THE WORKFORCE IMPLICATIONS OF INDUSTRY 4.0: MANUFACTURING

WORKFORCE STRATEGIES TO ENABLE ENTERPRISE TRANSFORMATION

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Abstract

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Under the Supervision of Prof. Wendy Brook

Statement of the Problem

This paper discusses the transformative challenges that the prevalence of the Industrial Internet of Things (IIoT) and advanced manufacturing, also known as, Industry 4.0 presents to domestic manufactures in terms of workforce management, skills, and talent effectiveness.

Methods and Procedures

A review of current academic and industry research is utilized to construct an overview of the disruptive industrial technologies that hallmark Industry 4.0 and their impacts on the manufacturing landscape, as well the intersecting demographic challenges faced by domestic manufacturers, is provided.

Summary of Conclusions

Research indicates that strategies that encourage manufacturers to engage in public-private partnerships, the development of standard skills certifications, and the development of advanced manufacturing career pathways are best suited to increase the technical fluency of the workforce while serving to reskill the aging incumbent manufacturing force.

The Workforce Implications of Industry 4.0: Manufacturing Workforce Strategies to Enable Enterprise Transformation

Changes in operational and industrial technologies are reshaping the manner in which manufacturers produce goods in all industries. These changes, referred to as Industry 4.0, are hallmarked by the employment of big data, advanced analytics, human-machine interfaces, and the digital to physical transformation process in manufacturing (Bauer & Wee, 2015). For manufacturers, Industry 4.0 presents productive opportunities by ushering in new operational technologies and allowing for enhanced implementation of transformative LEAN cultures (Sanders, Elangeswaran, & Wulfsberg, 2016).

Manufacturers must adapt to rapidly changing markets in order to remain competitive and capture market share as Industry 4.0 is projected to add $2.2 trillion to domestic GDP by 2025 (Manyika, Ramaswamy, Khanna, Sarrazin, Pinkus, & Sethupathy, 2015). This growth is brought to industry through increases in labor productivity, capital efficiency, and operational process and resource management productivity; with nearly one-third of growth resulting from increases in labor productivity (Manyika et al., 2015).

However, in order for the manufacturing industry to capitalize on capital and labor productivity opportunities, a corresponding transformation within the workforce is required to ensure that the emerging skills needs are met. In response, manufacturers will need to employ updated training and workforce development strategies to match evolving industry trends (Longo, Nicoletti, Padovano, 2017).

In addition to enabling manufacturing productivity, Industry 4.0 has enabled manufacturers to digitize information across their enterprise. However, despite prevailing industrial trends towards leveraging big data, advanced analytics, human-machine interfaces, and digital transformation to drive manufacturing productivity and product quality, only forty-eight percent of the top 300 manufacturers surveyed by McKinsey & Company, a leading industrial research firm, stated that they were prepared for advances in industry 4.0 trends (Bauer & Wee, 2015). The risk to manufacturers that this lack of preparedness presents in terms of lost value is significant. It is projected that by the year 2025, the estimated maximum value of the operational transformation brought by industry 4.0 in the form of the industrial internet of things (IoT) to the global manufacturing industry is $3.7T dollars per year, representing the largest share of value to be generated by increasing economic digitization (Manyika et. al., 2015).

As manufacturing organizations position themselves to transform the roles, technologies, and expectations of their workforce to remain competitive, the increasingly dynamic and fast-paced nature of an internet of things enabled industrial environment will challenge the current workforce to adapt in real-time to complex situations, placing emphasis on cultivating new skills and abilities in the labor market. Emerging emphasis on evolving cognitive, analytical, and social skills in the labor market will require organizations to shift traditional skills emphasis to match the demands of future industry (Eberhard, B. et. al, 2017).

For domestic manufacturers, shifting US demographics and workforce trends form another headwind into fully operationalizing the benefits of Industry 4.0. Recently, a lack of skilled workers are preventing manufacturers from capitalizing on these trends, with twenty-seven percent of manufacturers not able to expand their production as a result of lacking a properly skilled workforce (McLeman, 2014). This challenge is further exasperated by a declining, experienced baby-boomer workforce, with an estimated 10,000 boomers crossing the age 65 threshold to retirement each day through 2029 (Passel & Cohn, 2008). Thus, unfavorable labor market conditions paired with an evolving skills need will challenge manufacturers as they face adoption of industry 4.0.

The primary purpose of this paper is to investigate the current body of research regarding Industry 4.0 and workforce strategies in manufacturing. The existing body of research, although extensive across the breadth of manufacturing implications in both descriptive and predictive transformational strategies, does not adequately prescribe comprehensive workforce strategies that enable organizations to adapt to the required skills shift. Therefore, this paper will leverage research into leading current technological trends in manufacturing, process and organizational transformation, and workforce training to construct a holistic view of the current skills landscape in terms of demanded skills and current availability.

Furthermore, this paper will leverage the existing body of research to provide original recommendations that manufacturing organizations can leverage to adequately develop their workforce to meet the skills demands of industry 4.0. Utilizing academic research and industrial case studies, an aggregate description of current organizational strategies and best practices will be constructed to bridge the gap between current research and applications to workforce management strategies.

The primary methodology for this seminar paper will consist of a review of relevant statistics related to technological adaptations in industry and workforce development and a secondary review of the current body of published research. Statistics regarding workforce skills, demographic trends, and labor statistics will be obtained through private industry research groups, the Department of Workforce Development, and the Bureau of Labor Statistics. Supporting research of peer reviewed scholarly articles, industry case studies conducted by industry accreditation institutes, and credible literature published by industry leaders, theorists, and scholars will be leveraged to illustrate and support the findings of this paper.

Secondary review of research obtained from credible industry sources and scholarly journals will be analyzed and reviewed to illustrate the current landscape of manufacturing skills requirements and utilized to create an aggregate summary of effective manufacturing workforce development strategies to meet the needs of the illustrated skills gap. Focus will be applied on analyzing industry practices and organizational strategy to depict a scholarly methodology for understanding and deploying workforce strategy within the context of industry 4.0.

Literature Review

Understanding Industry 4.0

According to research conducted by McKinsey and Company (Baur & Wee, 2015), Industry 4.0 represents the increasing digitization of the manufacturing industry driven by four major technological disruptions; (1) a rapid increase in the connectivity, volume, and computational power of manufacturing technology, (2) developments in data analytics and business intelligence, (3) new and emerging technologies for human-machine integration, and (4) improvements in transitioning digital content and instructions to the physical manufacturing space. These disruptions are represented in prevailing manufacturing trends; the emergence of big data, advanced analytics, human machine interfaces, and digital to physical transfers. Research shows that these disruptions will impact all aspects of supply chains, including what equipment is used in manufacturing and how operators interact with the manufacturing space. The study conducted by Baur & Wee (2015) surveyed 300 leading manufacturing organizations, and less than half (48%) of respondents reported that their organization was prepared for the disruptions brought by Industry 4.0. Behind this hesitation is the perceived investment needed to prepare and update manufacturing models. The retooling and replacement of equipment represents a significant capital investment by organizations, as executives surveyed by Baur and Wee (2015) estimated that 40 to 50 percent of today's industrial equipment will need to be upgraded or replaced to allow for Industry 4.0 transformation.

The empirical research conducted by Baur and Wee (2015) provides a high-level overview of Industry 4.0 according to first-hand accounts from manufacturing leadership, creating a visionary level understanding of the industrial landscape of Industrial 4.0. This research adds a valuable framework to understanding the emerging trends of Industry 4.0, but does not adequately discuss the impacts to the workforce at the task level. As illustrated by Baur and Wee (2015), the transition of manufacturing platforms will require the retraining and retooling of the workforce; however, in order to understand the impact of the disruptions illustrated by McKinsey on the current industrial workforce, an academic survey of technologies impacting the operators needs to be discussed.

