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How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies

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Abstract

Purpose – Investing in Industry 4.0 is an important consideration for manufacturing firms who strive to remain competitive in this global economy, but the uncertainty and complexity of where to focus technology investments is a problem facing many manufacturers. The purpose of this paper is to highlight a region of manufacturing firms in the Midwest USA to investigate the role of firm size, access to funds and industry type on decision to invest in and deploy various Industry 4.0 technologies.

Design/methodology/approach – A survey was developed, piloted, and deployed to manufacturing companies located in the Midwest USA, specifically, Indiana, USA. A total of 138 manufacturing firms completed the full survey. The survey participants were requested to rank order the various technology categories with respect to previous historical spending, workforce capabilities and anticipated return on investment. The survey was supplemented with publically available data. Due to the use of rank-order data to identify Industry 4.0 priorities, a non-parametric analysis was completed using the Kruskall Wallis test.

Findings – The findings suggest that manufacturers with less than 20 employees and/or less access to funds (sales less than \$10m) prioritize digital factory floor technologies (e.g. technology directly impacting productivity, quality and safety of manufacturing processes). Larger manufacturers with 20 or more employees and/or access to more funds (sales greater than or equal to \$10m) prioritize enterprise support operations technologies.

Originality/value – Research studies and reports tend to lump manufacturing's perspective of Industry 4.0 into one homogenous group, and rarely acknowledge the limited participation of "smaller" Small and medium-sized enterprises, which account for the far majority of manufacturing firms in the USA. The value of this study is on the "novelty of approach," in that the data collection and analysis focuses on heterogeneity of manufacturing firms with respect to size, access to funds and industry type. The findings and recommendations are beneficial and relevant to organizations supporting Industry 4.0 efforts through workforce development and economic development initiatives.

Keywords Decision making, Technology implementation, Strategy

Paper type Research paper

1. Introduction

Manufacturing is an economic engine driving innovation and prosperity through providing jobs and improving life with a diverse array of products including food, pharmaceuticals and technology. In 2016, the USA was home to 251,774 manufacturing firms, provided \$2,175bn in total manufacturing output, and employed about 12.3m manufacturing workers (National Association of Manufacturers, 2016). Scientists and engineers comprised only 3.4 percent of all private sector jobs in 2016, yet they are central players in high-tech organizations, research-based companies, and advanced manufacturing; US manufacturers employ 64 percent of scientists and engineers and are accountable for 70 percent of US patents to US entities (Bureau of Labor Statistics Occupational Employment Statistics, 2016). In the USA in 2016, manufacturing had the highest economic impact in that for every \$1 which adds value to manufacturing, \$1.40 in additional value is created in other sectors (US Department of Commerce Bureau of Economic Analysis, 2016). Manufacturing creates jobs throughout the economy and US economic growth is very much correlated with

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innovation and entrepreneurship. The breadth of this economic growth is due to advances in new product development and manufacturing process technologies, combined with increased access to product and process information, in a new paradigm commonly referred to as Industry 4.0 (Deloitte, 2014; Baur and Wee, 2015; Abubaker *et al.*, 2017). This new "smart factory" approach describes manufacturing's trend toward automation and data exchange, and includes the Internet of Things, cloud computing, predictive analysis and enhanced auto-response systems.

The benefit of Industry 4.0 technologies, also described as digital manufacturing and smart manufacturing technologies, is they are capable of generating large quantities of real time data which can be converted into useful information for deploying scalable productivity improvements. Unfortunately, the seemingly infinite number of high-tech solutions and continuous technology upgrades can leave manufacturing firms overwhelmed. Furthermore, many firms are understandably cautious about running into issues related to inoperability due to vendor specific closed standards resulting in formatting inconsistencies across various systems and platforms (Wajid and Bhullar, 2018; Nikolaos *et al.*, 2015). In these instances, information cannot be translated or understood due to inconsistencies in machine readable formats, and has the potential to result in data inconsistencies, redundancies and increased amounts of inefficient work and inevitable cost. Even more complexity is added to the technology mix when manufacturing firms consider their upstream and downstream supply chain partners. Enforcing suppliers to use the same software and file standards as the original equipment manufacturer (OEM) is possible, but it comes at a cost typically absorbed by the OEM to get the desired data and information representation (Bermingham, 2018; Christos and Keith, 2009; Nor and Zulkifli, 2009). In summary, investing in Industry 4.0 is an important consideration for manufacturing firms who strive to remain competitive in this global economy, but the uncertainty and complexity of where to focus technology investments is a problem facing many manufacturing firms.

In the USA, there have been many efforts toward assessment and evaluation of the multiple facets of Industry 4.0 including areas such as research and innovation, technology adoption and workforce development. Several government agencies, consulting firms and academic institutions have taken the lead on analyzing, documenting and disseminating Industry 4.0 growth and best practices (Indiana University Kelley School of Business, 2016; Bsquare, 2017; Katz Sapper and Miller, 2017; Deloitte, 2015a; Mckinsey & Company, 2017). These initial efforts have been very beneficial to understanding trends and outlooks. Furthermore, they can be used to assist manufacturing firms in the continued establishment of priorities for moving forward. However, the majority of studies tend to lump manufacturing into one homogenous group, and rarely acknowledge the limited participation of "smaller" small and medium-sized enterprises (SMEs). Many of the assessment reports fail to recognize the large amount of heterogeneity associated with manufacturing companies, such as size of workforce, access to finances and type of industry. Furthermore, although a few initiatives recognize the need to focus on SMEs, the majority concentrate on technology development regardless of firm size or capabilities. The purpose of this study is to explore the vast amount of differences represented in manufacturing and how the differences impact investing priorities for Industry 4.0. The research question is as follows:

RQ1. What is the current status of Industry 4.0 implementation with respect to size of workforce, access to funds, and type of industry?

The paper concludes with recommendations for how to accelerate the speed of implementation of Industry 4.0 technologies using a niche approach to target manufacturing firm's according to characteristics such as size of workforce, access to funds, and type of industry.

