Industry 4.0 in Retrospect and in Context

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1 Coming to Terms with the Concept of Industrial Revolution

What is an industrial revolution? Does the concept take us back to the history or does it carry us to the future of industrial manufacturing? Quick Google search gives us both perspectives. Industrial revolution connects the past, the present, and the future.

It is widely agreed that the Internet, artificial intelligence, Internet of things, automated robots, sensors, augmented reality, Big Data and several other groundbreaking innovations will configure global industrial landscape. Industrial companies can collect, analyze and process data and use the Internet and advanced ICT for the manufacturing of high quality industrial goods.

Current changes in manufacturing systems are significant, but not exceptional in history. Many radical and even more frequent incremental changes in manufacturing systems have taken place during the two centuries that sophisticated machines have been used in manufacturing processes. Sometimes radical changes disrupt the evolutionary path and the

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reigning manufacturing paradigm breaks down—a new type of manufacturing system is established and the new era is typically coined as another "Industrial Revolution". Although several paradigm changes have taken place since the late eighteenth century, it is still unknown, what mechanisms drive these changes. As Peter Temin (1997) and other scholars have claimed, the term "industrial revolution" is itself either too vague to be of any use at all, or it produces false connotations of abrupt changes [1].

Although the mechanisms of change that drive industrial development are still unknown, the concept of industrial revolution is widely used in popular literature, textbooks, and in policy documents. The human mind likes to bring structure in to the chaotic past and the evolution of industrial manufacturing is commonly divided in three or four chapters:

The First Industrial Revolution started in Britain during the latter part of the eighteenth century. The steam engines were invented and connected to textile looms. As a result, the manufacturing of consumer goods changed from the individual and domesticated setting into the factory. Steam engines were gradually applied to other sectors of production, then to transportation, and finally to production of energy. The rate of change was slow and it took decades before the new manufacturing system resulted in radical changes in the society. The first industrial revolution was a local phenomenon that spread from the Great Britain to Western Europe, and to the United States.

The Second Industrial Revolution started approximately hundred years later in the United States. The discoveries of electricity, the combusting engine, the telephone, and innovations in chemical and material technologies sparked "The Great Leap Forward". A technological torrent flushed over industrialized nations and the manufacturing systems expanded rapidly, both vertically and horizontally. Large scale factories were built and connected via transmission lines to the centralized power and heat producing plants and started exchanging information through telecommunication networks. Henry Ford developed a non-stop manufacturing system and applied it to his automobile factories in Detroit. Mass production system of manufacturing changed the division of labor within factory walls. Semi-skilled workers operated along the assembly line, which poured out highly standardized industrial goods. The Second Industrial Revolution spread across the Atlantic Ocean, developed further in Western Europe and Scandinavia, and entered into the Soviet Union.

Less than hundred years later, traditional industries based on oil and fossil-fuels and on mass production could no longer be considered a complete solution to the economic or the social problems. A cluster of radical innovations in communication- and energy-technologies merged into a new economic era. A powerful new infrastructure was created for manufacturing industries. What is the *Third Industrial Revolution* is still an ongoing process, but visible changes are already taking place in advanced industrial economies. Centralized production systems and energy production networks are challenged by de-centralized systems that engage hundreds of millions of people to produce their own green energy in their homes, offices, and factories and to share information online [2].

Although the Third Industrial Revolution is still in its infancy, the *Fourth Industrial Revolution* is already knocking at the door. Advanced ICT applications, Big Data, industrial robotics, and automated production systems will merge into Cyber-Physical (CPS) systems, which provide new platforms and infrastructure for manufacturing industries. The concept of Industry 4.0, or the Fourth Industrial Revolution, is recognized in national and international forums and the change-process is included in the major policy documents and development programs [3].

Although, it is widely recognized that the classification of industrial development into three or four "industrial revolutions" is inadequate and even misleading, the concept is still used to demonstrate, how the manufacturing industry has changed over time. The concept of "Industrial Revolution" is also used for propaganda purposes to promote technological enthusiasm and radical changes in the industrial landscape.

What drives industrial change? This question is widely debated among economists, historians, and social scientists. For engineers, the problem is less difficult to answer. From the engineering point of view, the evolution of industrial production can be viewed through the lens of technology. Technological change drives social changes and the accumulation of radical innovations cause disruptions in manufacturing systems. This type of argumentation defines technology as an autonomous phenomenon in society—technology accumulates according to the deterministic laws, which are dictated by scientific knowledge.

Classification of manufacturing systems is shaped by technological determinism. As Boyd and Holton [4] conclude, the changes in manufacturing systems are generated by the changes in technology. Technological determinism narrows down the argumentation into technical details and technological solutions. Technological determinism bypasses social issues, which are hidden conditions of existence of and for the new technologies.