In order to understand the challenge that Industry 4.0 presents to operators within manufacturing organizations, an academic description of the technological and informational hallmarks of the movement is needed. Vaidya, Ambad, and Bhosle (2018) surveyed the current body of academic research to illustrate the disruptive trends and emerging technologies brought on by the fourth industrial revolution, known as Industry 4.0. The first industrial revolution of 1784 brought the employment of water and steam power to assist in the production of goods and services, which was expanded upon in the second industrial revolution through the inclusion of electrical power to create an environment for mass production in 1870 (Vaidya et al., 2018). The third industrial revolution brought the deployment of programmable logic and information technology (IT) systems to automate production processes. According to the authors, Industry 4.0 has emerged as a movement to transition traditional manual and automated manufacturing machines of the third industrial revolution to smart machines, which are self-aware and self-learning, in order to optimize the overall production of goods (Vaidya et al., 2018). Furthermore, an evolution of the factory floor from analog data systems and unconnected technologies to production platforms consisting of smart machines that are networked together to create smart factories has been brought upon by Industry 4.0 to create more intelligent systems of manufacturing (Vaidya et al., 2018). This creates an environment wherein data can easily be generated, shared, and analyzed to control and optimize production processes.

The rapid development of technologies and information infrastructure has enabled Industry 4.0 to redefine how goods and services are produced. According to the study, this data rich, connected, and intelligent manufacturing environment is the product of four enabling forces; (1) the Internet of Things (IoT), the increasing connectivity of everyday technologies, (2) the Industrial Internet of Things (IIoT), the emerging connectivity of industrial machines and equipment, (3) the rise of cloud-based manufacturing systems, and (4) the emergence of smart manufacturing (Vaidya et al., 2018). These four drivers have enabled the transition to an intelligent manufacturing system and the has led to the digitization of process and services.

Utilizing a survey of academic research, Vaidya et al. (2018) illustrate a taxonomy of the technological pillars of Industry 4.0. The *Industrial Internet of Things (IIoT)* represents the group of technologies in manufacturing that allow the connectivity of machines with embedded communication and information technologies to seamless interface with each other as manufacturing systems, as well as with human operators (Vaidya et al., 2018). Typical applications of IIoT in manufacturing consist of smart sensors, intelligent machines, integrated physical technologies, and human interface devices. *Cyber Physical Systems (CPS)* represents groupings of systems that integrate human and physical manufacturing systems with computerized control and communications systems (Vaidya et al., 2018). CPS allows for the optimization of the physical manufacturing space through better information, controls, and requirements planning through digital operating systems. *Big data* and *analytics* represent the movement towards the generation, collection, and analysis of real-time data to increase the efficiency of decision making (Vaidya et al., 2018). The presence and understanding of this large body of data will allow organizations to conduct *simulations* to mirror the physical manufacturing environment in cyberspace and run scenarios to find optimal operating conditions. *Cloud* based manufacturing creates the framework for sharing data across manufacturing enterprises in Industry 4.0, allowing for the dissemination of relevant data from all aspects of the enterprise to operators and creating a comprehensive view of the value chain (Vaidya et al., 2018). Furthermore, Vaidya et al. (2018) outline the *systems integration* present in Industry 4.0 through the horizontal integration of the value chain, the vertical integration and networking of manufacturing systems, and the end-to-end integration across the entire product life cycle (Vaidya et al., 2018). This integration will leverage emerging industrial technologies, such as *autonomous robotics* to carry out tasks within a collaborative manner with both humans and other robotic devices. *Augmented reality* (AR) will allow organizations to bring relevant information to human operators in real-time in response to changing conditions and tasks, allowing worker to be more productive and assist in decision making (Vaidya et al., 2018). Lastly, Industry 4.0 will be hallmarked by the employment of *additive manufacturing technologies* that allow for smaller batches of highly customized products through the deployment of high-performance, decentralized manufacturing systems as opposed to traditional batch manufacturing (Vaidya et al., 2018).

The research conducted by Vaidya et al. (2018) contributes to the current body of research through the identification of nine-pillars of Industry 4.0 technologies. However, the rapid nature of technological advancements within the Industry 4.0 landscape requires ongoing research into emerging technologies. However, the framework created serves as a basis for understanding the technological environment that today's workforce must be prepared for.

Impact of Industry 4.0 on the manufacturing floor.

The impact of technological change brought on by Industry 4.0 onto operators in manufacturing is illustrated through the applications of these technologies in the production environment. In order to broaden the current academic understanding of Industry 4.0, Zhong, Xu, Klotz, and Newman (2017) conducted an academic review of applications of Industry 4.0 technologies to understand and catalogue the benefits and challenges presented to the manufacturing workforce. According to the research conducted by Zhong et al. (2017), three distinct manufacturing systems exist in Industry 4.0, each characterized with distinct challenges and opportunities. The first system is intelligent manufacturing systems (IMS), also known as smart manufacturing. In this system of manufacturing, the process of producing goods and services is optimized through the employment of advanced manufacturing technologies and information systems, resulting in increased production efficiency, greater product quality, increased service levels, and greater manufacturing competitiveness (Zhong et al., 2017). The second manufacturing environment is viewed as IoT enabled manufacturing, relying on the employment of smart manufacturing objects (SMOs) to connect production and production control through smart sensors, digital interface devices, radio frequency identification (RFID) tracking, and advanced IT infrastructure (Zhong et al., 2017). According to Zhong et al. (2017), the third major manufacturing system present in Industry 4.0 is cloud manufacturing. Cloud manufacturing builds on IoT enabled manufacturing by allowing for the digitization of manufacturing resources into services that can be stored and shared through cloud computing, representing networked manufacturing systems wherein production resources can be intelligently managed (Zhong et al., 2017). The significance of the description of the three distinct manufacturing environments is that it allows further research to contextualize the experience of operators in Industry 4.0 within established manufacturing platforms.

With the three major manufacturing systems of Industry 4.0 outlined, Zhong et al. (2017) surveyed the current body of research to produce a catalogue of key techniques deployed in Industry 4.0. According to Zhong et al. (2017), *IoT* is a primary lever in the implementation of Industry 4.0, as it allows for the interconnectivity and integration of an array of manufacturing sensors, actuators, controllers, and other devices to exchange data to optimize production on the manufacturing floor. Relevant examples of the employment of IoT in manufacturing include the control and automation of HVAC systems, autonomous assembly robotics, precision-controlled machining, and remote production monitoring through RFID; while advances in IoT are allowing for machine learning and advances in artificial intelligence (AI) (Zhong et al., 2017). The employment of IoT technologies occurs on the framework provided by a *CPS.* CPS allows for the integration of cyber and physical spaces in manufacturing, represented by the employment of sensing technologies integrated through communications systems to enable autonomous technology on the shop floor (Zhong et al., 2017). The digitization provided by a CPS creates agility and flexibility within the value chain, bringing speed and efficiency to the product lifecycle. CPS is deployed in a wide range of industries and applications; an example from manufacturing include integration of production lines across multiple sites providing real-time data to manufacturing and design engineering teams. According to Zhong et al. (2017), *cloud computing* applications in manufacturing allow for scalable resources to be deployed over the internet to stakeholders across the enterprise. This means that data on the shop floor will be available on-demand, with broad access to allow for resource pooling, and producing timely reaction to changes in operational demands (Zhong et al., 2017). The increase in the presence of IoT and CPS in manufacturing results in large increases in the amount of data being generated by industry and the rise of *big data analytics*. The impact of big data analytics on the shop floor is seen through the application of real-time data analysis at the production line, allowing operators to quickly make decisions and optimize processes, conduct analysis of process failures and quality defects, and optimize maintenance to minimize operating costs (Zhong et al., 2017). The last technique discussed by Zhong et al. (2017) is the deployment of information and communications technology (ICT) within Industry 4.0. ICT allows information within smart factories to be shared seamlessly between machines and with operators. While ICT can be viewed as an extension of advancements in computing and broader IT technologies, the applications of ICT in production appear to be more niched in a data rich environment, increasing the technological fluency requirements of operators on the manufacturing floor.

