this paper then seeks to use to determine the skill-sets that will be in most demand by manufacturers, in the state, in the future.

Problem Statement

The decade, starting in 2015 and ending in 2025, will see the US manufacturing sector add nearly 3.4 million jobs. Of these jobs, 2 million will go unfilled due to an expected skills gap in the workforce. Again, the skill-sets necessary for these jobs are at best a nebulous concept that centers on computer/technical and problem solving skills. Of greatest worry to manufacturers is that they will not be able to maintain or increase production levels with growing customer demand (82% of the respondents in the Deloitte survey) and or implement new technologies to achieve production targets (78%)(Deloitte Consulting & Manufacturing Institute, 2015; Deloitte Consulting & The Manufacturing Institute, 2018; Mckinsey Global Institute, 2017; McLeod, 2019). A thorough understanding of occupational skill-sets, predicted to be in high demand, is needed. This must take place through a multidisciplinary approach to looking at this problem.

History of manufacturing employment

US manufacturing employment can be broken up into four specific periods, since employment in the field has been tracked (See figure 1) (U.S. Bureau of Labor Statistics, 2019). The first period represents the prewar industrial boom that occurred during the 1930s lasting until the end of the Second World War in 1944. The second era began in 1946, the postwar period, lasting until the middle of 1979. In 1979, the US's manufacturing employment was at a record high of 19.5 million workers. The decades preceding the 1970s saw a huge downturn in US manufacturing employment and this did not end until the beginning of 2010. This period of US manufacturing employment represented a 41% decline or the loss of 8.1 million jobs over three decades. Many researchers and governmental entities have explained this decline as being a side effect of globalization and productivity growth (Autor, Dorn, & Hanson, 2011; Deitz & Orr, 2006; National Academies of Sciences, Engineering, & Medicine, 2017b). The fourth era began in 2010 with increases in employment over the past decade. A notable fact of the decades preceding the fourth era, is that the bulk of manufacturing jobs lost in the US were mostly felt by those workers considered low skilled (Autor et al., 2011; Deitz & Orr, 2006). On the other hand, much of the increases in employment during the fourth era are attributable to jobs that require more high skilled labor (McLeod, 2019).