2. Background

2.1 Current initiatives to increasing manufacturing competiveness through Industry 4.0

Literature review. Continued manufacturing competiveness is an important economic indicator for several nations to ensure sustained participation in the world economy. Many countries offer government-supported Industry 4.0 efforts, where trends in strategic planning include objectives related to system standard and development of a reference architecture, organization realignment toward efficient management structures, establishing a reliable broadband infrastructure, eliminating safety and security threats, redesigning how people work, staff professional development and training, and taking inventory and optimizing resource efficiencies (Zhou *et al.*, 2015). Specifically, the US federal government continues to invest in initiatives aimed at increasing manufacturing competitiveness (Baily and Bosworth, 2014), including well known programs of Manufacturing USA and the manufacturing extension program Network. The Manufacturing USA program, as of 2018, has 14 regional institutes strategically spread throughout the USA to stimulate a national impact. Each institute has its niche, however, they all seek to increase collaborations between industry and innovation to better understand early stage research and challenges preventing technology adoption. One of many notable achievements of the program is the online digital manufacturing certificate program offered through Coursera, developed in collaboration with the Chicago-based Digital Manufacturing and Design Innovation Institute and University of Buffalo – State University of New York (Putre, 2017). In addition, in fiscal year 2016, although only nine institutes were established at that time, seven institutes had active research and development activities happening for a total of 191 projects (Manufacturing USA, 2016). Furthermore, of the 830 active Manufacturing USA partner members, about 550 were manufacturers, of which 34 percent were large manufactures (500+ employees) and 66 percent were small manufacturers (less than 500 employees) (Manufacturing USA, 2016). The manufacturing extension partnership (MEP) was authorized by the government in 1988 with a focus on increasing productivity and technology performance with a particular emphasis on small to medium-sized manufacturers. MEP is designed as a public-private partnership with a cost-share program and has 51 centers in all states and Puerto Rico. Per the most recent annual report, in 2016, the "program interacted with over 25,000 manufacturers (Manufacturing Extension Partnership, 2016)." Other integral initiatives, as stated on Manufacturing.gov, include the following support programs:

- Advanced manufacturing technology consortia – started in 2013 to offer competitive grants program.
- Investing in manufacturing communities partnership – incentives regional economic development agencies toward establishing manufacturing initiatives.
- Materials genome initiative – launched in 2011 to increase the development and deployment of advanced materials.
- MForesight: the alliance for manufacturing foresight – established in 2014 to drive knowledge dissemination and communication around advance manufacturing growth.
- National export initiative and NEXT – announced in 2014 to increase American business access to overseas markets.
- National nanotechnology initiative – created in 2000 to promote research and development around nanotechnology-related activities.
- National robotics initiative – grant program offered since 2012 to encourage the development of robots which work collaboratively with humans.

- SelectUSA – government-wide program aimed to increase relocation of manufacturing and economic development to the USA.
- Sustainable manufacturing clearinghouse – online searchable database offering resources related to increasing competitiveness using environmentally sustainable methods.

Another recent Industry 4.0 trend in the USA is the establishment of advanced manufacturing demonstration facilities (MDFs) and test beds with a focus on partnerships between industry, academic institutions, and government. A US Department of Energy Advanced Manufacturing workshop offered in 2012, describes MDFs as a collaborative effort to increase broad and quick adoption of manufacturing technologies (Advanced Manufacturing Office, 2012). The first MDF was founded at Oak Ridge National Laboratory in Knoxville, TN, with a mission to reduce technical risk and validate a business case and value proposition for investing in digital manufacturing. In comparison to MDFs, test beds have a similar mission but a shorter, less-permanent lifespan. Two test beds of particular interest are the smart manufacturing leadership coalition (SMLC) test beds and industrial internet consortium (IIC) test beds. SMLC test bed is an initiative coming out of the Manufacturing USA's Clean Energy Smart Manufacturing Innovation Institute, headquartered in Los Angeles, CA. IIC test bed, headquartered in Massachusetts, describes its approach as a controlled experimentation platform completed in time increments of short (less than 12 months), medium (12–24 months) and long (24–60 months).

Relevance to study design. Manufacturing plays an important role in the US economy, as indicated by its estimated multiplier effect (which is the highest of all economic sectors) in that for each US$1 invested in manufacturing, another US$1.89 is inserted into the economy (National Association of Manufacturers, 2017c). Furthermore, manufacturing accounts for about 12 percent of the US gross domestic product (National Association of Manufacturers, 2017b) and about 9 percent of workers are employed within the manufacturing sector (National Association of Manufacturers, 2017a). However, at the state level, some states are more heavily invested in manufacturing, such as the state of Indiana. Here, in Indiana, manufacturing accounts for about 28.6 percent of the gross state product, the highest within the USA (National Association of Manufacturers, 2017b) and about 17 percent of workers are employed within the manufacturing sector, again, the highest within the USA (National Association of Manufacturers, 2017a). In addition, according to the "2018 Indiana Manufacturing Survey: Industry 4.0 Has Arrived," in 2018, a record 58 percent of Indiana manufacturers reported the need to invest in machinery, facilities, and associated information technologies (Katz Sapper and Miller, 2018). The report continues to state that about one-third of Indiana manufacturing firms have already invested in and implemented Industry 4.0 technologies. This study will evaluate Industry 4.0 implementation with a specific focus on the state of Indiana.

2.2 Industry 4.0 key concepts

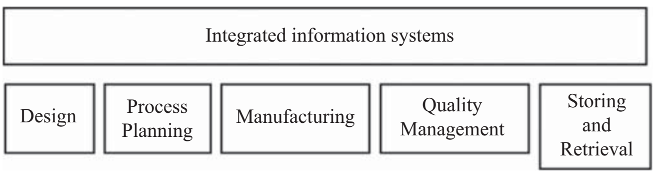
Literature review. Industry 4.0 can be defined as "the information-intensive transformation of manufacturing and other industries in a connected environment of data, people, processes, services, systems and IoT-enabled industrial assets with the generation, leverage and utilization of actionable information as a way and means to realize smart industry and ecosystems of industrial innovation and collaboration (I-Scoop, 2017)." The literature suggests three different approaches to described Industry 4.0 key concepts. The first approach focuses on the technology itself regardless of why or where the technology might be implemented within the manufacturing process. Li *et al.* (2017) describe Industry 4.0 through the lens of industrial wireless networks including: applications (smart city, users, smart enterprises, smart services); cloud (big data, databases, servers, data mining);

networks (cellular networks, wired networks, wireless networks); and devices (machines, robots, mobile devices, AGVs). Posada *et al.* (2015) describe Industry 4.0 to include Semantic Technologies, IoT/Industrial Internet/Cloud, Industrial Big Data, Cybersecurity, Product Life Cycle Management, Intelligent Robotics, Visual Computing and Industrial Automation. A second approach focuses on the design principles, proposed motivation and anticipated outcomes of implementing a technology intervention including area such as corporate social responsibility, product personalization, service orientation, smart product, smart factory, interoperability, modularity, horizontal integration, vertical integration, decentralization, real-time capability and virtualization (Ghobakhloo, 2018). Another approach to Industry 4.0 technology implementation can be viewed from an area or activity perspective taking into consideration where improvements can be made, such as product design and engineering, planning, supply chain and factory operations (Groover, 2015; Kusiak, 2000).

Relevance to study design. When talking with manufacturing firms about opportunities for Industry 4.0 implementation, the authors propose the ideal method is to reach common ground and understanding through a focus on potential manufacturing bottleneck areas, such as activities and information-processing functions (Figure 1). It is important to note, that although supply chain characteristics (e.g. distribution, logistics, suppliers, customers, etc.) are not specifically called out, they are inherent within the information-processing functions which are further explained later on in the study. Every manufacturing firm is different, due to the immense diversity of products available on the market and the associated countless number of potential tools and combinations of processes that can be used to take a product from raw material to finished product. Yet, there are a few things manufacturing firms tend to have in common; they typically include people, equipment and buildings, and procedures all working toward the common mission of producing quality products, within a timely manner, while keeping people safe. To accomplish this mission, manufacturing firms usually departmentalize according to key information-processing areas including design, process planning, manufacturing, quality management, storing and retrieval and integrated information systems (Kusiak, 2000). Thus, from a continuous improvement perspective, it would be intuitive for organizations to identify target improvement initiatives according to activity area. This study will evaluate Industry 4.0 implementation from the area and activity perspective.