Although the research by Zhong et al. (2017) largely concurs with the current body of research and the taxonomy of Industry 4.0 technology published by Vaidya et al. (2018), the manufacturing systems framework proposed adds value to the academic body of knowledge, while the survey of technological applications gives new insight into the challenges faced by operators in an ever-changing production environment. Additional research should further explore the discreet manufacturing systems proposed.

Wherein literature regards the Industry 4.0 transition of shop floor technologies from analog to SMOs as a means to increase industrial productivity, manufacturing leadership concerns traditional LEAN manufacturing system adoption as a key element of shop floor process transformation (Sanders, Elangeswaran, & Wulfsberg, 2016). Because Industry 4.0 is concerned with the optimization of the value chain, the aims of LEAN production and the prevailing trends of Industry 4.0 intersect with the purpose or waste elimination. Research indicates that Industry 4.0 technologies largely enable the adoption of LEAN manufacturing, creating an alignment of skills and technology requirements desired in the manufacturing workforce. Sanders et al. (2016) surveyed the current body of Industry 4.0 and LEAN research and found that technological advances resulting from Industry 4.0 adoption presented positive techniques for overcoming traditional barriers to LEAN shop floor transformation. The integration of Industry 4.0 and LEAN manufacturing systems across the ten dimensions of LEAN manufacturing was shown to offer transformative solutions on the shop floor. These solutions leverage IoT, SMOs, and the presence of CPS to optimize the production environment, as illustrated in table 1.

Table 1

Dimension of LEAN Manufacturing	Supporting Industry 4.0 Technology
Supplier Feedback	Advanced ICT, big data, CPS
Just-In-Time Material Delivery	RFID, IoT, IIoT, simulation technology
Supplier Development	CPS, advanced ICT
Customer Involvement	IoT, IIoT, big data analysis, SMOs

Pull Production	RFID, IIoT, AR
Continuous Flow	Automation, IIoT, AR, big data analysis, SMOs
Setup Time Reduction	Machine learning, IIoT, big data analysis
Total Preventive Maintenance	AI, machine learning, AR, simulation
Statistical Process Control	CPS, advanced ICT, RFID
Employee Involvement	IoT, AR, CPS

Source: adapted from Sanders et. al (2016)

While the research conducted by Sanders et. al (2016) illustrates a positive correlation between the functionality of Industry 4.0 technologies and LEAN manufacturing principles, the research was theoretical in nature and a comprehensive study through a survey of current manufacturing firms employing both Industry 4.0 technologies in a LEAN manufacturing environment is needed to validate the findings. Furthermore, the opportunities that rapidly evolving industrial technology presents manufacturers should be evaluated for additional value creation through continuous improvement upon initial LEAN implementations.

The creation of value across the supply chain through the adoption of Industry 4.0 is a key benefit of technological innovation in all industries. Roblek, Mesko, and Krapez (2016) studied the influence of Industry 4.0 on the creation of value and its impact on complete value chains. For manufacturing, the study indicated three leading characteristics of the manufacturing industry that will impact the current workforce. First, the study concurs with the widely published assertion that Industry 4.0 will result in the digitization of production, with specific optimization of manufacturing information systems and production planning (Roblek et al., 2016). This transition will be accelerated by rapid advances in AI, big data, and connectivity within manufacturing sites. Secondly, automation will not only change the manner in which product is built, but automated data collection will become more integrated with the deployment of SMOs and CPS (Roblek et al., 2016). Lastly, advances in ICT and network performance will allow for the seamless interchange of data between manufacturing sites and suppliers, which will connect operators to the entire supply chain in real time creating entirely new value chains (Roblek et al., 2016). New value will be created through gained efficiency, new business models, and increased responsiveness to changes in customer demands. Roblek et al. (2016) assert that workers relieved of manual and tedious responsibilities we be increasingly leveraged to develop new products and solutions, which are pursuits that require more abstract thinking than what can be digitized.

With the role of operators in manufacturing transitioning from the routine and repetitive to more thoughtful exercises in product development and process design, the role of knowledge management (KM) will become increasingly important for firms to remain competitive. Because advances in CPS and ICT will allow for more seamless sharing of data and knowledge across the enterprise, managing proprietary data and operator knowledge will become increasingly automated (Roblek et al., 2016). In reviewing the advances in data generation brought on by IoT, Roblek et al. (2016) discuss the transition required from classical KM processes to IoT enabled KM processes. As Industry 4.0 advances, data regarding process and operator performance that had been traditionally acquired manually or from private intranets will be generated and acquired by SMOs and analyzed in the cloud. Realtime content will be made available to operators via AR interfaces, allowing for real-time collaboration between operators and manufacturing resources across the enterprise (Roblek et al., 2016). Access to data and knowledge between person and SMOs will become theoretically limitless, requiring operators to conduct real-time analysis and engage in quick decision making at the point of execution. This exchange of information across the value chain will link operators on the manufacturing floor closer to the end customer, creating a more customer orientated adoption of IoT technologies that will increase value for the organization and the customer. However, Roblek et al. (2016) advocate for additional research into how these new value chains can be openly operated across varying geographies and cultures while ensuring the integrity of KM processes. The research by Roblek et al. (2016) illustrates the opportunities that the creation of new value chains and KM systems presents to organizations adopting Industry 4.0 technologies, adding to the current body of literature. However, it also opens concern for additional research into the evolution of KM and how IoT enabled KM can assist manufactures in overcoming emerging skills gaps and knowledge loss in the workforce.

Impact of Industry 4.0 on the workforce.

Although domestic manufacturing output has grown steadily over the past 30 years, surpassing $5.4 trillion in 2016, employment in the manufacturing sector has been in decline for decades (Desilver, 2017). According to a report published by the Pew research center, manufacturing employment has declined nearly 40% since its peak in the late 1970's while the percentage of total employment manufacturing represents has fallen to 8.5% from its peak of 32.1% (Desilver, 2017). This means that American manufacturers have become more productive with a smaller portion of the workforce. According to the study, the Bureau of Labor Statistics index of labor productivity for the manufacturing industry is 2.5 times greater than it was 20 years ago (Desilver, 2017). However, despite gains in industrial productivity, 64% of manufacturing leaders surveyed during a 2015 workforce development study (Pelliccione, 2015) believe that the industry will experience a growing shortage of qualified workers in the next 3-5 years. Furthermore, the rapid advancements in manufacturing technology represented in Industry

4.0 are positioned to accelerate the growth of the workforce shortage. Thus, an academic survey of the impacts of Industry 4.0 on the workforce is needed in order to develop counter strategies for manufacturing against worker shortages.