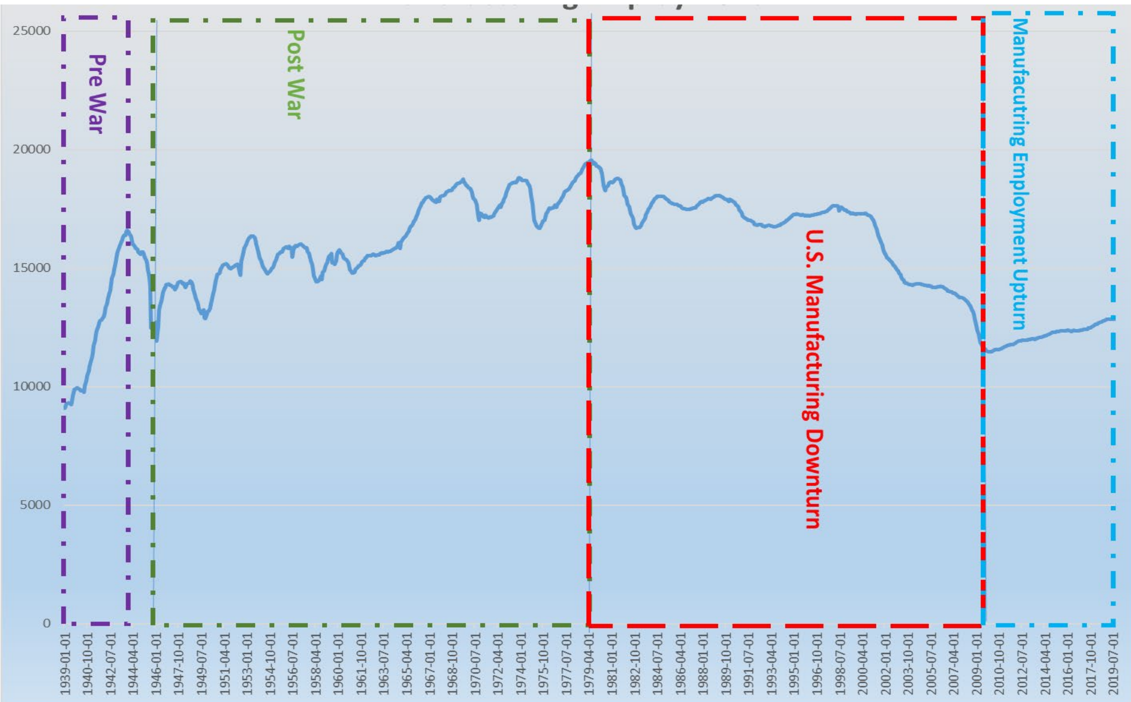

Figure 1. Manufacturing Employment 1939 - 2019 (U.S. Bureau of Labor Statistics)

The era of manufacturing downturn lasted three decades and it was during this timeframe that most manufacturing subsectors experienced a large growth in their share of highly skilled workers (Carnevale et al., 2015; Deitz & Orr, 2006; Mckinsey Global Institute, 2017). In the 20 subsectors of manufacturing studied by Deitz and Orr (2006), only two did not show an increase in highly skilled workers in 2002 when compared to 1983. When employment growth in the manufacturing sector was analyzed between 2001 and 2016 by McLeod (2019), this deficiency seems to have reversed itself. In jobs considered low skilled/low technology intensive, the usage of robotic systems, in its various forms, correlated with increases in employment. At the heart of this trend is the need, by smaller manufacturing entities, to be innovative. Innovation, improves the survivability of small to medium-size manufacturing entities allowing them to avoid price competition with their larger peers and also in serving niche markets that desire specialty products (McLeod, Stephens, & McWilliams, 2016).

Skill-sets manufacturers seek

While the need for highly skilled workers has been widely documented, there has been no consensus on the specific nature of the skill sets needed (Deloitte Consulting & The Manufacturing Institute, 2018; Mckinsey Global Institute, 2017; McLeod, 2019). Frey and Osborne (2013, 2017) have ascribed probabilities to the likelihood of certain occupations and their viability in the future. This has opened a possible path to understanding the nature of the skill sets that are currently being perceived as being necessary for future employment. By identifying jobs at risk and their opposite counterparts, the usage of the occupational information network (O*NET) content model was deemed necessary. This model is a sociotechnical framework identifying the most important traits of work and then integrating them into a theoretically and empirically sound structure. O*NET categorizes and defines 974 occupations into structured hierarchical taxonomies with six domains. This database is widely used by entities and researchers in the field of human resource management, policy research, economic development, career development and workforce development (National Center for O*NET Development, 2016).

Methodology
The initial phase of analysis involved the identification of 71 Standard Occupation Classification (SOC) codes that were attributable to the manufacturing sector in Indiana. Once the codes were identified probabilities of computerization were assigned to 49 occupations using the results of the Frey and Osborne (2013) study. For the other occupations that had no ascribed probability, they were excluded and the remaining 49 occupations were updated to reflect the number of workers in the state. The remaining occupations accounted for 52% of all manufacturing employees in the state (Bureau of Labor Statistics, 2016). Sorted based on probability of computerization two groups of occupations were created based on the lowest and highest probabilities for automation and then analyzed to determine skill-sets more prone to computerization. The first group is comprised of occupations with probabilities of computerization of 52 percent or less. These occupations seemed to be resistant, according to Frey and Osborne (2013), to computerization and therefore more insight into their nature was sought. Occupations in the second category were more prone to computerization and had probabilities that ranged from 97 percent to 99 percent. Once the two groups were created their non-susceptible inputs were assessed based on the importance of the skill-set to job. Susceptibility referred to the presence of factors related to worker and job-oriented characteristics that were more prone to be automated in the future, while non-susceptibility was the opposite. A count of all similar and dissimilar skill-sets, ranked in importance above 50%, amongst the nine occupations were then analyzed to determine any significant differences.

Broad categories were created for the susceptible and non-susceptible jobs identified. For jobs that were identified as being susceptible six main categories were created. These categories are:

(1) reading and comprehension - this category was based on the domains of worker characteristics and worker requirements,
(2) monitoring - this category was solely based on the domain of worker characteristics,
(3) operation monitoring, control and quality analysis - this category was solely based on occupational requirements,
(4) active listening and service orientation - this category was based on the domains of worker characteristics and worker requirements,
(5) speaking - this category was based on worker characteristics,
(6) critical thinking, coordination judgment decision making, time management, equipment maintenance and troubleshooting - this overarching category was based on worker characteristics and worker requirements.