2.3 Human capital, firm size and Industry 4.0

Literature review. Human capital includes a manufacturing firm's workforce, including associated talents and skills (Vomberg *et al.*, 2015; Anyanwu, 2018; Mcguirk *et al.*, 2015). A company's access (or lack thereof) to human capital can greatly impact its attitude, behavioral intentions, and decision to invest in and implement new Industry 4.0 technologies. A commonly used proxy for human capital is firm size (Colombo *et al.*, 2004; Black *et al.*, 1999). The literature provides a few key findings related to the impacts of firm size on Industry 4.0 adoption. Sommer's (2015) study suggests that smaller SMEs are at increased risk to become victims instead of benefit from Industry 4.0; furthermore, the findings show that larger enterprises feel



Source: Kusiak (2000)

Figure 1. Basic information-processing functions for a manufacturing firm

better prepared for implementing Industry 4.0 than their smaller counterparts. Moeuf *et al.* (2018) completed a review of the literature which found SMEs tend to limit Industry 4.0 technology implementation to cloud computing and Internet of Things, focus more on monitoring industrial processes than production planning, and tend to implement Industry 4.0 one small project at a time based on a cost-benefit analysis rather than as an enterprise-wide business model transformation. In a recent project completed by Schröder (2016), research associate Schroder identifies four key challenges for SMEs in implementing Industry 4.0 technologies: limited resources; lack of a digital strategy; poor data security; and absence of standards.

Relevance to study design. In the USA in 2016, there were 343,000 manufacturing jobs available. Yet, in May 2017, 6,461,000 workers were unemployed (Bureau of Labor Statistics Occupational Employment Statistics, 2017). Despite the abundance of available workers, manufacturing companies continually struggle to hire qualified employees (Society for Human Resource Management, 2015). The limited pool of qualified workers creates a challenging environment for manufacturing organizations who vie for the short supply of experienced and capable workers (Society for Human Resource Management, 2015). This misalignment costs individual companies millions of dollars and places the US economy at a disadvantage when competing in the global manufacturing marketplace.

Issues related to the skills gap are exponential increased when considering SMEs. In 2015, there were 251,774 manufacturing firms in the USA, of which 98.5 percent are categorized as SMEs with less than 500 employees. Furthermore, about 75 percent of these small firms have fewer than 20 employees. These data are summarized in Table I, along with comparative data specific to the state of Indiana. This study will evaluate Industry 4.0 implementation taking into consideration firm size: larger SMEs = 20–499 employees and smaller SMEs = 0–19 employees.

2.4 Financial capital, sales and Industry 4.0

Literature review. Financial capital includes a firm's access to cash, lines of credit, contracts and bonds (Bhardwaj, 2018; Best, 2017), and focuses on realizing a company's potential return on investment (ROI) associated with adopting a new technology. A firm's access to financial capital, and moreover, the perceived ROI, can greatly impact its attitude toward, behavioral intentions toward, and decision to invest in and implement new Industry 4.0 technologies. Carvalho (2017) suggests that increased access to cash flows can afford firms some initial research and development losses, and thus increases the likelihood a company will innovate around Industry 4.0 technologies. Schumacher *et al.* (2016) developed a maturity model to assess Industry 4.0 readiness; one of the key dimensions associated with Industry 4.0 readiness is strategy, which includes ability to access resources for realization. Access to resources is critical for investing in Industry 4.0; cooperation strategies is one approach for firms with limited access to funds to successfully and cooperatively implement Industry 4.0 within and across organizations (Müller *et al.*, 2017).

Quantity of employees	Number of US enterprises (2015) (United States Census Bureau, 2015)	Number of Indiana enterprises (2016) (Indiana Department of Workforce Development, 2018)
0–19	187,862 (74.6%)	6,236 (68.0%)
20–499	60,099 (23.9%)	2,836 (30.9%)
500+	3,813 (1.5%)	95 (1.0%)
Total	251,774	9,167

Table I.
Summary of employee breakdown for US manufacturing

Relevance to study design. Comparative advantage is an economic theory which posits that within international trade, countries will gain an advantage over others if they are capable of producing goods at a lower relative cost; this same concept applies to individual manufacturers (Hunt and Morgan, 1995). The Manufacturers Alliance for Productivity and Innovation Foundation reports that manufacturing companies participating in exports earn more profit, allowing them to support higher-paying jobs, as much as 18 percent on average (National Association of Manufacturers, 2017c). The report goes on to say that the highest trade-intensive manufacturing firms are capable of paying employees' wages that are over 56 percent more than companies less engaged in the trade industry. Table II provides a summary of sales breakdown of US manufacturers. It is important to note that the statistics for the USA, as a whole, are proportional to that of the state of Indiana. This study will evaluate Industry 4.0 implementation taking into consideration access to financial resources: high sales = \$10m+ and low sales = less than \$10m.

2.5 Industry type and Industry 4.0

Literature review. Industry classification schemes are integral for government and researchers, alike, to conduct business and economic analysis related to market share, economic activity, business census, and creating sector indices, to name a few (Phillips and Ormsby, 2016). Yet, incorporating industry classification schemes into Industry 4.0 research (e.g. categorizing Innovation 4.0 needs and trends by industry type), is waiting to pick up momentum. Researchers acknowledge that "there is no one-size-fits-all strategy that suits all businesses or industries (Ghobakhloo, 2018)" and "[…] full automation depends on the type of manufacturer, the type of industry, and most important, the type of product (Haddara and Elragal, 2015)." Other studies have made a point to intentional include a diversity of industry sectors in an effort to optimize generalizability but fail to consider Industry 4.0 implications to individual industry sectors (Luthra and Mangla, 2018; Groggert *et al.*, 2017). Liao *et al.* (2018) offer a qualitative approach to consider the integration of industry classification and Industry 4.0 using a systematic literature review; however, the findings are limited to a summary of what has been researched with respect to industry classifications and implementations of industrial Internet of Things.

Relevance to study design. The US Federal Government adopted the North American Industry Classification System (NAICS) in 1997 to replace the Standard Industrial Classification system. The NAICS was developed in collaboration between the USA, Canada and Mexico with the purpose to increase the accuracy of comparable business statistics across the partnering countries. The NAICS code has six digits and each digital provides a level of detailed information. Digits 1 and 2 represents the economic sector, digit 3 provides the subsector, digit 4 specifies the industry group, digit 5 designates the NAICS industry, and the last number, digit 6, describes the national industry (US Department of Commerce, 2017).