In a study of the consequences of Industry 4.0 on global businesses and economics, Maresova, Soukal, Svobodova, Hedvicakova, Javanmardi, Selamat, and Krejcar (2018) found that the current body of research regarding the impact to the workforce and workforce development strategies is well documented in terms of impact to current business models and economies. The authors expect that Industry 4.0 will create new business models, which will change entire value chains, including the manner in which goods are produced (Maresova et al., 2018). Increases in the adoption of automation technology and integration of SMOs into the manufacturing environment will displace lower skilled workers. According to Maresova et al (2018), Industry 4.0 will require workers that are engaged in repetitive and routine tasks to adopt new skills and engage in continued learning, as easily replicated tasks will be automated. This implies the development of new market strategies for developing the manufacturing talent and skills needed to remain competitive in an increasingly dynamic economy. Unfortunately, a review of the current Industry 4.0 research shows that many higher educational institutions are lacking effective curriculum to prepare students for the technology and processes they will be exposed to in future manufacturing (Maresova et al., 2018). To this point, consideration is given to the development of learning factories, defined as factories in which operators are connected with digital resources and integrated within a smart factory (Maresova et al., 2018). Within a learning factory, workers are able to develop the required skills through scenario-based experiences with AR, IIot, and CPS and learn data analysis within simulated manufacturing environments. However, the research conducted by Maresova et al. (2018) illustrates a gap in training the incumbent workforce, which may be hostile to the displacement brought by Industry 4.0 and calls for further research into retooling current workers. The study depicts three likely scenarios for workforce development:

- The growing gap scenario, wherein the skills gap between unqualified and highly qualified works continues to grow and accelerate with Industry 4.0.
- The general upgrade scenario, wherein the need for highly qualified workers continues to grow to the point that all workers are required to obtain advanced training and education.
- The central link scenario, wherein the skills required increase as well as the qualifications required of the workforce (Maresova et al., 2018).

Which scenario presents itself will depend on the degree of implementation of Industry 4.0 technologies. According to Osborne and Strokosch (2013, in Maresova et al., 2018), 47% of total US employment is at risk of needing higher levels of training and qualifications in the future. Research indicates that as automation and manufacturing technology advances, skill sets related to IT, automation technology, software development, and ICT will be required, as well as experience in operating within customer relationship management (CRM) and enterprise resource planning (ERP) environments (Maresova et al., 2018).

In addressing the increasing complexity of the roles and responsibilities required of the workforce in Industry 4.0, Longo, Nicoletti, and Padovano (2017) put forth a human centered approach, which places the operators at the center of the CPS and views IoT and AR technologies as methods for supporting the complexities faced by future workforces. At the core of their study, Longo et al. (2017) advocate for the adoption of a SOPHOS-MS, Sophos meaning “wisdom” in Latin and MS standing for manufacturing system, with AR as its primary interface device with human operators. According to the study, the SOPHOS-MS system is designed to deliver operator information on safety measures relevant to the machine/operation being worked, potential hazards, the ability to start and stop SMOs, change machine modes, set-up instructions, and maintenance messages (Longo et al., 2017). Empirical experimental research shows that the adoption of a human-centered approach to training using AR reduced the learning curve for new employees by 4% percentage points and reduced set-up times by 12% (Longo et al., 2017). The experiment was designed to compare traditional learning and set-up times on a controlled fabrication machine with the learning curve and set-up times leveraging a Sophos-MS system with AR technology. The results showed a statistically significant improvement in both measures.

The original value of the experimental research conducted by Longo et al. shows that human centered approaches to learning in the workplace that leverage IoT technologies can assist in the optimization of production processes and workforce development. However, the conclusion of the study does not fully differentiate the long-term benefits of the suggested SOPHOS-MS model versus a focused application of IoT within the existing definition of CPS. Because there is ambiguity in the benefit of one approach over the other across the breadth of the product life cycle, the current CPS paradigm for contextualizing the application of IoT technologies and training should be maintained, while further research is required to validate the broader benefits of the SOPHOS-MS model.

The core concept of Longo et al.'s (2017) human centered approach to IoT is represented within the research conducted by Ruppert, Jasko, Holczinger, and Abonyi (2018) into enabling technologies for operators working within Industry 4.0, which the study labels Operator 4.0. The evolution of Operator 4.0 begins with Operator 1.0, represented by workers engaged in mechanically operated tools and manual labor, and transitions to Operator 2.0, represented by the use of computer assisted tooling and ERP systems (Ruppert, 2018). Operator 3.0 represents operators who are collaboratively working alongside robotics and smart machines utilizing computer assisted tools (Ruppert et al., 2018). Through the rapid development of wearable IoT and IIoT devices, Industry 4.0 presents an opportunity for organizations to develop more intelligent work spaces that operators can interact with digitally, enabling the development of human-cyber-physical systems (H-CPS) (Ruppert et al., 2018). The expansion of Operator 3.0 into an H-CPS environment represents the transition to Operator 4.0.

The Operator 4.0 concept is useful in framing the discussion of human centered technologies that the workforce must learn to use in order to continue to deliver manufacturing productivity during the transition to Industry 4.0. The study by Rupprt et al. (2018) reviewed industry case studies and the current body of literature to provide a catalogue of theoretical operator types, and the IoT devices that support them. The first six operator types are classified through the methods of work execution. *Analytic operators* represent the group of workers engaged in conducting real-time analysis of production data utilizing big data. *Augmented operators* are defined as workers who execute their responsibilities with the assistance of AR technologies, such as smart glass and handheld tablets (Ruppert et al., 2018). *Collaborative operators* work directly with manufacturing robotics to perform tasks that may not be suitable for human work alone due to repetition or other ergonomic risks (Ruppert et al., 2018). Workers who are assisted by personal assistant technologies, leveraging advances in AI are classified as *smarter operators,* wherein workers who are using mobile networking services to collaborate across the enterprise with other functions are referred to as *Social Operators* (Ruppert et al., 2018). In turn, operators who are immersed in virtual manufacturing environments and simulated processes within the CPS through the employment of VR technologies are referred to as *virtual operators.* The last two categories of operators classified in the study are associated with abilities that supplement the physical abilities of the operators. First, Ruppert et al. (2018) describe developments in biomechanical assistive devices being able to increase the strength of operators, reducing the risk of injury. These operators are referred to as *super strength operators.* Lastly, the study discusses *healthy operators* whose health and fatigue levels are monitored by personal fitness devices. While the concept of Operator 4.0 types is based largely on case-studies and theoretical changes in production technologies, the operator types are useful in contextualizing the types of work that workers will be required to do in Industry 4.0.

Emerging Skills Requirements

The World Economic Forum's (WEF) Future of Jobs Report (2018) depicts a rapid shift in the types of skills needed for domestic manufacturers to remain competitive in an equally rapidly changing market. Emerging skills in analytical thinking, creativity, complex problem solving, and emotional intelligence are of increasing importance for today's economy. In response, domestic companies are not only looking to Industry 4.0 for solutions but also to effective workforce development strategies to reskill the incumbent workforce. According to the WEF survey (2018), eighty-four percent of organizations are likely to automate work in response to the growing skills gap, with an equal percentage looking externally to acquire qualified staff to work with new technology. Additionally, new job roles are emerging. Growth is expected for data analysts, operations managers, supervisors, and network professionals within manufacturing (WEF, 2018). However, skills shortages in the workforce are making it increasing difficult to attract new talent as the labor market for qualified candidates becomes increasingly competitive, meaning that organizations will have to develop skills internally and invest in training. According to WEF (p.2, 2018), "in order to truly rise to the challenge of formulating a winning workforce strategy for the fourth industrial revolution, businesses will need to recognize human capital investment as an asset rather than a liability." However, in order to invest in effective workforce development strategies, manufacturers will need a more discreet understanding of not only the required skills of Industry 4.0 but also the capabilities of the workforce.