The susceptible categories were solely based on characteristics that were specific to the worker and interrelated occupational functions, as these occupations considered these characteristics to be off moderate to high importance. For jobs that were identified as being non-susceptible eight main categories were created. These categories encompassed the entire O*NET content model. Worker, interrelated occupational, job and occupation specific characteristics for all utilized to describe these occupations. The categories are:

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(1) reading comprehension, English language and writing - this category was based on the domains worker characteristics and worker requirements,
(2) monitoring - this category was based on the domains worker characteristics,
(3) operation monitoring, control, quality analysis, production and processing, operational analysis and systems evaluation - this category was based on the domains occupational and worker requirements,
(4) active listening, service orientation, perceptiveness, persuasion and negotiation - this category was based on the domains worker characteristics, worker requirements and experience requirements,
(5) speaking and instructing - this category was based on the domains worker characteristics, worker requirements and occupational requirements
(6) critical thinking, coordination, judgment decision making, time management, equipment maintenance, troubleshooting, complex problem-solving - this category was based on the domains worker characteristics, worker requirements, occupational requirements and experience requirements,
(7) design and mechanical - this category was based on the domains worker characteristics, occupation specific information, worker requirements and occupational requirements,
(8) Mathematics - this category was based on the domain worker characteristic (National Center for O*NET Development, 2016).

To present the data obtained from this categorization a radar/cobweb chart was created to display the multivariate nature of these categories per occupation. A complete explanation of these ten occupations are then explored in the discussion section. This is done to offer more details on the relevance or insignificance of these occupations.

Results

In the initial phase of this study the number of workers that would be affected by computerization and their associated probabilities according to the Frey and Osborne (2013) model are presented in figure 2. In 2016, there were 522,000 manufacturing jobs in the state. The data gathered was based on a sample that looked at 269,386 jobs in the state that were associated with the probabilities of the Frey and Osborne (2013) model. Of this sample, 1% of the occupations were rated as being least likely to be automated (probabilities below .52) while the rest (99% of the sample) were rated as being most likely to be automated (probabilities above .61). The top five occupational categories having probabilities above .62, accounted for 13% of the current jobs in the sample. Overall, predicted job losses, from automation, in the state would account for 35% (or 93,541) of all the jobs in the sample. The three occupations that are predicted to have the most job loss are 1) Inspectors, Testers, Sorters, Samplers and Weighers, 2) Machinist, and 3) Packaging and filling machine operators and tenders. These jobs combined are predicted to lose 41,018 employees, of 2016 manufacturing employment numbers.