Table III provides a summary of NAICS breakdown for US manufacturing and the state of Indiana from 2015, with a focus on the first three digits. It is important to note that the two largest categories of manufacturing companies (as designated using gray highlighting) are the

Sales	Number of US enterprises (2012) (United States Census Bureau, 2012)	Number of Indiana enterprises (2016) (Indiana Department of Workforce Development, 2018)
< \$10m	226,148 (88.2%)	7,658 (83.5%)
\$10m +	30,215 (11.8%)	1,509 (16.5%)
Total	256,363	9,167

Table II. Summary of sales breakdown of US manufacturers

Table III.
Summary of NAICS breakdown for US manufacturing

NAICS code – Part 1	Category	Number of US firms (2015)		Number of Indiana firms (2015)	
311	Food manufacturing	22,673	8.8%	816	8.5%
312	Beverage and tobacco product manufacturing	7,372	2.9%	229	2.4%
313	Textile mills	1,974	0.8%	38	0.4%
314	Textile product mills	5,968	2.3%	113	1.2%
315	Apparel manufacturing	7,021	2.7%	22	0.2%
316	Leather and allied product manufacturing	1,144	0.4%	18	0.2%
321	Wood product manufacturing	12,260	4.8%	431	4.5%
322	Paper manufacturing	2,674	1.0%	167	1.7%
323	Printing and related support activities	24,449	9.5%	727	7.6%
324	Petroleum and coal products manufacturing	968	0.4%	102	1.1%
325	Chemical manufacturing	9,628	3.8%	319	3.3%
326	Plastics and rubber products manufacturing	9,543	3.7%	407	4.2%
327	Nonmetallic mineral product manufacturing	9,292	3.6%	320	3.3%
331	Primary metal manufacturing	3,600	1.4%	253	2.6%
332	Fabricated metal product manufacturing	50,751	19.8%	1,864	19.4%
333	Machinery manufacturing	21,320	8.3%	1,012	10.5%
334	Computer and electronic product manufacturing	11,200	4.4%	275	2.9%
335	Electrical equipment, appliance, and component manufacturing	4,952	1.9%	175	1.8%
336	Transportation equipment manufacturing	9,827	3.8%	516	5.4%
337	Furniture and related product manufacturing	14,551	5.7%	515	5.4%
339	Miscellaneous manufacturing	25,304	9.9%	1,299	13.5%
Total		256,471		9,618	

Note: Gray highlighted cells identify largest categories of manufacturing companies for both the USA and Indiana

same for both the USA and the state of Indiana. NAICS code 332 represents manufacturing companies designated as subsector Fabricated Metal Product Manufacturing, which makes up about 19.8 percent of all US manufacturers and about 19.4 percent of all Indiana manufacturers. NAICS code 339 represents manufacturing companies labeled as Miscellaneous Manufacturing, which makes up about 9.9 percent of all US manufacturers and about 13.5 percent of Indiana manufacturers. This study will evaluate Industry 4.0 implementation taking into consideration industry classification.

3. Methods

3.1 Survey design

A survey instrument was developed in collaboration between the Purdue University IN-MaC (Indiana Next Generation Manufacturing Competitiveness Center) and the Purdue University MEP (Manufacturing Extension Partnership). The latter organization is the Indiana-based extension of the federal MEP program, funded and administered by the US Department of Commerce National Institute of Standards and Technology (NIST). NIST has a mission is to enhance the technology and productivity performance of US manufacturing (www.nist.gov/mep/about-nist-mep).

The survey design started with a focus on manufacturing activities and functions (vs the technology and outcome), explained in Section 2.2, in an attempt to offer language relatable to the majority of manufacturing firms. The survey design went through several pilot iterations where feedback was obtained from academic, industry, and government partners. As a result, the taxonomy of definitions was updated to better communicate Industry 4.0 concepts to manufacturing firms ranging in size, access to funds and industry type.

Enterprise support operations (ESO), similar to Figure 1 integrated information systems, is defined as follows:

> These types of technology assist with the integration and automation of **company sales, accounting, procurement, scheduling, logistics, and lifecycle management** into day-to-day operations to optimize productivity and profitability.

Supply chain data exchange (SCDE), similar to Figure 1 process planning, is defined as follows:

> These types of technology assist with the integration and automation of **information tracking and traceability of raw materials, WIP (work in progress), and finished goods** into day-to-day operations to optimize productivity and profitability.

Computer-aided design and engineering (CADE), similar to Figure 1 design, is defined as follows:

> These types of technology assist with the integration and automation of **design and new product development practices using CAD/CAM/CAE files and software** into day-to-day operations to optimize productivity and profitability.

Digital factory floor (DFF), similar to Figure 1 manufacturing, quality management, and storing and retrieval, is defined as follows:

> These types of technology assist with the integration, automation, and simulation of **productivity, quality, and safety practices of manufacturing processes (e.g. machining, painting, assembly, shipping)** within the company's day-to-day operations.

Cybersecurity (CS) is defined as follows:

> These types of technology assist with the **IT security practices and prevention of security threats (e.g. physical damage, facility downtime, customer data breaches, and theft of intellectual property)** within the company's day-to-day operations.

The actual survey instrument was divided into two main components: demographic information and Industry 4.0 priorities. The demographic information included company and individual contact information, which was cross-linked and supplemented with publically available data including NAICS code, quantity of employees and quantity of sales. The Industry 4.0 priorities section first introduced the survey participants to the language and definitions associated with the various technologies. Then the participants were requested to rank order the various technology categories with respect to previous historical spending, workforce capabilities, and anticipated ROI. The actual survey instrument is provided in Appendix. The survey was intentionally kept short to encourage completion and focus on the variables of interest.

3.2 Data collection and participants

Qualtrics, an online survey platform, was used to distribute the surveys to a total of 5,323 manufacturing companies located in the state of Indiana. The e-mails were obtained from publically available manufacturing data accessible through two primary sources. First, the US General Services Administration System Acquisition Management (SAM) database provided contact information for Indiana manufacturers who have registered to do business with the Federal Government. Second, the Conexus Indiana platform provided contact information for Indiana manufacturers posted through the supplier database. The request for participation e-mail asked that the survey be completed by a company representative knowledgeable about the company's adoption of technology and their business processes. E-mailed recipients were requested to respond within five days; two reminders were sent within that time period.

The population breakdown, total manufacturing firms in Indiana (Indiana Department of Workforce Development, 2018) and sample breakdown (survey respondents) is summarized in Table IV. A total of 221 people started the survey and 138 people completed the full survey. Survey respondents primarily included people with self-reported titles of president, owner and other executive level positions. The respondents were further broken down by quantity of employees and quantity of sales, as summarized in Table IV. The largest respondent group (45 percent) fits the category of less than 20 employees and less than \$10m in sales. Although the response rate was relatively low, about 2.6 percent, it is not surprising given that low response rates are often reported for executive level respondents (Anseel *et al.*, 2010; Baruch and Holtom, 2008). Furthermore, given that the sample statistic percentages are comparable to the population statistic percentages, as indicated in Table IV, the researchers feel comfortable drawing conclusions despite the lower than normal response rate.