In order to understand the labor market, the driving forces behind the skills shift must be understood. Through an analysis of the current body of literature regarding Industry 4.0 trends and first-hand surveys of university professors, the research of Eberhard, Podia, Alonso, Radvica, Avotina, Peiseniece, Sendon, Lozano, and Sole-Pla (2017) concluded that disruptive trends represented by the aging workforce of industrial economies, the shift of economic activities to emerging markets, and the technological impact of Industry 4.0 will transform the labor market and skills requirements of the manufacturing workforce. According to research, equipment assemblers, operating engineers, and most production workers are at high risk of displacement (Eberhard et al, 2017). As routine and labor-intensive tasks are increasingly automated through workflow digitization and robotics, workers displaced from these duties will need to acquire value-add skills for the new economy. This removal of mechanical and routine functions from the human workforce will require that operators engage in more cognitive intensive functions, such as analysis and design work which cannot be easily replicated through machine learning and AI (Eberhard et al, 2017).

With the reduction of manual labor and jobs requiring routine functional skills, higher order cognitive functions will be highly sought after by manufacturing firms. Utilizing market and educational research, Eberhard et al. (2017) created a skills portfolio of nine highly valued and sought-after skills for Industry 4.0 as a recommendation for both organizations and educational institutions to use as framework for workforce development strategies. Of primary importance to future workforce development strategies is the development intellectual and social skills, which will allow workers to collaborate with an increasingly diverse group of cohorts and quickly interpret information presented through human-machine interfaces. Technical skills and the ability to think systemically is also of increasing importance as the workplace becomes increasingly complex and interconnected (Eberhard et al., 2017). These skills are illustrated in Table 1 and create a framework for understanding the general characteristics of a qualified workforce in order to compete in the Industry 4.0 environment.

Table 1: Industry 4.0 skills portfolio

Rank	Skill	Example
1	Social skills	Negotiations, emotional intelligence, collaboration
2	Cognitive skills	Data analysis, abstract thinking
3	Personal/mental abilities	Decision making under pressure, persistence
4	Process skills	Critical thinking and deductive reasoning
5	System skills	Integrated decision making, entrepreneurial skills
6	Technical skills	Programming and adapting to new technologies
7	Content skills	Understanding ICT, active learning
8	Intercultural skills	Working across cultures and geographies
9	Resource management skills	Managing time and resources efficiently

Adapted from Eberhrad et al. 2017

Demographic Challenges to Adopting Industry 4.0

A white paper published by ARC insights, a manufacturing and supply chain advisory group, illustrated and discussed the challenges of shifting demographics in the manufacturing workforce through surveying leading manufacturing firms and reviewing demographic trends reported by the US Census Bureau (Wilkins, 2007). The average age of manufacturing workers in mature manufacturing economies had already eclipsed 50 years of age, while the average age of retirement in manufacturing had fallen to 58 years of age, presenting a significant challenge in that not only is the manufacturing workforce aging but also retiring sooner (Wilkins, 2007). Unfortunately, the challenge to replace the incumbent workforce is equally daunting for manufacturers, as research indicates that manufacturing careers lack appeal to the generation of millennials entering the workforce, citing an antiquated perception of what manufacturing is (Wilkins, 2007). According to the study by Eberhard et al. (2017), digitally native millennial workers will represent half of the workforce by the year 2020. Thus, it will be critical for manufacturers to promote the technological advancements of Industry 4.0 to shift the perception of manufacturing careers for the entry-level workforce. Furthermore, the ARC reports (Wilkins, 2007) that millennials are less likely to grow tenure and experience with one company, in favor of gaining additional experience and advancement through changes organizations. This will challenge manufactures to create KM systems that capture and operationalize "tribal" knowledge of the exiting generation of workers, while also reinvesting in training and certification programs to retool and retain workers (Wilkins, 2017). Although the research by the ARC was published at the beginning of the shift towards Industry 4.0, the body of literature maintains that the challenges of engaging the millennial workforce has yet to be met by manufacturers and the insights provided add value in discussing potential workforce development strategies under Industry 4.0.

A 2015 workforce development study conducted by the Plant Engineering Research Journal validated the conclusions of Wilkins (2007), finding that thirty-one percent of manufacturing facilities surveyed have been unable to expand their operations due to shortage of qualified operators (Plant Engineering, 2015). The same study found that employers in the manufacturing industry found younger members of the workforce lacking relevant skills; deficiencies reported include: Instrumentation skills (51%); problem solving skills (51%); project management skills (47%); communication and presentation skills (44%); electrical skills (44%); production skills (41%); team building skills (40%); mechanical skills (40%); and engineering skills (39%) (Plant Engineering, 2015). However, the primary concern of manufacturing organizations is obtaining enough skilled or unskilled candidates to fill their production lines, as sixty-four percent of organizations reported a workforce shortage in general. Thus, the challenge to organizations is not only how to train millennials to become qualified workers in Industry 4.0, but also how to attract this generation into the manufacturing workforce.

A survey of industry leaders indicated that there are three prevailing strategies for attracting millennials. In order to appeal to millennial workers, manufacturers should focus on connecting with prospective workers by highlighting the emerging IoT technologies and advancements in ICT present in manufacturing, connecting the role of the operator to the larger value chain to instill meaning in the role of the operator, embrace immediacy of change in the workplace, and provide opportunities for new workers to provide leadership in the workplace (Barr, 2016). However, manufacturing executives will be challenged to employ workforce development strategies to attract millennial workers into Industry 4.0 that do not alienate the current incumbent workforce of generation X and baby boomers. Thus, in order to adapt the workforce to Industry 4.0, manufacturers must understand the generational differences that separate millennials from their counter parts.

A white paper published by the Kenan-Flagler Business School at the University of North Carolina (Brack & Kelly, 2012) discussed the differences in workplace expectations between millennials and older generations, aggregating generation X and baby boomers into one cohort for comparison. When compared to their older counterparts, millennials demonstrated a higher level of expectation for gaining a sense of accomplishment and meaning from their work, with less emphasis on pay and level of responsibility according to a survey conducted by Levit and Licina (2011, in Brack & Kelly, 2012). Specific to Industry 4.0 relevant workplace attributes, millennials prefer an unstructured flow of information over more managed and controlled dissemination or information, tend to be more outward facing, and influence and collaborate through networks rather than position (Brack & Kelly, 2012). These preferences can be exploited in the workplace through the adoption of IoT, AR, and CPS systems to encourage a more connected and collaborative workspace. Studies show a majority of millennials believe that office attendance is not needed on a regular basis (Eberhard et al., 2017), increasing the importance of engaging with mobile and remote interface technologies, such as VR workspaces to increase output. Furthermore, the output and engagement of millennials can be optimized in the workplace through creating development strategies that incorporate coaching from more experienced operators and leadership, creating transparent measures of performance, allowing for collaboration across the enterprise, and providing individualized reward and recognition programs (Brack & Kelly, 2012).