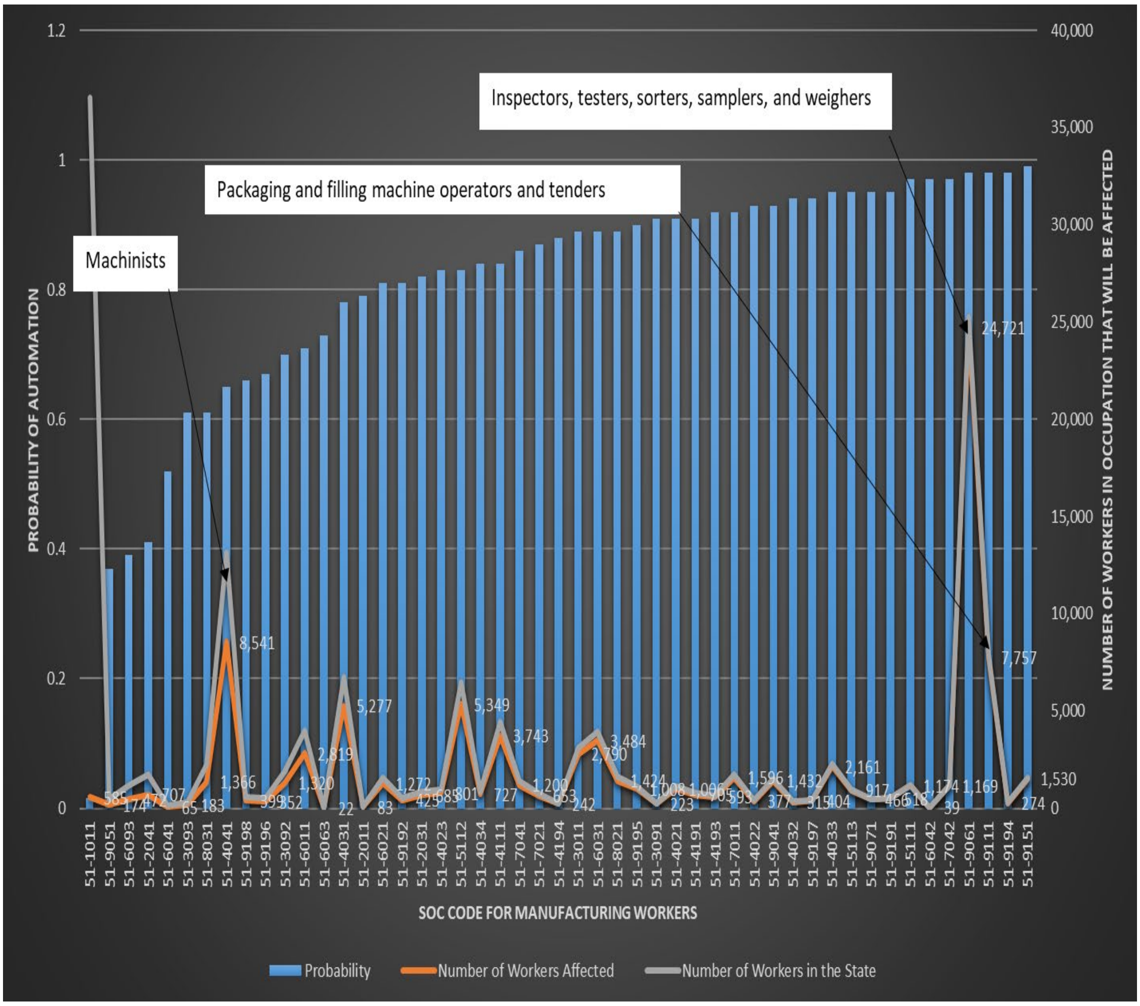

Figure 2. Number of workers affected by computerization and their probabilities

The secondary part of this study resulted in a comparison of the top four jobs least likely to be automated occupation and the lower five occupations most likely to be automated. In this phase, we identify all the skill-sets with an importance of 50% or more in each of the occupations selected. The lower five occupations that were most likely to be automated are (See figure 3):

(1) Photographic Process workers – had a probability of .99
(2) Etchers and Engravers – had a probability of .98
(3) Inspectors – had a probability of .98
(4) Machine Operators – had a probability of .98
(5) Woodworking machine operators – had a probability of .97

To report the most dominant skill-sets needed by these occupations, a radar chart was chosen. The chart depicts six skill-sets all of which have an importance of 50% and above. If the occupation did not have a 50% importance rating on a particular skill, it was not reported. The highest dominant skill-set reported had an importance of 66%, monitoring of equipment, and this was reported by the Woodworking Machine Operator occupation. Three occupations reported dominant skill-set importance in all six categories collated. These occupations were that of Etchers and Engravers, Inspectors, and Photographic Process Workers. Machine operators had the lowest number of important dominant skill-sets necessary to undertake the occupation, as only three were ranked above 50%.