A histogram is provided in Figure 2, showing a breakdown of survey respondents by industry types, via NAICS codes. The largest NAICS code represented is 332 (about one-third of the data), includes machines shops within the subsector group of fabricated metal product manufacturing.

3.3 Data analysis

The Statistics Package for Social Sciences was employed to analyze the collected data. Due to the use of rank-order data to identify Industry 4.0 priorities, a non-parametric analysis was completed using the Kruskall-Wallis test, and further pairwise comparison *post hoc* analysis was applied as needed. Kruskall-Wallis test can be thought of as a one-way analysis on rank ordered data. This approach was used to explore potential statistical significance, at $p = 0.05$, according to grouping variables including quantity of employees, quantity of sales, quantity of employees vs quantity of sales and industry classification.

Table IV. Summary of population (total manufacturing firms in Indiana) vs sample (survey respondents)

	< 20 employees		≥20 Employees		Total	
Low Sales (< \$10m)	67.20%	*45%	17.20%	*33%	84.40%	*78%
High Sales (≥\$10m)	1.50%	*0%	15.10%	*22%	16.60%	*22%
Total	68.70%	*45%	32.30%	*55%	100%	*100%

Notes: *Gray highlighted cells identify the breakdown of survey respondents. White cells identify the breakdown of manufacturing firms in Indiana

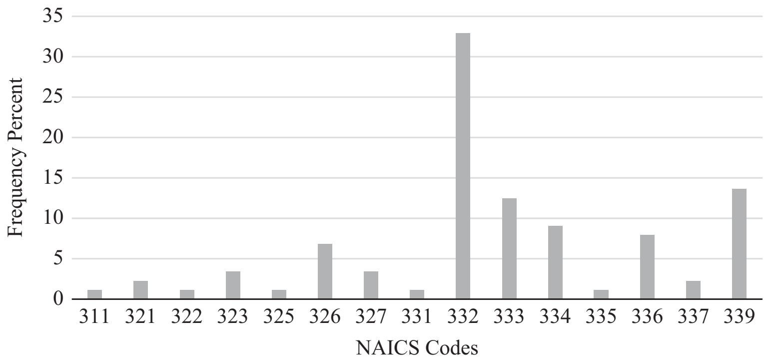


Figure 2. Survey respondent breakdown by industry

4. Results

4.1 Firm size: SME large vs small

The quantity of employees were grouped into a binary variable, where 0 is less than 20 employees (SME-small) and 1 is greater than or equal to 20 employees (SME-large). As shown in Table IV, 45 percent of the respondents were from manufacturing firms with less than 20 employees, and 55 percent of respondents were from manufacturing firms with greater than or equal to 20 employees. The significant differences in priorities are provided in Table V. Manufacturing companies with less than 20 employees, in comparison to manufacturing firms with the quantity of employees greater than or equal to 20, had statistically significant different responses for four technology priority areas. Firms with less than 20 employees: have historically spent more on DFF technology in the past five years; have more workforce capabilities in DFF; have less workforce capabilities in ESO technology; and anticipate a lesser ROI for ESO. These findings suggest that smaller manufacturing companies with less than 20 employees have a preference for investing in DFF technology and has a workforce to better support DFF technology in comparison to ESO.

4.2 Quantity of sales: above or below \$10m

The quantity of sales were grouped into a binary variable, where 1 implies less than \$10m in sales and 0 equates to greater than or equal to \$10m in sales. As shown in Table IV, 78 percent of the respondents were from manufacturing firms with less than \$10m in sales, and 22 percent of respondents were from manufacturing firms with greater than or equal to \$10m in sales. The significant differences in priorities are provided in Table VII. Manufacturing companies with sales less than \$10m, in comparison to manufacturing firms with sales greater than or equal to \$10m, had statistically significant different responses for three technology priority areas. Firms with less than \$10m in sales: have historically spent less on ESO technology in the past five years; have historically spent more on DFF technology in the past five years; and have more workforce capabilities in DFF technology.

Technology area	Mean	SD	Mean rank (1)	Mean rank (0)	χ^2	Asympt. Sig.
Historical spending						
ESO	3.62	1.420	31.92	24.56	3.076	0.079
SCDE	2.80	1.183	31.17	25.42	1.833	0.176
CADE	3.14	1.394	25.57	31.88	2.186	0.139
DFF	2.56	1.419	24.35	33.29	4.405	0.036*
CS	2.88	1.427	30.25	26.48	0.785	0.376
Workforce capabilities						
ESO	3.65	1.248	34.23	21.88	8.788	0.003**
SCDE	2.88	1.211	29.33	27.54	0.182	0.669
CADE	3.35	1.412	26.80	30.46	0.740	0.390
DFF	2.78	1.362	23.97	33.73	5.355	0.021*
CS	2.35	1.468	28.15	28.90	0.035	0.851
Financial capabilities						
ESO	3.51	1.379	34.03	22.12	7.869	0.005**
SCDE	2.97	1.133	26.68	30.60	0.883	0.347
CADE	3.09	1.403	26.08	31.29	1.492	0.222
DFF	3.21	1.417	26.77	30.50	0.783	0.376
CS	2.22	1.408	28.32	28.71	0.011	0.917

Notes: ESO, Enterprise support operations; SCDE, supply chain data exchange; CADE, computer-aided design and engineering; DFF, digital factory floor; CS, cybersecurity. $*p < 0.05$; $**p < 0.01$

Table V. Grouping by firm size (1 = 20–499; 0 = 0–19)

These findings suggest that firms with lower sales and less access to funds have a preference for investing in DFF technology and has a workforce to better support DFF technology in comparison to ESO (Table VI).

4.3 Industry classification using NAICS codes

Due to the high spread of outcomes shown in Figure 2, this section focuses on NAICS code 332 because it had the highest quantity of respondents. NAICS code 332 is classified as Fabricated Metal Product Manufacturing and includes manufacturing companies such as "machine shops." The industry classification was grouped into a binary variable, where 1 implies NAICS code 332 and 0 equates to all NAICS codes other than 332. These variables are 33 and 67 percent, respectively. The significant differences in priorities are provided in "Summary of Statistically Significant Findings – Firm Size and Sales Grouping." Manufacturing companies listed as NAICS code 332, in comparison to manufacturing firms other than NAICS code 332, had statistically significant different responses for three technology priority areas. Firms identified as NAICS code 332: have historically spent more on SCDE technology in the past five years; have less workforce capabilities in cybersecurity; and anticipate a smaller ROI for SCDE technology (Table VII).

5. Discussion

5.1 Firm size and access to funds

"Summary of Statistically Significant Findings – Firm Size and Sales Grouping" provides a summary of statistically significant findings according to firm size and quantity of sales. DFF (as defined in the survey) includes technologies aimed to increase productivity, quality and safety practices of manufacturing processes; whereas, ESO (as defined in the survey) technologies include a company-wide approach to managerial tasks such as sales, accounting, procurement, scheduling and logistics.