The drafting of a comprehensive workforce development strategy for Industry 4.0 must not only effectively attract and develop the millennial workforce, but must also account for the challenges of retooling and integrating the aging incumbent workforce into the Industry 4.0 environment. According to the Society for Human Resource Management (SHRM, 2015), twenty-seven percent of the manufacturing workforce is now above the age 55, increasing the importance of both adapting these workers into the body of technological change but also preparing for their retirements. While Roblek et al. (2016) discussed the need to integrate IoT and SMO's into KM systems to digitize the knowledge of the incumbent workforce, the ability of organizations to fully leverage the experience of its operators to optimize KM for the onboarding and training of the incoming workforce is dependent on the successful integration of its generation X and Baby Boomer operators into the Industry 4.0 environment. Although the perception that operator performance degrades with age exists, empirical research conducted by Thun, Grobler, and Miczka (2007) concludes that when compared to younger operators aging operators demonstrate an increased awareness of product and process quality, higher levels of practical knowledge in operations, and greater demonstrated performance reliability. However, increased physical and ergonomic requirements impeded the performance of aging workers to a greater degree than their younger counterparts (Thun et al., 2007). According to the study, counterproductive working conditions for an aging workforce include forced postures, physically exhausting tasks, environmental conditions, time pressures, nights shifts, tact time driven work, and responsibilities that require permanent attentiveness. These workplace attributes both present significant headwinds to the adoption of Industry 4.0 technologies, such as requiring real-time, AR enabled problem solving of a workforce that may struggle with the permanent attentiveness required, while also presenting an opportunity for Industry 4.0 to provide technological solutions to an aging workforce such as collaborative robotics and biomechanical assistance.

Recommended Emerging Workforce Strategies

Over the next ten years, 3.5 million manufacturing workers will exit the workforce through retirement, and it is expected that two million of those positions will go unfilled because of a shortage of qualified workers (Anid, 2018).

Developing new qualified manufacturing workers as well as reskilling the current workforce addresses the increasing polarization of workforce skill-sets. As the complexity of manufacturing continues to increase, the skills gap between lower skilled workers and highly skilled workers continues to grow. According to research published by the McKinsey Global Institute (Manyika et al., 2015), in order for manufacturers to develop an advanced manufacturing workforce, organizations will need embrace an approach that encourages and invests in on-going learning and talent development to not only reskill the incumbent workforce but to attract and retain talent.

Attracting New Workers to Manufacturing

According to research published by SHRM (Aging workforce, 2015), the manufacturing organizations surveyed have deployed varied solutions to prepare for the potential gaps as the result of the loss of older workers, with the top two strategies being increased training and constraining efforts (53%) as well as developing succession planning for critical retirements (39%). Furthermore, manufacturers were likely to utilize both cross training (66%) and job shadowing (33%) to transfer job knowledge from the exiting workforce to the younger people entering the workforce. However, in order for job shadowing and cross training efforts to be successful, organizations will need to successfully manage the existing generational differences in the workplace for manufacturing teams to be successful in organizing multi-generational work teams (Aging workforce, 2015). Furthermore, SHRM (Aging workforce 2015) recommends that manufacturers leverage their HR business partners to conduct complete skills audits of the skills required within their production environments against the skills, education, and experience of the incumbent workforce. This allows organizations to compare their needs against the skills and experience available in the workforce, including a thorough review of the skills of the available workforce, review workforce demographics, and expose any gaps in supply. However, it is important to note that retraining existing employees to adapt to the technical changes of Industry 4.0 is more cost effective than attracting and onboarding new employees (Aging workforce, 2015). Thus, the research published by SHRM provides a framework for understanding how manufacturers can prepare their current mature workforce in a manner that increases the cost competitiveness of the organization.

In order to attract millennials to manufacturing, organizations need to take a holistic approach to developing a workplace that encourages active engagement and meaningfulness. According to Brack and Kelly (2012), thirty percent of millennials view meaningful work as the most valued job factor in a potential career, making it the most important job characteristic. Research has shown that emotional intelligence (EI) training can contribute to the development of meaningfulness in work (Thory, 2016), which not only will function to attract and retain the millennial workforce, but also serves to develop highly valued social skills advocated for by Eberhrad et al. (2017). Social skills, influencing, and emotional awareness can be taught through employee development programs to increase the level of meaningfulness and satisfaction experienced by the workforce, which leads to greater levels of performance and retention (Thory, 2016).

In addition to creating smart workplaces that are also engaging and meaningful, manufacturers must also challenge the perception of manufacturing as a viable career opportunity. According to research, the majority of plant managers (57%) report that manufacturing is not seen as a positive career choice by future job candidates (Pelliccione, 2016). This is often based on a collective social bias that views manufacturing as an inherently low-skilled, low-paid career path that is commonly hazardous to the health and well-being of entry level-workers (Campbell, 2014). However, this deeply held stereotype fails to acknowledge the complex and advancing technologies deployed in Industry 4.0 discussed by Zhong et al. (2017), Vaidya et al. (2018), and Sanders et al. (2016). Thus, the manufacturing industry is challenged by a need to rebrand the industry as a high-tech and lucrative career choice for individuals entering the workforce. In order to change the public perception of manufacturing, organizations should promote new technologies and the modern manufacturing environment by engaging students and educators through factory tours and industry sponsored manufacturing and STEM days (Campbell, 2014). The creation of public-private partnerships between manufacturers and the supporting communities and educational systems can reshape the image of manufacturing and the career landscape for workers entering the workforce for the first time.

Worker Certification Approach to Workforce Development

In order to attract and train qualified younger workers, manufacturers will need to partner with social and governmental institutions to create a more robust and qualified workforce. A study published by the Brookings Institution (Parilla, Trujillo, & Berube, 2015) applied best practices from Germany in workforce development for adoption in the United States. According to research, the German education system has been highly effective in preparing its students for the adaption of new technology in the workforce, while also creating certainty in the labor market. (Parilla et al., 2015). The development of a qualified workforce begins with the alignment of social and governmental partners with private organizations to address the educational needs to the future workforce through creating a dual system of education and employment (Parilla et al., 2015). The dual system consists of employing students in full-time positions with manufacturers to acquire on-the-job training, and this training supplements formal classroom learning provided by the educational system. However, this system also represents a significant investment in human capital, as industry firms contribute upwards of two-thirds the overall cost of the dual system as well as the development of curriculum (Parilla et al., 2015). Educational curriculum is centered around the achievement of industry established credentials and certifications. According to Brookings (Parilla, et a., 2015), the established credential system has three distinct benefits; (1) students will receive education that is aligned with sought after skills of employers, increasing their confidence that training will result in employment; (2) the curriculum of the educational system will create additional value through its economic relevance; (3) employers can easily identify if the qualifications and experience of employees will meet the requirements of their business (Parilla et al., 2015). Furthermore, Brookings concludes that "the (German) system endows manufacturing workers with general skills in different clusters of industries, providing a basic foundation so they can accrue very specialized on-the -job skills (P. 17, Parilla et al., 2015)." This strategy relies on the partnership between private industry and governmental bodies to create a qualified pool of candidates prepared for entry level work in Industry 4.0 while relying on organizations to provide specialized training in the specific manufacturers individual deployment of advanced technologies.

In the United States there has been a recent growth in partnerships between private industry, educational systems, and governmental entities. The primary partnership for domestic manufacturers is represented by fourteen distinct innovation institutions in the Manufacturing USA network (Anid, 2018). Because traditional educational systems remain as the principal providers of the next generation of manufacturing workers, private-public partnerships must continue to develop curriculum that addresses the rapidly changing needs of the manufacturing industry.

Although the research published by the Brookings Institution (Parilla et al., 2015), provides a compelling case for the partnership of private industry and the public sector, further research is needed in examining the role of differences in the private and public sectors, specifically the role of labor unions, which play an integrated role in the development of the dual system in Germany. However, the significance of developing formal accreditation systems for worker skills qualifications as a solution for gaining technological fluency in the general workforce provides a template for domestic organizations to partner with local and regional governmental bodies.