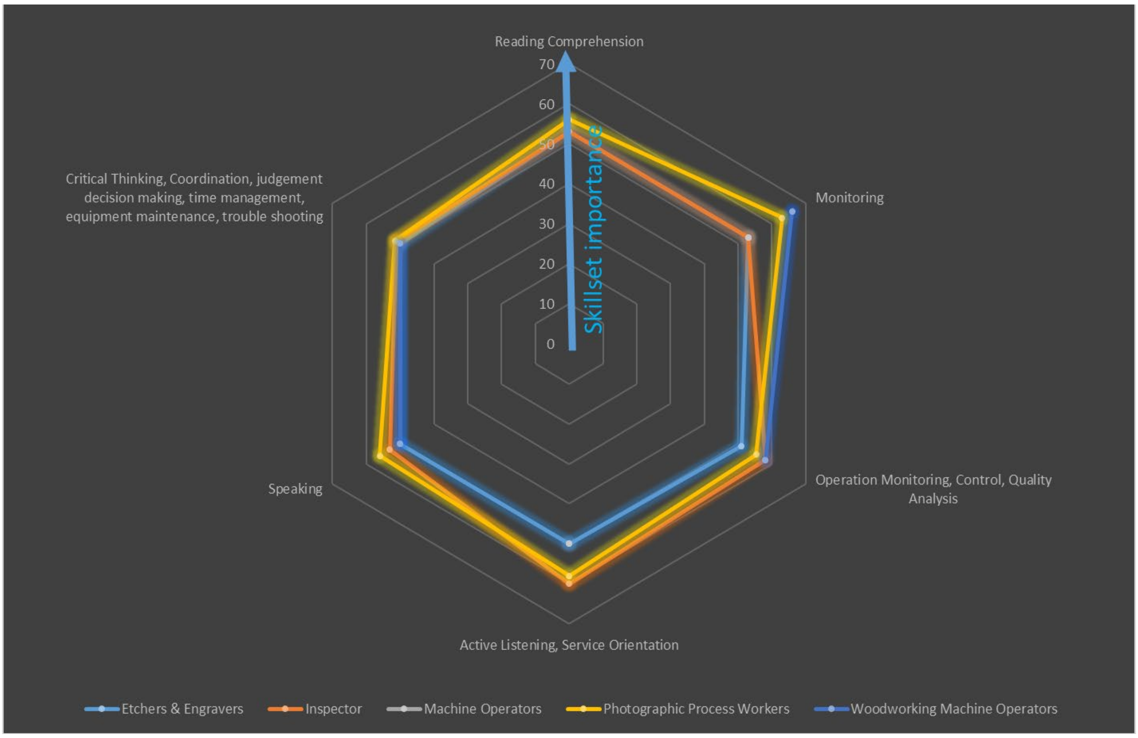

Figure 3. Susceptible occupations and their most dominant skills

The top four occupations that were least likely to be automated were comprised of eight categories representing the dominant skill-sets of that occupation. These occupations are reported in a radar chart (See figure 4) and once again, dominant skill-sets with an importance of over 50% were reported. These occupations are:

(1) Metal Fabricators - had a probability of automation of .41
(2) Upholsterers - had a probability of automation of .39
(3) Furnace Operators – had a probability of automation of .37
(4) First line Supervisors - had a probability of automation of .016

The chart depicts eight skill-sets all of which have an importance of 50% and above. If the occupation did not have a 50% importance rating on a particular skill then it was not reported. The highest dominant skill-set reported had an importance of 68%. Two dominant skill-sets had an importance of 68% and they were: 1) Design and Mechanical and 2) Mathematics. This was reported by the Metal Fabricator occupation. No occupation reported dominant skill-set importance in all eight categories collated. Furnace Operators and First line Supervisors reported six important dominant skill-sets, the most need for an occupation in this group. Upholsterers had the lowest number of important dominant skill-sets necessary to undertake the occupation, as only two were ranked above 50%.