In summary, companies with lower sales less than \$10m make up about 84 percent of all manufacturing firms in Indiana (Indiana Department of Workforce Development, 2018) and

Technology Area	Mean	SD	Mean rank (1)	Mean rank (0)	χ^2	Asympt. Sig.
Historical spending						
ESO	3.62	1.420	37.31	25.12	6.206	0.013*
SCDE	2.80	1.183	33.50	26.30	2.129	0.145
CADE	3.14	1.394	26.62	28.43	0.133	0.715
DFF	2.56	1.419	20.08	30.45	4.374	0.036*
CS	2.88	1.427	24.08	29.21	1.077	0.299
Workforce capabilities						
ESO	3.65	1.248	32.31	26.67	1.348	0.246
SCDE	2.88	1.211	33.00	26.45	1.787	0.181
CADE	3.35	1.412	27.27	28.23	0.037	0.847
DFF	2.78	1.362	20.00	30.48	4.535	0.033*
CS	2.35	1.468	28.38	27.88	0.012	0.914
Financial capabilities						
ESO	3.51	1.379	31.12	27.04	0.680	0.410
SCDE	2.97	1.133	28.62	27.81	0.028	0.868
CADE	3.09	1.403	29.54	27.52	0.165	0.684
DFF	3.21	1.417	28.62	27.81	0.027	0.869
CS	2.22	1.408	24.92	28.95	0.826	0.363

Notes: ESO, Enterprise support operations; SCDE, supply chain data exchange; CADE, computer-aided design and engineering; DFF, digital factory floor; CS, cybersecurity. $*p < 0.05$; $**p < 0.01$

Table VI.
Grouping by quantity of sales (1 = < \$10m; 0 = \$10m+)

Technology area	Mean	SD	Mean rank (1)	Mean rank (0)	χ^2	Asympt. Sig.
Historical spending						
ESO	3.62	1.420	28.29	28.61	0.005	0.943
SCDE	2.80	1.183	35.11	25.11	5.006	0.025*
CADE	3.14	1.394	28.37	28.57	0.002	0.965
DFF	2.56	1.419	28.32	28.59	0.004	0.950
CS	2.88	1.427	24.55	30.53	1.776	0.183
Workforce capabilities						
ESO	3.65	1.248	30.74	27.35	0.595	0.440
SCDE	2.88	1.211	30.29	27.58	0.374	0.541
CADE	3.35	1.412	31.87	26.77	1.293	0.256
DFF	2.78	1.362	31.32	27.05	0.920	0.338
CS	2.35	1.468	21.58	32.05	6.174	0.013*
Financial capabilities						
ESO	3.51	1.379	31.26	27.08	0.873	0.350
SCDE	2.97	1.133	22.39	31.64	4.439	0.035*
CADE	3.09	1.403	31.47	26.97	1.005	0.316
DFF	3.21	1.417	28.92	28.28	0.021	0.886
CS	2.22	1.408	27.76	28.88	0.078	0.780

Notes: ESO, Enterprise support operations; SCDE, supply chain data exchange; CADE, computer-aided design and engineering; DFF, digital factory floor; CS, cybersecurity. $^{*}p < 0.05$; $^{**}p < 0.01$

Table VII. Grouping by industry (1 = Code 332; 0 = other)

99 percent of all businesses in the USA (Dun and Bradstreet, 2017). In addition, small companies with less than 20 employees make up about 69 percent of all manufacturing firms in Indiana (Indiana Department of Workforce Development, 2018) and 74 percent of all manufacturing firms in the USA (National Association of Manufacturers, 2017c). As a result, these findings and insights may be useful for organizations with a focus on workforce development and economic development organizations in knowing where to focus efforts for companies who have limited access to resources.

Summary of statistically significant findings – firm size and sales grouping.

Statistically significant findings: grouping by firm size (0 = 0–19; 1 = 20–499).

Historical spending within the technology priority area of DFF was statistically significantly higher for smaller firms (0–19 employees) in comparison to larger firms (20–499 employees).

Workforce capabilities within the technology priority area of DFF was statistically significantly higher for smaller firms (0–19 employees) in comparison to larger firms (20–499 employees).

Workforce capabilities within the technology priority area of ESO was statistically significantly lower for smaller firms (0–19 employees) in comparison to larger firms (20–499 employees).

Financial capabilities within the technology priority area of ESO was statistically significantly lower for smaller firms (0–19 employees) in comparison to larger firms (20–499 employees).

Statistically significant findings: grouping by quantity of sales (1 = < \$10m; 0 = \$10m+).

Historical spending within the technology priority area of ESO was statistically significantly higher for firms with smaller sales (< \$10m) in comparison to firms with larger sales (\$10m+).

Historical spending within the technology priority area of DFF was statistically significantly lower for firms with smaller sales (< \$10m) in comparison to firms with larger sales (\$10m+).

Workforce capabilities within the technology priority area of DFF was statistically significantly lower for firms with smaller sales (< \$10m) in comparison to firms with larger sales (\$10m+).

The results for firm size (SME large vs small) and quantity of sales (above or below \$10m) were similar. Namely, SMEs with lower sales and less employees have a preference for investing in DFF technology and SMEs with larger sales and more employees have a preference for investing in ESO. Smaller SMEs, in comparison to larger SMEs, may have different preferences not simply because of size but because they are at different enterprise growth stages; thus, they could have perspectives that fit earlier, less mature stages of development regarding Industry 4.0. In any case, the similar results for quantity for employees and quantity of sales are not surprising as research suggests firm size is highly correlated with financial performance (Orlitzky, 2001; Stanwick and Stanwick, 1998). As such, firm size and access to funds will be considered together, generalized as firm resources for the purpose of this discussion section.

These findings add to the literature in that they go beyond the generalized SME results of previous studies (Sommer, 2015; Moeuf *et al.*, 2018; Schröder, 2016) to dig deeper into influence of firm size comparing perspectives of large-sized SMEs (20 employees or more) to smaller-sized SMEs with less than 20 employees, and access to funds (less than \$10m in sales vs more than \$10m in sales). Although limited research has been conducted comparing firm size to Industry 4.0 implementation, there is literature which investigates how performance and innovation varies among smaller and larger sized SMEs, which provides interesting insights given the findings.

Garengo *et al.* (2005) conducted a research review on SMEs and found that from a performance perspective, small manufacturing firms (less than 20 employees) tend to focus more on technical and technological capabilities rather than formalized managerial practices. Additional research suggests that the success of small SMEs is highly correlated with an entrepreneur-owner's personal capability toward managing manufacturing activities (Bridge *et al.*, 1998; Neubauer and Lank, 2016). Although this research was not directly investigating Industry 4.0 implementation, it does offer insight into the role SME firm size plays in a firm's likelihood to implement Industry 4.0 technologies.