Technological determinism is challenged by social constructivists, who argue that technology is (also) shaped by social forces, ideologies, and values. Although technology has the ability to change social structures and human behavior, the effect is never a one-way-street. Same technological applications are used and shaped differently depending on social, cultural and political environments. According to David Noble [5] manufacturing systems are more than technological artifacts. They are social processes that reflect social structures, values, and ideologies. Manufacturing systems are designed to shape societies, change power structures, and to benefit particular economic and ideological goals. The interaction between technology and society is a systemic process, where social forces shape the systems and the systems shape social forces.

Hence, in order to understand what is meant by Industry 4.0, or the Fourth Industrial Revolution, the phenomenon must be placed in the historical context. Manufacturing systems are complex large technological systems, which are managed by highly trained professionals. As Thomas Hughes [6] points out, large manufacturing systems contain messy, complex, problem-solving components, which are physical artifacts, but they also contain organizations and immaterial components. Manufacturing systems are socially constructed and adapted in the society in order to function effectively. They use natural resources, but also social, political and cultural resources, such as knowledge, legislation, regulation, and ideology. Manufacturing systems contribute to the development of modern industrial societies, but while doing this, they become depended and intimate parts of modern industrial and post-industrial societies.

2 Unde Venis Industry 4.0?

"Industry 4.0" was introduced at a press conference at the Hannover Fair, in 2011. Three German engineers, Henning Kagermann (SAP), Wolfgan Wahlster (Professor of artificial intelligence), and Wolf-Dieter Lucas (Senior officer at the German Ministry of Education and Research) introduced a vision of the future manufacturing system, "The Industry 4.0". The idea was received with enthusiasm in Germany and the concept spread rapidly to other European countries. Five years later, it had already gained international recognition and The World Economic Forum in Davos organized a thematic session titled "Mastering the Fourth Industrial Revolution".

The first strategic paper drafted by Henning Kagermann and others [7] defined the goals of Industry 4.0 as follows: "*It will address and* solve some of the challenges facing the world today *such as resource and energy efficiency, urban production, and demographic change. It enables continuous* resource productivity and efficiency *gains to be delivered across the entire value network. It allows work to be organized in a way that takes demographic change* and *social factors into account. Smart assistance systems release workers from having to perform routine tasks, enabling them to focus on creative, value-added activities. In view of the impending shortage of skilled workers, this will allow older workers to extend their working lives and remain productive for longer. Flexible work organization will enable workers to combine their work, private lives, and continuing professional development more effectively, promoting a better* work-life balance".

As Kagermann and others' [7] strategic paper demonstrated, Industry 4.0 is not only a technological platform for manufacturing industry. It is a social program, which targets major social, economic, and political challenges in the twenty-first century. The concept reflects also political and economic discourses, which have taken place in Germany, Europe, and North America since the international financial crises in 2008. The collapse of the global financial systems drove Western countries into an economic and political chaos, which had long lasting consequences. Global economy, free and almost unregulated flows of goods, capital and knowledge divided the world into winners and losers.

Western industrial countries had gone through a rapid de-industrialization process, when large swathes of manufacturing industries moved to China, India, and to other developing countries. The transformation was regarded as a positive and a progressive turn in the development of Western economies, which focused on the information technology, services, innovations, and on the creation of useful knowledge. Mass production of industrial goods was no longer viewed as a necessary part of the economy. Instead, the 'chimney industries' polluted the environment and offered monotonous and unattractive jobs for low salary workers. However, as Joseph Heathcott and Jefferson Cowie [8] have concluded, de-industrialization was a much broader and fundamental transformation than anybody had anticipated. It turned out to be a socially complicated, historically deep, geographically diverse, and a politically perplexing phenomenon [9].

When factories were closed and abandoned in the Western world, new production facilities and manufacturing systems were rapidly erected in

China. The growth of industrial production in China alone was spectacular and in less than 40 years, China had become the factory of the world. Chinese factories produced about 50% of the world's major industrial goods. This reflected to the GDP, which grew more than 10% annually.

Meanwhile, Western economies struggled to cope with the unprecedented consequences of globalization and de-industrialization. After financial crises, the unemployment rates stayed high, economic growth was slow and deficits climbed to alarmingly high numbers. The political climate that had hailed the destruction of walls and barriers, open borders, and economic liberalization was suddenly challenged by neo-nationalism which tried to put a stop to global flows and restore the nation-state as the sovereign political and economic actor in society [10].