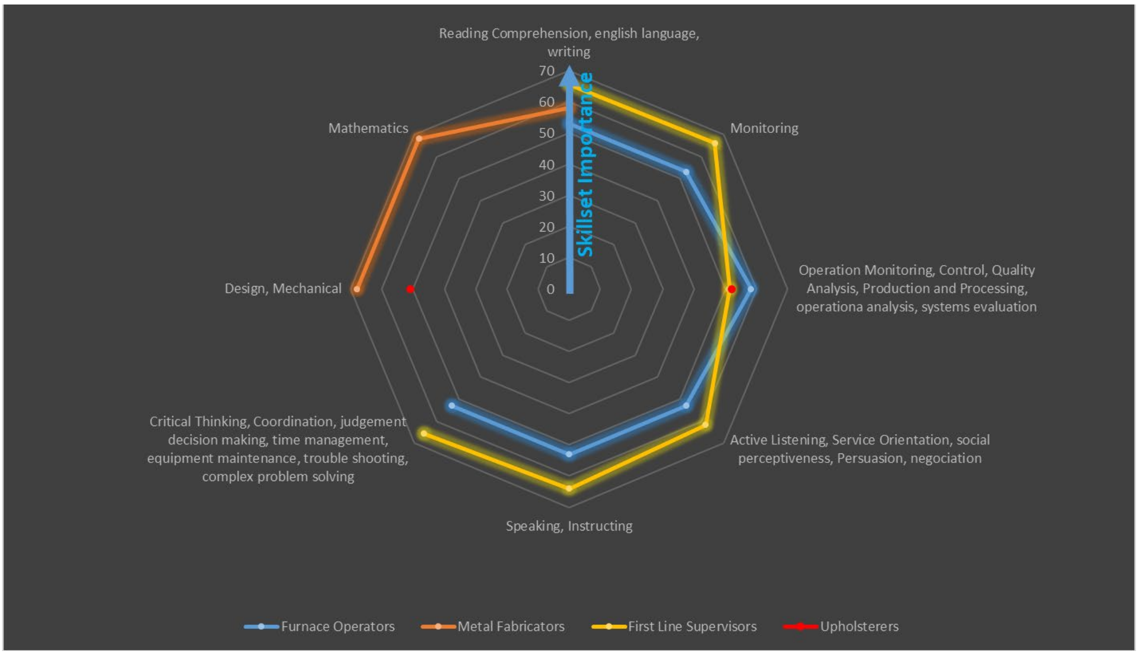

Figure 4. Non-susceptible occupations and their most dominant skills.

Discussion

There are a number of factors external to the Cobb-Douglas production function, used by Frey and Osborne (2013, 2017), that will impact the certainty of occupations future. There is now a clear need to understand skill-sets that will be viable in the future, see Autor (2013), Diamond and Şahin (2015), Houseman, Bartik, and Sturgeon (2014), and Sasser-Modestino, Shoag, and Ballance (2019). Of the nine occupations studied in detail in this paper, the susceptible ones had just the basic requirement of skill-sets that were needed in order to undertake. Basic requirements meant that all these occupations could be broken up by tasks that could be individually analyzed and automated. For example, all occupations, in the susceptible category, ranked monitoring and a highly prized skill. Monitoring involved reviewing information from materials events or environment to detect or assess problems. This skill-set also meant that the task of obtaining the information had to be undertaken by the worker.

Another highly prized skill in the susceptible category had to do with decision management at the local level. This all-encompassing skill-set required: 1) critical thinking, 2) coordination, 3) judgment decision making, 4) time management, 5) equipment maintenance and 6) troubleshooting. Its focus at the local level meant that workers in these occupations are self-driven it pertains to the task they have to undertake. If issues arose surrounding the performance of that specific task then they would be required to find creative solutions to mitigate potential problems. The other skill-sets identified amongst most susceptible occupations is that of operation monitoring, control and quality analysis. The only occupation not rating this skill-set as being important, in the susceptible occupation category, was that of machine operators. Control dealt with the physical activities that were necessary to create machinery or processes that were dearth of automated or mechanical devices. The operation monitoring skill-set meant that the most important thing one had to undertake for this occupation was the watching of gauges, dials and other indicators ensuring proper machine function. Proper machinery function is the skill-set that most modern machines are able to undertake themselves at the beginning of an operation. These machines typically engage in preventative maintenance activities that center on calibration, current machine capability determination (this could be based on tooling or hours of operation for example) and the notification of maintenance teams when the issues are beyond their control. Quality control is another facet of this category and it only required a knowledge of the process such that deviations can be detected in a timely manner.

Being an active listener and having the disposition to offer service to others was also ranked by four occupations as the important skill sets. Only woodworking machine operators did not have this particular skill-set. The active listening skill-set required basic understandings of what was expected during the undertaking of the task with provision for further clarity via questioning. Complementing active listening was service orientation, which meant that the worker was actively looking for ways to help people. Speaking was another category and skill-set that was required by only four occupations. Machine operators did not rank speaking as being a dominant skill in their occupation. For this particular skill set, the ability to communicate information and ideas to others so that they can understand what is important. This form of communication relates to objectives that may or may not be attainable given the limited operating parameters of production equipment.