When considering an investment in Digital factor floor technologies, decision makers can more easily and accurately estimate ROI, especially when implementing changes on small project at a time and especially when making changes related to hourly production employees. This increased accuracy results in lowered risk and uncertainty associated with investing in Industry 4.0, which is a positive aspect regardless of firm-size. However, risk and uncertainty, or the lack thereof, are of greater consequence when it comes to small SMEs vs large SMEs. The smaller the company, the more a firm is exposed to the damaging effects of risks due to limited resources and company structures (Verbano and Venturini, 2013). Thus, for smaller SMEs, it makes sense to focus on making investments with a more straightforward, low-risk ROI, such as DFF, in comparison to uncertain, higher-risk ROIs, such as ESO. In addition, for larger SMEs with managers that do not have the personal capability of managing all aspects of company activities, investing in ESO is important from a knowledge access and sharing perspective.

5.2 Industry classification

"Summary of Statistically Significant Findings – Industry Grouping" provides a summary of statistically significant findings according to industry classification.

Summary of Statistically Significant Findings – Industry Grouping.

Statistically significant findings: grouping by industry (1 = Code 332; 0 = other).

Historical spending within the technology priority area of SCDE was statistically significantly higher for firms with industry code classification 332 in comparison to firms with other industry code classifications.

Workforce capabilities within the technology priority area of Cybersecurity was statistically significantly lower for firms with industry code classification 332 in comparison to firms with other industry code classifications.

Financial capabilities within the technology priority area of SCDE was statistically significantly lower for firms with industry code classification 332 in comparison to firms with other industry code classifications.

SCDE (as defined in the survey) includes technology to assist with information tracking and traceability of raw materials, work in progress and finished goods. Cybersecurity (as defined in the survey) includes technology to aid in IT security practices and prevention of security threats.

Companies within NAICS code 332 (e.g. machine/job shops) makes up about 20 percent of all manufacturing firms in Indiana (Indiana Department of Workforce Development, 2018) and 17 percent of all manufacturing firms in the USA (Unites States Department of Labor, 2018). As such, these findings and insights may be useful for organizations with a focus on workforce development and economic development organizations in knowing where to focus efforts for companies such as machine shops.

These findings suggest that firms with NAICS code 332 have historically prioritized SCDE technology although the ROI is low. This implies that machine shops are likely under pressure from their customers, OEM, to invest in the technology. Furthermore, this group of manufacturers is likely investing in SCDE technology as a strategic maneuver to keep the business of the OEM. Lastly, this group of manufacturers have limited workforce capabilities in cybersecurity technologies. This is not surprising as machine shops tend to have less resources (employees and access to funds), and see cybersecurity as a higher-risk, low ROI priority area.

Although research comparing industry sectors and their adoption of Industry 4.0 technologies is limited, some research on Industry 4.0 has been completed with a specific focus on the machine/job shop industry sector. Waschneck *et al.* (2016) invested Industry 4.0 implementation within semiconductor job shops; they authors found several challenges to Industry 4.0 adoption including limited communication between decentralized decision makers and shop-wide change agents, lack of horizontal and vertical IT integration, and a higher percentage of employees focused on completing repetitive actions rather than incorporating creative elements into the process.

5.3 Other variables influencing investment decisions

This paper investigated the role of firm size, access to funds and industry type on decision to invest in and deploy various Industry 4.0 technologies. However, it is important to note the potential for other variables to influence technology investment decisions. Malte *et al.* (2014) conducted interviews with managers from industry to explore reasons for the adoption and barriers to implementing Industry 4.0. They found that product design has the potential to heavily impact new machinery purchasing decisions, noting the desired product family complexity must be determined early on in the design process to ensure consideration for assessing the ROI for purchasing and installing new technology. Oesterreich and Teuteberg (2016) completed a systematic literature review focused on the adoption of Industry 4.0 technologies within the construction industry. The findings provide evidence of consideration toward political, social, environmental, and legal implications, to name a few, when considering whether or not to invest in new technologies. Another study, targeting SMEs, found that whether a manufacturing firm is internally motivated to invest in Industry 4.0 technologies and/or pressured by an external firm (either up or down stream) impacts the investment decision (Müller *et al.*, 2018). Many research articles have focused on business model innovations as the key driver for adopting Industry 4.0, investing the influence of servitization (Huxtable and Schaefer, 2016), lean manufacturing goals (Sanders *et al.*, 2016), trends related to marketing and the relationship-oriented organization (Nguyen and Simkin, 2017), and ability to exploit novel key partner networks (Arnold *et al.*, 2016). Specifically, Ibarra *et al.* (2018) found that investing in new technologies can result in opportunity recognition and value creation related to process optimization, customer relationship improvements and new product/service development.

6. Conclusions

This study aimed to respond to the following research question:

RQ2. What is the current status of Industry 4.0 implementation with respect to size of workforce, access to funds, and type of industry?

As with any research, this study has limitations. First, the participant group was restricted to manufacturers in Indiana, USA. Although, the firm demographics (size, sales and classification) were comparable from the participant group to the national demographic numbers, there may be concerns of generalizability from a national and global perspective. Second, in an attempt to utilize common language related to Industry 4.0 priorities, the resulting definitions may not be consistently used or applied across all types of manufacturing firms. Although pilot surveys were sent and feedback was obtained from many industry stakeholders prior to distributing the official full survey, there may have been misperceptions around the language and survey directions. Third, the survey introduction requested that it be completed by a company representative knowledgeable about company technology and business processes. This self-reported approach has the potential to result in different responses depending on who complete the survey, so it may not be truly representative of the firm's decision making.

6.1 Accelerating implementation of Industry 4.0: recommendations for workforce and economic development agencies

As shown in Table I, manufacturing firms with less than 20 employees make up about 75 percent of US manufacturing firms. Furthermore, as shown in Table II, 89 percent of manufacturing companies have sales less than $10m. The data analysis, results, and discussion suggest that smaller companies (with less than 20 employees) prioritize DFF technologies and larger companies (with 20 or more employees) prioritize ESO technologies. Also, the same priorities can be inferred for manufacturing firms with less access to funds (sales less than $10m) in comparison to firms with more access to funds (sales greater than or equal to $10m). As such, this information may be beneficial to organizations supporting workforce development and economic development initiatives in developing strategic initiatives and activities resulting in the largest amount of impact.

The researchers recommend that workforce and economic development agencies need to be promoters of Industry 4.0 and the digital way by developing programs, content and structures to provide the necessary training to meet organizational needs within several different technology focus areas. These agencies should not only focus on assisting with job acquisition but also job retention. Workforce and economic development agencies should partner with regional stakeholders (e.g. manufacturing firms, government agencies, educational institutions, etc.) to provide nimble and progressive programs for current and future employees. In particular, local economic development organizations should leverage their connections to get all parties to the same table. In addition, future initiatives should consider providing workshops and training with a greater focus on strategic planning with a holistic enterprise-facing perspective, as anecdotal evidence suggests manufacturing firms with a smaller workforce tend to center hiring practices around employees with a greater technical background in comparison to a business background.