Private-Public Partnerships

The Manufacturing Institute advocates an approach to advanced certifications that creates private-public partnerships through community partnerships, establishes productive relationships with community and technical colleges, and invests in the development of private certifications (Developing skilled workers, 2015). Manufacturers can partner with their communities to ensure that the local workforce is being prepared for advances in manufacturing technology. Once manufacturers have established a network of public and private partners in workforce development, the established consortium becomes a platform for the development of regional workforce forums, the development of training solutions, and the development of a manufacturing workforce organization (Developing skilled workers, 2015). Productive partnerships with local manufacturing associations and the chamber of commerce create a platform for community action against common workforce issues and skills gaps to develop a workforce pipeline plan, which can be measured and monitored to assess the effectiveness of the community development plan (Developing skilled workers, 2015). Furthermore, manufacturers should ensure representation on workforce investment boards (WIB).

For example, in 2012, Pennsylvania's WIB submitted a proposal to the United States Department of Labor for a $12 million grant to create a statewide training program to address the growing skills gap in the manufacturing workforce. The proposal would create a state-wide training system that would focus on developing operators capable of programming SMOs and automated equipment, provide training to the next generation of automation technicians, and revamp curriculum for mechanical, electrical, and computer engineering related to industrial automation (Ryan, 2012). This proposal addressed the Pennsylvania skills gap in two manners; the new training system would allow operators displaced by automation and smart manufacturing technologies to develop new skills and it establishes a channel for attracting and developing new workers into manufacturing (Ryan, 2012). This model illustrates the workforce opportunities that manufacturers can create through community partnerships geared towards developing skills to help industry and communities adapt to Industry 4.0.

According to research published by McKinsey and Company (Cheng, Dohrmann, Kerlin, Law, & Ramaswamy, 2018), in order to address the growing talent shortage in manufacturing, employers need to transition from hiring available candidates to actively building a pipeline of next generation talent. Beyond fostering community partnerships, growing partnerships with local and regional educational institutions that offer technical degrees and certifications allows private manufacturers to influence the curriculum of community colleges to align with emerging technologies and address skills gaps found in the workforce (Developing skilled workers, 2015). This approach allows organizations to focus on building more qualified entry-level candidates and bridge the gap to the younger workforce while they are still enrolled in secondary education. The Manufacturing Institute (Developing skilled workers, 2015) recommends that employers engage the technical education system through taking positions on industry advisory boards, offering plant tours and presentations to students, sharing key recruitment needs and skills requirements, and sponsoring technical club activities such as FIRST Robotics or SkillsUSA.

Beyond cultivating a pipeline of new qualified employees through partnerships with local and regional colleges, manufacturers utilize technical colleges to reskill the incumbent workforce through the pursuit of non-degree skills programs (Cheng et al., 2018). Non-degree seeking training is a mechanism for operators to engage in lifelong learning to keep current with technological trends in manufacturing. As changes in technology become increasingly rapid in Industry 4.0, the ability for the workforce to learn new skills and adapt to dynamic environments will be of increased value. Thus, the role of manufacturers is to influence the curriculum of educational institutions by providing market feedback and skills requirements to educators, as well as partnering to understand the development needs of the current workforce (Cheng et al., 2018). Additionally, private industry can apply influence to the government to fund reskilling and certification programs and provide the framework for understanding the public return on investment in such programs.

An example of a developing a private-public partnership to evolve the educational system to meet the needs of Industry 4.0 is illustrated by the 2018 founding of California's 115th community college. According to an official press release by the California Community College System (2018), the 115th community college was created to provide training to meet the demand for highly-trained, high-tech workers in the growing digital economy. Through partnerships with private industry, the 115th community college will address the discreet needs of the industry while increasing access to traditionally underserved populations through online access and the most affordable certifications in the country (California Community College System, 2018). According to the press release, sixty-five percent of future jobs in California will require some form of advanced credential or educational degree by the year 2020 and that these workers will earn twenty to thirty percent more than non-qualified workers (California Community College System, 2018). Thus, not only does the creation of an affordable and accessible technical college tailored to the needs of an increasingly digital economy help fill the emerging manufacturing skills gap, but it also can be viewed as an engine of economic growth.

The development of custom workforce development strategies that incorporate Industry 4.0 technical training, social and personal skills, and formal technical certifications is a strategy that can not only increase the size of the candidate pool for manufacturers to pull from but also increase the skill level of entry and mid-level workers (Campbell, 2014). These strategies not only create more effective educational offerings, but deliver increased value to the worker, the community, and the organization.

Internal Workforce Development Strategies

In creating a workforce development strategy, research has shown that an approach that leverages formal off-the-job training to develop core competencies such as problem solving and critical thinking is effective when paired with structured on-the-job training that supplements formalized training with individual and workplace relevant technical skills (Saadat, Tan, Owliya, and Jules, 2012). However, training is representing a costly investment for manufacturers, and a measured and planned approach with clear goals and objectives is needed in order to optimize the workforce development plan (Developing skilled workers, 2015). An effective strategy to develop the required skills through a targeted development approach is the deployment of manufacturing career pathways.

Creating pathways for the incumbent workforce to advance their skillsets through on-the-job training involves the creation of a structured program that incorporates classroom training with hands-on experience on the production floor with the actual technology that workers will be using. This strategy allows organizations to customize training to their production environment, acknowledging the skills gap of their incumbent workforce and placing formalized development plans to increase the qualifications of the incumbent workforce (Developing skilled workers, 2015). Career pathways (also referred to as ladders) are progressive occupation paths that organize positions and skills into levels of operator, with corresponding skills and wages increasing as one progresses through the pathway (Campbell, 2014). In the context of Industry 4.0, operator skill levels should incorporate the SMOs and IIoT technologies that operators will be expected to interact with in the production environment. Wherein traditional career pathways in manufacturing were considered with developing high order assembly skills and machine operator competencies, manufacturers must now incorporate connected ICT, IoT, and advanced processes into the skills matrix. The connected nature of the Industry 4.0 environment places greater emphasis on the creation of training programs that will create additional value through worker flexibility and agility to respond to real-time changes in demand. Figure 1 represents a theoretical career pathway for operators in an Industry 4.0 environment.

Figure 1

Theoretical Industry 4.0 Career Pathway

Job Complexity	Position Level	Role	Technical Requirements	Training Required
Job Complexity	Entry-Level Positions	Role	Technical Requirements	Training Required
	Skills Portfolio Required: Resource Management Skills, Social Skills, Content Skills	Order Pickers	AR devices, RFID, mobile ICT	On-the-job
		Sub Assemblers	ERP Systems, AR devices	On-the-job
		Data Clerks	Big data, CPS	On-the-job
		Lift Operators	Industrial trucks, RFID, Mobile ICT	On-the-job
		Manual Operator	AR devices, RFID	On-the-job
	Mid-Level Positions	Role	Technical Requirements	Training Required
	Skills Portfolio Required: Resource Management Skills, Social Skills, Content Skills, Cognitive Skills, Technical Skills, Content Skills	Robotics Operator	Automation, AI, AR devices, CPS, SMOs	On-the-job, Certifications
		Materials Lead	Big data, CPS, AI, AR, simulations	On-the-job, Certifications
		Machine Operators	Automation, AR devices, SMOs, IIoT, ICT	On-the-job, Certifications
		Welder	Automation, IIoT, AR, ICT	On-the-job, Certifications
		Production Analyst	Big data, SMOs, IoT, CPS, ICT, simulations	On-the-job, Certifications
	Advanced-Level Positions	Role	Technical Requirements	Training Required
	Skills Portfolio Required: Resource Management Skills, Social Skills, Content Skills, Cognitive Skills, Technical Skills, Content Skills, Process Skills, System Skills	Automation Technician	Automation, AR devices, AI, CPS, SMOs, ICT	2 year degree, On-the-job, Certifications
		Systems Tester	IIoT, IoT, AI, AR devices, CPS, ICT, SMOs	2 year degree, On-the-job, Certifications
		Systems Integrator	CPS, IIoT, AR devices, ICT, SMOs	2 year degree, On-the-job, Certifications
		Machine Programmer	SMOs, IIoT, CPS, ICT, big data	2 year degree, On-the-job, Certifications

The creation of career pathways provides the framework for advancing one's career as well as reskilling and motivating incumbent workers to engage in continuous learning. A pathway model also provides manufacturers the opportunity to conduct a value-based skills assessment of the current production landscape and allows organization to contextualize training and certification needs in response to demand changes and technical advances unique to their own business model.

