

Industry 4.0, AI & the Future of Work

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Abstract

Industry 4.0 (IR4) encompasses Information Systems and Information Technology (IS/IT) systems, as well as the automation and integration among various systems. The increasing sophistication of Application Programming Interfaces (APIs) and Internet of Things (IoT) has extended the ability of automated computing systems to sense, interact with, and control physical systems, creating significant improvements in automation. The recent rise of generative Artificial Intelligence (AI) systems has further extended the ability of IS/IT systems to automate processes, including the ability to interact with humans and utilize agentic capabilities to carry out tasks and solve problems that were once the sole domain of humans. This manuscript does not address IR4 or IS/IT systems directly. Instead, it offers a brief overview of the First Industrial Revolution (IR1) and the Second Industrial Revolution (IR2) to provide context for issues that society may face with IR4. The Third Industrial Revolution is not addressed here as the purpose of this manuscript is to identify adverse sociological effects of industrial revolutions which are well documented for IR1 and IR2, but not the third. A common profession in the 18th century was spinning cotton to make cloth, which served as the livelihood for married couples working from home. IR1 introduced the automation of cloth production, displacing these families economically. Fear over the loss of livelihoods caused angry crowds to smash cotton spinning equipment in the streets to protest the automation that eliminated their jobs. Likewise, in IR2 farmers were left without employment as tractors dramatically reduced employment opportunities in farming drastically reducing the largest employment segment. Recent college graduation ceremonies, where speakers have been booed and heckled by graduating seniors, demonstrate similar frustrations as AI, and the automation it enables, is perceived to be taking jobs to which students aspired. This paper seeks to identify disparities that occurred in IR1 and IR2 and the need for academia to understand the disparities when addressing how to help workers prepare for their futures in IR4.

Keywords: Industry 4.0, industrial revolution, AI, Future of Work, Micro Credentials

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1. INTRODUCTION

Industry 4.0 is characterized by the fusion of IS/IT technologies and the resulting impact on the many fields that incorporate IS/IT infrastructures into their operations. Industry 4.0 (IR4) is built upon the outcomes of the three preceding industrial revolutions and draws together the many IT and IS capabilities from the Third Industrial Revolution, including data analytics capabilities using Bayesian mathematics and statistics to model items of interest and draw conclusions, inferences, and predictions from the modeled data. The Internet of Things (IoT) offered the ability for computers to leverage all five human senses using devices that collect evidence in the physical domain and transform it into a form that can be processed in the digital domain, and vice versa. Finally, artificial intelligence (AI) provides computers with the ability to not only process, understand, and interact with activities in the physical domain but also to act and exert a measure of agency in socio-technical systems.

This paper does not examine either IR3 or IR4 as potential sociological impacts are unknown. The adverse sociological impacts of IR1 and IR2 are well documented and can be summed into four categories which are 1) labor degradation and exploitation, 2) urban crowding and public health harms, 3) disruption of family and kinships structures, and 4) class formation and inequality. In the case of IR3 there is no base of literature linking it to these adverse outcomes. There certainly has been a growth in inequality as many billionaires, and now a trillionaire have been formed, but even this has not led to a dedicated literature base. Explanations for the lack of literature related to IR3 may be that 1) it is too recent and a literature base will coalesce around IR3, 2) that IR3 was not a revolution at all in the sense of having dramatic workforce harms and realignment, or 3) that IR and IR4 are actually part of the same elongated industrial revolution and we will see the sociological harms coming along soon.

This paper is the first in a series investigating potentials impacts of IR4 on the future of work along with potential mitigations. There is a growing base of literature examining the impact of data analytics and AI on the workforce moving forward. However, there is less literature examining the overall impact of changes in information systems, coupled with discipline-specific capabilities, and their effects on the workforce. Certainly, some disciplines, such as manufacturing and biotechnology, are currently receiving significant attention in the literature along with massive investment and growth. Other disciplines, however, receive little or no attention, leaving the workforce, businesses, and government with little information to support planning and operations. This paper is further focused on the potential role of academia in preparing students for IR4, which includes a review of the two initial industrial revolutions to gain insight into ways that workers, businesses, academia and governments can prepare and potentially even leverage or exploit that impacts of IR4 in ways that benefit the workforce.

While many fields have studied the first two industrial revolutions, perhaps none have focused on this topic more than sociology and economics. This paper draws heavily from literature in these fields to gain insight into the impacts of these technological revolutions. Again, the Third Industrial Revolution (IR3) was not evaluated, as it is the field in which most authors in this space have worked for years so it is well known to practitioners and academics and it did not lead to a critique in literature in a manner similar to IR1 and IR2. Additionally, IR3 is perhaps too recent to allow for full reflection on its societal impact.