6.2 Accelerating implementation of Industry 4.0: recommendations for manufacturing firms

There is no standard approach for investing in Industry 4.0 technologies. However, manufacturers should be conducting strategic analysis on a consistent basis. Similar to lean manufacturing, investing in Industry 4.0 should be thought of as a philosophy that is never-ending and aimed more toward continuous improvement. This requires a regular systematic identification of pain points both on the shop floor and within the office setting, which includes collection of baseline data to determine "how" painful it is taking into consideration costs related to productivity, quality, and safety, to name a few. In addition, manufacturers should consider feasibility issues related to infrastructure and data preparation. This allows decision makers to conduct a cost-benefit analysis for effective decision making. In some cases, it may make sense for small SMEs to leverage the capabilities of the larger SMEs and OEMs they support; the smaller SMEs may consider investing in SCDE technology as a strategic maneuver to keep the business of the OEM.

Lastly, this approach to strategic analysis encourages manufacturers to start with the problem and not a potential new technology solution. Ultimately, manufacturers need to consider the types of Industry 4.0 technology investment changes that make the most sense for their organization.

The researchers recommend that manufacturing firms recognize Industry 4.0 technology training as a value-added opportunity and not simply an expense. Furthermore, they must identify important industry-sanctioned credentials and incentive employees to follow through with obtaining these value-added certifications.

6.3 Accelerating implementation of Industry 4.0: recommendations for researchers

Media and research reports suggest a number of challenges around investing in Industry 4.0, such as limited skilled workforce, government regulations, cost of electricity, unclear ROI, to name a few (Chryssolouris *et al.*, 2009; Deloitte, 2014, 2015b). However, many of these reports fail to recognize the large amount of heterogeneity associated with manufacturing companies, such as size of workforce, access to finances, and type of industry. Researchers should be aware of the many challenges associated with manufacturing research (David, 2014). First, many assumptions must be made as there is no standard manufacturing company or standard approach to the manufacturing process. Second, future research should consider the choice of language to ensure "academic jargon" does not result in confusion and should consider the choice of data collection instrument to ensure the sample population is reflective of the true population being studies. Third, there needs to be an intentional focus on theoretical/basic research and applied research, so that the work conducted in academic research labs translates to the needs of the corporate researchers and other end users in manufacturing. Fourth, future research should consider other investment decision making variables as mentioned in Section 5.3.

The researchers recommend that future research taken into consider the vast amount of differences represented in manufacturing when making recommendations for investment in Industry 4.0 technology. Although this study focused on human capital, financial capital, and industry classification, future studies may want to consider the influence of demographics (e.g. distance from a major city, distance from a major university, etc.), cost of electricity, type of export, regulatory compliance, access to data, technology adoption costs, and intentionally taking into consideration SMEs which make up the majority of manufacturing companies. Future research should consider the notion of convergence within the digital/smart manufacturing space. Much of the future meaningful research within Industry 4.0 will be done at the intersection of domains and disciplines, where their commonalities meet to produce something new.

6.4 Accelerating implementation of Industry 4.0: recommendations for policy makers

The researchers recommend that policy makers treat technology spending as a capital investment. In addition, policy makers should conduct an honest assessment of what Industry 4.0 will mean to employee displacement and need to retrain an existing workforce. Policy makers should consider the role of incentives (e.g. technology and financial assistance, shared cloud resources, etc.) toward assisting SMEs in technology development, technology upgrades, and adoption strategies, leveraging the implications for economic development. Policy makers should consider the role of incentives (e.g. tax breaks, etc.) toward assistant large OEMs in taking their Industry 4.0 efforts to the next step. In general, policy makers should be cognizant of the need for a greater educational emphasis on coding, visualization and analytics, user experience and their intersection with the electromechanical objects within our world.

The authors provide recommendations for researchers and policy makers. The recommendation to focus on incentives for technology upgrades is interesting. In many cases policy makers currently seem to focus on technology development and generic adoption strategies. Maybe this section could be strengthened a little bit (e.g. by distinguishing a bit between the various recommendations for policy makers).

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Appendix. Survey

Enter your Email

Enter your Name

Enter your Job Role

Enter your Company Name

Enter your Company Street Address

Enter your Company Zip Code

Is your company part of a larger organization?

Please review this information prior to answering the next 4 questions.

1 ENTERPRISE SUPPORT OPERATIONS

These types of technology assist with the integration and automation of **company sales, accounting, procurement, scheduling, logistics, and lifecycle management** within the company's day-to-day operations.

2 SUPPLY CHAIN DATA EXCHANGE

These types of technology assist with the integration and automation of **information tracking and traceability of raw materials, WIP (work in process), and finished goods** within the company's day-to-day operations.

3 COMPUTER-AIDED DESIGN AND ENGINEERING

These types of technology assist with the integration and automation of **design and new product development practices using CAD/CAM/CAE files and software** within the company's day-to-day operations.

4 DIGITAL FACTORY FLOOR

These types of technology assist with the integration, automation and simulation of **productivity, quality, and safety practices of manufacturing processes (e.g. machining, painting, assembly, shipping)** within the company's day-to-day operations.

5 CYBERSECURITY

These types of technology assist with the **IT security practices and prevention of security threats (e.g., physical damage, facility downtime, customer data breaches, and theft of intellectual property)** within the company's day-to-day operations.

Question 1: In the past 5 years, rank the technology focus areas where your company actually invested resources. For example, if the most spending was incurred for Cybersecurity, select 5. If the least amount of spending was incurred for Digital Factory Floor, select 1.

	1	2	3	4	5
Enterprise Support Operations					
Supply Chain Data Exchange					
Computer-Aided Design and Engineering					
Digital Factory Floor					
Cybersecurity					

Explain (as needed)

Question 2: Considering your current WORKFORCE (salary and hourly employees), rank the technology focus areas where your employees have the greatest technical expertise to implement FUTURE technology changes. For example, if the greatest collective employee technical expertise is in Cybersecurity, select 5 for Cybersecurity. If the least collective employee technical expertise is in Digital Factory Floor, select 1 for Digital Factory Floor.

	1	2	3	4	5
Enterprise Support Operations					
Supply Chain Data Exchange					
Computer-Aided Design and Engineering					
Digital Factory Floor					
Cybersecurity					

Explain (as needed)

Question 3: Considering your current FINANCIAL resources, rank the technology focus areas where your investments are likely to have the greatest return on investment for implementing FUTURE technology changes. For example, if the greatest ROI is expected in Cybersecurity, select 5 for Cybersecurity. If the least ROI is expected in Digital Factory Floor, select 1 for Digital Factory Floor.

	1	2	3	4	5
Enterprise Support Operations	○	○	○	○	○
Supply Chain Data Exchange	○	○	○	○	○
Computer-Aided Design and Engineering	○	○	○	○	○
Digital Factory Floor	○	○	○	○	○
Cybersecurity	○	○	○	○	○

Explain (as needed)

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