The Manufacturing Institute recommends that the creation of pathways for incumbent workers begins with a job and task analysis of critical roles, allowing for a complete skills inventory and skills gap analysis (Developing skilled workers, 2015). According to SHRM, conducting a current state analysis of the requirements of the production environment as well as a skills inventory is critical as it forms the baseline for internal workforce development strategies (Aging workforce, 2015). With the skills baseline established, a survey of existing skills certifications allows organizations to match gaps in their workforce with established industry standards and training, which can be incorporated into the workforce development plan (Developing skilled workers, 2015). Additionally, mentorship programs that match new workers with more experienced and skilled workers can be leveraged to develop the needed skills within the context of the daily production environment, resulting in practical and relevant skills development. Formalized mentorship programs also assist in the transfer of knowledge and can be supplemented with advancements in KM systems in production. The transfer of knowledge ensures that there is operational consistency as the incumbent workforce exits and can result in increased levels of productivity as KM systems enable the quick operationalizing of existing knowledge applied to advanced manufacturing processes (Roblek et al., 2016). Furthermore, knowledge transfer and development can be supplemented by formalized training provided by community and technical colleges to provide additional in-depth and theoretical exposure to industry trends and technical skills that may not yet be present in the production environment (Developing skilled workers, 2015).

An example of an advanced manufacturing career pathway for production workers is illustrated by the Missouri Department of Economic Development's Economic Research and Information Center (2017), wherein entry-level workers are provided short-term on the job training in roles such as team assembler, welder, and machine operator in order to obtain basic machine operator certifications, with an average wage of $28K-$40K (MERIC, 2017). Once establishing the required basic skills sets, production employees can choose to advance their careers through additional training and experience to transition to second tier workers. The second tier of production workers represents advanced positions, such as sheet metal workers, tool and die makers, production supervisors, and CNC programmers, all of whom have received long term on-the-job training, certificates, and associate's degree and have an average wage range of $34K to $55K (MERIC, 2017). Furthermore, by obtaining a relevant bachelor's degree in engineering, business administration, or management, workers in advanced manufacturing can progress into production management with an average annual salary of $101K (MERIC, 2017).

In the Missouri model, incentive through increased compensation potential is given to the workforce to engage in continuous learning as a means for career advancement. Furthermore, publication of manufacturing career pathways illustrates career opportunities and increases interest to those entering the workforce while also providing a pathway of advancement to the incumbent workforce.

Conclusions

This paper provided an overview of the disruptive industrial technologies emerging in Industry 4.0 and the impact that these technologies has on the advanced production floor, as well the intersecting demographic challenges faced by domestic manufacturers. Through a review of the current body of literature regarding Industry 4.0 trends, this paper provided a profile of emerging manufacturing technologies and the development of smart manufacturing spaces hallmarked by the IIoT, SMOs, and an increasingly connected CPS environment. The importance of successful adoption of Industry 4.0 technologies is clearly identified through increases in worker productivity and an estimated $2.2T growth in domestic GDP (Manyika et al., 2015). Rapid advancements brought on through Industry 4.0 will reshape entire value chains across industry as well create a new competitive landscape (Roblek et al., 2016), creating a "must win" condition for manufacturers.

Although the emergence of Industry 4.0 and its disruptive technologies is well researched, the speed of change evident in the Industry 4.0 creates the need for ongoing research into how new technologies area affecting the workforce as well as how economies respond to the rapid speed of change. This paper provides a description of current technologies; however, ongoing research is needed to ensure a relevant academic understanding.

This paper also identifies and discusses the demographic challenges present in Industry 4.0 as declining participation by an aging incumbent manufacturing workforce as well as waning interest in manufacturing careers by the emerging millennial workforce. An attraction and retention strategy that utilizes internal mentorships and the creation of intergenerational teams to assist in knowledge transfer and develop workers, as well as increased managerial focus on creating meaningful and emotional intelligent workspaces, is advocated to attract digitally native millennials into the manufacturing industry. Furthermore, the “rebranding” challenge of changing the public perception of manufacturing as a career choice is discussed, and recommended that manufacturers engage their community and local colleges in factory tours and class presentations to acknowledge the complexities and opportunities of advanced manufacturing.

Although manufacturers are challenged by adopting new technologies in a changing labor environment, Industry 4.0 presents technological solutions that can assist in extending the productivity of aging workers through smart operator assist technologies and for capturing and operationalizing through enhanced KM systems.

The impact of the growth of millennials in the workforce should be a topic for future research, as the current body of literature is largely theoretical. Furthermore, cross functional surveys of demographic preferences and industrial trends are needed to advance the academic understanding of how millennials will reshape the manufacturing environment.

Utilizing the Industry 4.0 skills portfolio concept proposed by Eberhard et al. (2017) as a framework for understanding the skills required for advanced manufacturing, a three-part strategy consisting of technical skills certifications, private-public partnerships, and internal development strategies was proposed to counter workforce shortages as well as develop the technical and soft skill fluency required within the local workforce. This strategy is supported by a literature survey of current workforce development strategies, including published recommendations from SHRM and the Manufacturing Institute.

The need for establishing standard worker certifications through partnerships with educational institutions and local governments is presented as a viable strategy, mirroring the successful approach taken in Germany (Parilla et al., 2015). Advancing the call for public-private partnerships in meeting the needs of Industry 4.0, this paper recommends that domestic manufacturers engage workforce investment boards and college industry advisory councils to ensure that the skills requirements of industry are adopted into properly funded technical curriculum. These proposed strategies are bolstered by industry examples. Additionally, this paper identifies the need for manufacturers to invest in the creation of manufacturing career pathways to provide framework for training employees and adapting to emerging technologies. Furthermore, the establishment of career pathways is shown to increase the earning potential of workers while also creating the framework for career growth in advanced manufacturing. A theoretical model of a career pathway for Industry 4.0 workers is presented.

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Appendix 1

Acronyms

AI – Artificial Intelligence

AR – Augmented Reality

CPS – Cyber Physical Systems

CNC – Computer Numerical Control

CRM – Customer Relationship Management

EI – Emotional Intelligence

ERP – Enterprise Resource Planning

ICT – Information and Communications Technology

IT – Information Technology

IIoT – Industrial Internet of Things

IoT – The Internet of Things

IMS – Intelligent Manufacturing Systems

KM – Knowledge Management

RFID – Radio Frequency Identification

SHRM – Society for Human Resource Management

SMO – Smart Manufacturing Objects

SOPHOS-MS – Human Centered Manufacturing System

WEF – World Economic Forum

WIB – Workforce Investment Board