The industrial revolutions of the past have each brought about exciting outcomes that propelled humanity forward in many important ways. However, sociological literature points to highly disparate outcomes, with some individuals and communities benefiting greatly while others faced a bleak existence with little or no hope for the future. Sociological literature also distinguishes between the societal and individual impacts of the first two industrial revolutions, revealing far broader impacts than changes to technology and work alone. This paper explores sociological and economic literature to examine outcomes and trends that could inform IR4 and the ability of individuals, organizations, and governments to seek growth opportunities to prepare for the future of work.

2. CONTEXT AND MOTIVATION

Industry 4.0 (IR4) is tightly integrated with the IS/IT field; as a result, the IS/IT field has both an opportunity and a duty to engage in the development of IR4. While there is already a great deal of IS/IT literature on technical aspects of IR4, there also needs to be an intentional exploration of ways that IS/IT academics can contribute to supporting workforce outcomes both for workers within, and outside of, the IS/IT discipline. This paper initially focused on the manner in which work is completed and the technological advances that empower industry to alter workforce norms. However, a review of the literature revealed that sociological issues radically influenced the first two industrial revolutions, resulting in many positive as well as tragic outcomes.

IR4 is impacting the IS/IT field, and its development will continue to impact the workforce and academic programs in this space. There was no plan to write about previous IRs when this stream of research began. However, after completing a literature review, it became clear that previous IRs had a broader and greater impact on technology, education, and society than initially realized. This paper offers a narrative to understand these broader impacts of the first two IRs as the IS/IT fields navigate their roles in the development of IR4.

3. THE FIRST INDUSTRIAL REVOLUTION

The First Industrial Revolution (IR1) began in England and spanned the timeframe from 1760 – 1840 (Haradhan, 2019). While a number of causes have been postulated for the start of IR1, more recent literature highlights the development of cotton textiles, iron/steel, and transportation capabilities as being most influential in igniting the revolution (Mokyr, 1977). In this discussion of IR1, literature from England and the United States is considered together. This is due, in part, to the fact that IR1 began in England and spread to the United States while it was still an English colony. Additionally, the two nations share similarities in terms of resources, including water power, coal, and iron ore for machinery, along with rivers and harbors to facilitate transportation (Clark et al., 2008). These similarities, along with shared culture and language allowed the first industrial revolution to unfold in a similar manner in both nations. Furthermore, the fact that England had an established economy with businesses investing in scientific investigation such as Newtonian Physics, and related inventions, allowed England to lead industrialization and draw resources from its colonies to support its growth while also documenting activities as IR1 unfolded (Montagna, 1981).

3.1 Sociological/Educational Lens for IR1

Data regarding sociological and educational impacts are inconsistent due to large gaps in available records. Much of the information desired by researchers is unavailable, given that there were few consistent data collection processes at the time. However, sociologists and economists have dedicated significant work toward understanding the IR1 era, and a number of valuable insights are available. There is consensus that child labor increased in the earlier portion of IR1 but then subsided toward the latter portion (Berg & Hudson, 1992; You & Tertzakian, 2026).

Employment for women during IR1 is not as well understood but it is clear that manufacturing displaced many women from employment (Horrell & Humphries, 1995). Home-based family cotton spinning was replaced by factories completing this work at scale; however, while some women struggled for employment, others found factory jobs with set hours, which were perceived as an improvement over working at home (Tilly, 1994; Wilkes, 2017). There is also reporting of long-term negative societal impacts from IR1 (Obschonka, 2018). In fact, in their book *Power and Progress*, Acemoglu & Johnson (2024) note widespread fear of automation early in IR1 with workers smashing equipment in the streets and society suffering worsened conditions for some working-class people for nearly a century.

The impact on society during IR1 can be argued as two different stories in the first and second halves of the timeframe. As mentioned, employment for women stabilized and child labor initially increased but then decreased in the second half of IR1. Additionally, improved economic conditions led to the creation of women's colleges, which were established to train women as schoolteachers; 50 such colleges were created between 1838 and 1875 (Attridge, 2026; Carlton, 2023). The creation of teaching colleges for women then led to elementary schools across the nation and the education of the masses (Melder, 1972).

3.2 Technical Lens for IR1

The development of the flying shuttle by John Kay, used to manufacture thread and cloth, is considered to represent the start of the First Industrial Revolution (IR1). The production of cloth led to modern manufacturing, with factories employing many workers and producing goods at scale (Fitzgerald, 2002). While cotton textiles were growing, Abraham Darby derived a process to make iron from coke as opposed to charcoal greatly increasing its strength and paving the way for a seemingly endless array of innovations (Huntley, 2012).