Four occupations were identified as being non-susceptible and the skill-sets identified, as being important, represented and expansion of tasks and authority in their undertaking when compared to their susceptible counterparts. An expansion in task and authority within these occupations made the possibility of automation a daunting one. Three occupations, Metal Fabricators, Furnace Operators and First-line Supervisors expanded the basic categories of the occupations that were susceptible. Reading comprehension as a category was extended to include English language and writing. This meant that these employees are now responsible for direct two-way communication between managers and themselves about the operations and task they were in charge of or undertaking. In an effort to improve historical operational data tracking, these workers were also responsible for being able to describe in written form their interpretations of the process. The second category identified as being important by these two occupations was monitoring. This particular skill-set did not have any notable expansion in its tasks or authority when compared to its counterpart in the susceptible skills category. This might be because the worker still has to play some role in monitoring the operations and machinery they are in charge off.

The third skill-set category that was ranked important was done so by all the occupations in the non-susceptible category. Furnace operators, First-line Supervisors, Metal Fabricators and Upholsterers all saw an expansion of the skill-set operation monitoring, control and quality analysis. This skill-set category was expanded to include production and processing, operations analysis and systems evaluation. The expansion of this skill-set category meant that workers were in charge of identifying and creating measures of operational performance. In addition, they would now be in a position to lay the framework for new designs in product development due to their knowledge surrounding effective manufacture and distribution of goods. This particular skill-set has the potential in manufacturing to remove barriers associated with the silo mentality attributable to new product design.

In the fourth skill-set identified, an expansion of the skill-set category active listening and service orientation was noted. Perceptiveness, persuasion and negotiation were added as necessary skill-sets for these occupations. This expanded skill-set seems to be mainly responsible for the expanded role that teams will play in future product development and manufacture. Teamwork requires that members of the team are able to share their viewpoints and accept opposing viewpoints in the formulation of a solution. The fifth skill-set identified was that the speaking and it was expanded to include instructing. This skill-set meant that workers should be able to teach others about activities they carry out on a daily basis. Only two of the non-susceptible occupations, Furnace Operators and First-line Supervisors rated these two particular skill-sets as being important.

An expansion in the sixth skill-set, identified initially in the susceptible occupations, took place with the addition of complex problem solving. The initial skill-set category was comprised of critical thinking, coordination, judgment, decision-making, time management, equipment maintenance and troubleshooting. The addition of complex problem solving to this skill-set category means that these workers are now able to solve novel, ill-defined problems in real-world settings. Due to the expansion of authority afforded in the creation of measures and the design of new products complex problem-solving techniques are therefore crucial. The only occupations requiring this new and enhanced skill-set were Furnace Operators and First-line Supervisors.

The seventh and eighth skill-set categories only pertained to half of the occupations that were non-susceptible. The seven category was design and mechanical and this particular skill-set was needed by the occupations Metal Fabricators and Upholsterers. For this particular skill-set, these occupations required that workers have a knowledge of design techniques tools and principles necessary for the creation of precision technical plans, blueprints, drawings and models. In addition, a thorough understanding of tools and machinery, which includes use design maintenance and repair, is another aspect of this skill-set. Metal Fabricators was the only occupation requiring the eighth skill-set, mathematics. Specifically, this skill-set focused on the application of arithmetic, geometry, algebra, calculus and statistics in product design and manufacture.

Conclusion

The findings of this paper highlighted the need for more empirical studies to prove or disprove the Cobb-Douglas production function, used by Frey and Osborne (2013, 2017). An empirical study would be helpful in determining the true nature of the demand for non-susceptible skill-sets. As for the loss of jobs that require susceptible skill-sets, there is some evidence that points to increased employment in these occupations in addition to increases in robotic/computing systems usage (See Acemoglu and Restrepo (2017) and McLeod (2019)). Whether or not these trends are just short-term needs further examination as interest rates typically set by the Federal Reserve have more of an impact on manufacturing employment than other factors (McLeod, 2019). Furthermore, the seven occupations identified in the study, need to be tracked over a long-term period to determine changes in their employment over time. This study serves as a starting point for academicians in their pursuit of new course and program development. As robotic systems integrate themselves into everyday work-life, more needs to be understood about their effects.

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