Some accounts of IR1 argue that the development of the steam engine marked the start of the revolution (Handley & Croxford, 2025). The steam engine powered operations in mining and manufacturing and eventually powered locomotives that moved products from mass manufacturing sites to domestic markets or to ships for foreign markets.

3.3 IR1 Summary

There are competing claims regarding the genesis of IR1 with one school of thought suggesting social and economic factors driving innovation and another suggesting a scientific revolution along with economic factors. Perkin (1968) offers compelling arguments for social causes, positing that the presence of landless laborers in English society provided the means for manufacturing. Furthermore, Perkin argues that in the 18th century, population growth slowed to support real wages and encourage the development of labor-saving inventions.

Huff & Ben-Zaken (2011) make a case for the Renaissance leading to a scientific revolution, which yielded work from Sir Isaac Newton and many others. Research has created a link between the scientific revolution in the 17th century and the innovations that led to IR1 in the 18th century (Jacob & Stewart, 2004; Jones & Jacob, 2009).

Literature supports the narrative that the Renaissance sparked the scientific revolution of the 17th century, which in turn offered theoretical support and prompted curiosity that sparked the innovations of IR1. Literature also supports the contention that labor practices and population changes contributed to IR1. The fact that IR1 started in England and grew quickly while most of the rest of the world did not engage suggests that both social and technological supports were needed to motivate IR1. The migration of IR1 innovation to the United States was likely due to cultural homogeneity, natural resources, and legal structures that encouraged exploration and ingenuity.

4. THE SECOND INDUSTRIAL REVOLUTION

Geddes (1916) is credited with being the first to introduce the concept of a Second Industrial Revolution (IR2), which spanned the period from 1870 to 1914. The drivers of IR2 were primarily the outcomes of IR1, with a key difference being the increased attention and resources dedicated to IR2 because of the wealth generated by IR1. IR2 differed from IR1 in that it played out across all industrialized nations, with countries taking the lead in areas of development based on resource availability.

4.1 IR2 and Education

Between 1850 and 1914, industrial nations made strong commitments to education due to a shift from viewing education as merely useful knowledge to viewing it as a strategic driver of growth (Mokyr, 2013). The value proposition of labor changed with education being an important component in making labor more strategic. Elementary education became a predictor of success in employment in metal working and other industries, eventually becoming a near requirement for employment (Becker et al., 2011). In France there was an effort to go beyond average literacy to drive industrial growth (Squicciarini & Voigtländer, 2015).

Elites in society began to view educated and skilled workers as a form of capital (Galor & Moav, 2004). Cook & Erlich (2018) argue that the growth of the United States economy in the 20th century resulted from broad investments in education, skills development, and health, treating people as human capital and the engine of growth. A case is made that the U.S. ascendancy to a major superpower was the

result of the Morrill Act of 1862 (and the subsequent 1890 extension), which established land-grant colleges that sparked growth in higher education (Cook & Ehrlich, 2018).

4.2 IR2 and Management

Chandler (1977) in *The Visible Hand: The Managerial Revolution in American Business*, argued that the rise of large multi-unit corporations was rooted in IR2. Chandler argued there was a managerial revolution in which a professional managerial function was created to oversee large, multifaceted organizations. No longer did business leaders look solely to market forces (the "invisible hand") for guidance; instead, they were given explicit guidance by professional managers (the "visible hand"). Technology enabled new opportunities to achieve scale through railroads, communication, and continuous process changes, creating complexities that required a new professionally managed organization (Chandler, 1977).

4.3 IR2 and the Workforce

By 1880, nearly half of all American workers were still farmers (Hirschman & Mogford, 2009). Employment in farming during IR2 suffered in a similar fashion to spinning cotton in IR1. The industrialization of farming with modern equipment dramatically reduced employment and led to the abandonment of some towns. The move away from farming was not just a change in profession but a complete life change, often requiring relocation to industrialized cities.

A further complication during IR2 was mass migration into the United States. Immigrants and their children accounted for more than half of manufacturing workers in 1920. If third-generation workers are included, nearly two-thirds of manufacturing workers in the U.S. were immigrants or offspring of recent immigrants. It is certain that IR2 would have slowed significantly without this migratory influx, but their presence made the transition from farming to manufacturing more difficult. The 1920 restrictions on inbound migration had a significant effect on farmers attaining manufacturing work, with primarily Southern farmers relocating to Northern industrialized cities (Hirschman & Mogford, 2009).

4.4 IR2 and Government Regulation

Before IR2, disputes in the United States—such as industrial accidents, food/medical safety, and railroad pricing—were typically resolved through private litigation (Glaeser & Shleifer, 2003). However, by 1887, corporations became increasingly powerful, resulting in an inequality of legal resources that placed individuals at a disadvantage. This created a call for government intervention. U.S. regulatory laws grew rapidly throughout IR2, and the laws themselves were modified or restructured to address corporate entities (Horwitz, 1979; Leonard et al., 2015).

4.5 IR2 and Technology Innovation

Electrification is widely considered the defining technology of IR2. It was not only an invention with its own characteristics but also gave rise to a massive increase in capabilities enabled by electric power. Hughes (1983) posits that electrification was the greatest contribution of the 19th century and one of the greatest capability advances in human history.

While iron and steel were made possible during IR1, IR2 brought innovations that streamlined production, making steel plentiful and cheap (Mokyr, 1990). Cheap steel revolutionized the construction of railroads and shipbuilding, empowering transportation and production at scale (Chandler, 1977; Mokyr, 1990).

Chemistry and the development of electro-chemicals, heavy chemicals and more is a great example of multiple nations that were leading development efforts. Hardie (1958) notes that electro-chemicals were developed in the USA and heavy chemicals in France, but the predominant development occurred in Germany, including the origin of modern organic chemistry (Mokyr, 1990). Each of these innovations are merely examples of innovation sparked by IR2 that revolutionized society with the start of new branches of science and engineering which in turn led to societal improvements.

5. ANALYSIS

IR1 and IR2 offer clear lessons that are applicable to the changes seen today with the advancement of IR4.

5.1 Lessons from IR1

Lessons from IR1 include the need for scientific innovation to offer technical insights and the passion to pursue innovation. IR1 was dependent on the education of scientists who developed the discoveries and theories that unlocked the potential for innovation, as well as the social and legal structures that encouraged individuals to create new methods of accomplishing work. Finally, IR1 was dependent on social structures that incentivized workers to engage in these new elements of work.

In addition to creating the concept of manufacturing at scale, IR1 generated capacity in the workforce. Spinning cotton was a home business that occupied large amounts of labor; the automation of this process freed a significant portion of the workforce for other roles. This change resulted in good outcomes for those who benefited from the new employment generated by IR1 but created significant difficulties for individuals whose livelihoods were disrupted without the ability to gain alternative wage-earning opportunities. A key lesson from IR1 is to remain informed and agile, as those who clung to home-based spinning fared more poorly than those who pivoted to new roles quickly.

A final lesson of IR1 is that societal norms can be significantly disrupted by fundamental shifts in industry. Manufacturing at scale led to a reduction in the cost of basic staples and a path forward for the creation of wealth and capital. The creation of colleges to train women as elementary school teachers and the reduction in child labor in the latter half of IR1 led to schools opening across the nation, providing a better-educated workforce for IR2. However, many families were left to abandon farms to move to cities or remain on their land without a means to earn a living.

5.2 Lessons from IR2

IR2 built upon the successes of IR1 but with a better-educated workforce that expanded on previous innovations while adding new ones. Participation in IR2 spanned most developed nations and introduced electrification at scale, cheap high-grade steel, the telephone, the automobile, and countless chemical innovations. The lessons learned were that the confluence of scientific innovation, infusions of investment at key points, and an adequately trained workforce are all required for success. Additionally, IR2 gave rise to the modern corporation to provide cohesiveness and coordination between dependent business units.

6. CONCLUSION

Both IR1 and IR2 brought massive changes to society. Many of these changes were demonstrably positive, leading to advances in transportation, power, communications, medicine, education, and agricultural production. IR1 ushered in elementary schooling for the masses and IR2 initiated the start of colleges for the masses. However, each revolution brought unintended consequences, including major population shifts, the collapse of towns, and the end of many types of work. None of this is necessarily bad; however, it is disastrous for individuals caught in the middle of the process who lose their livelihood and are unable to find a pathway to meaningful work.

In IR1, home-based cotton spinning was most dramatically affected. IR2 brought an even greater dislocation of workers, with farmers losing work as modern equipment reduced the need for labor. This impact was exacerbated by high levels of inbound migration, with immigrants taking most of the industrial jobs created by IR2. One way academia can support workers and organizations during IR4 is through research related to reskilling. Individuals need forewarning regarding the demise of their current work and a pathway to new opportunities. Mechanisms such as micro-credentials can be leveraged to prepare workers for specific roles in IR4 and provide pathways toward more complex roles which will command greater income opportunities. This approach may help workers in planning for, and attaining work, and also ease fears related to IR4 at the outset and offer confidence when considering the future of work. This approach may also offer support for government in their planning as a reduction in inbound migration during IR2 may have reduced some workforce harms in IR2.

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