Reflecting the robust economic growth in China and in other Asian countries, the European Union and its member states tried to find ways to restructure the economic landscape. It was understood that the post-industrial information society did not alone provide a stable base for economic growth. Emerging industrial economies in Asia threatened to take over global markets and with the accumulation of capital to develop the next generation of technologies and industry, which would undermine the competitiveness of European corporations. These concerns were reflected in the ambitious research and development projects, which were initiated, organized and funded by the European Union under the Horizon 2020 umbrella. Europe was looking for a new momentum that would reverse the uneven growth and sluggish job recovery that resulted from the financial crises. The long term structural change called for an industrial recovery that would be based on smart, sustainable and technologically advanced manufacturing systems [11].

The strategy paper written by the advocates of the Industry 4.0 answered to this call. The attractive idea did not die after the Davos conference, but instead it spread out to the business community in Germany. The concept of Industry 4.0 and The Fourth Industrial Revolution was appealing to the managers and CEOs who sought to find ways to improve productivity and to increase production of high technology goods. Soon after, the political actors at the European Union and at the national level got engaged in the process and pushed it forward to the policy programs. Large corporations sensed the opportunity and adopted the narrative of the Industry 4.0 and the Fourth Industrial Revolution into their own strategy papers [12].

Hence, the basis for the concepts of Industry 4.0 is not a concrete and realistic analysis of the transformation that has taken place in the manufacturing industry—but instead, the Industry 4.0 is an effort to control the future, which is full of uncertainties and discontinuities [12]. The concept is not a concrete platform, but rather a vision used in the future-making process. Industry 4.0 tells the audience, how the future industries are organized to fulfill global strategic goals. This takes place in the globally connected and almost autonomously functioning manufacturing units. This future vision is competitive and it will overpower traditional mass production systems, which are neither ecologically nor socially sustainable. When the Industry 4.0 is applied globally, it will tame the future by reorganizing the production of industrial goods with new roles of and for human labor.

By now, Industry 4.0 has gained momentum beyond Germany. United States government has organized a series of discussions on the Advanced Manufacturing Partnership (AMP). German government passed in 2012 the High-Tech Strategy that targeted billions of euro to the development of cutting-edge technologies. The following year the French Government initiated "La Nouvelle France Industrielle" program and the UK Government followed the lead with the long-term program "Future of Manufacturing". The European Commission launched the new contractual Public-Private Partnership on "Factories of the Future" program in 2014. South Korean government joined the process in 2014 by announcing "Innovation in Manufacturing 3.0" program. The Chinese government followed the year after with the "Made in China 2025" strategy and the "Internet Plus" programs. The Japanese Government adopted the "5th Science and Technology Basic Plan", which included the "Super Smart Society" program. The following year the Singapore government invested $19 billion to the Research, Innovation, and Enterprise (RIE) plan. In addition, the American high technology corporations AT&T, Cisco, General Electric, IBM, and Intel established "The Industrial Internet Consortium". Similar collaboration was established between German, Japanese, and American high technology companies.

When we look back in the history of industrial manufacturing, the concept of Industry 4.0 does not fit in the typical pattern. It took more than hundred years before the term "First Industrial Revolution" was coined and the Second Industrial Revolution was defined approximately half a century after the take-off. Both revolutions had matured and gained momentum and both negative and positive consequences of the transformation could be observed and analyzed. The economic consequences of the first industrial revolution were significant, but it took several decades before changes in productivity and the GDP could be measured. Social consequences of the first industrial revolution were harsh and they were thoroughly analyzed by Karl Marx and Friedrich Engels among others already in the middle of the nineteenth century.

The second industrial revolution was monitored closer from the very beginning by the modern news media, which brought the radical innovations and heroic innovators to the international limelight. Economists and social scientists documented changes in national economies and social conditions. Future scenarios were painted, and for the first time, industrial production, manufacturing systems, and supporting infrastructure were included in the policy documents. Positive effects of the Second Industrial Revolution were contrasted to the negative effects of mass production, centralization of production and distribution, and the massive consumption of natural resources. These two contradictory pictures were embodied in the modern industrial society, which replaced slowly and gradually the traditional agricultural societies.

If compared to the first two industrial revolutions, the situation today is very different. Third and Fourth Industrial Revolutions provide very little concrete evidence for the economic and social analyses. Both concepts promise radical changes in the manufacturing systems and major changes in the organization of work and of everyday life. The positive scenarios promise rapid increases in productivity, sustainable production, and higher standards of living. Negative scenarios predict massive elimination of work and many of the current professions, which have formed the foundation of modern societies. How fast these changes will take place? If we draw conclusions from the past experience, the change will be slow and gradual. As Brynjolfsson and others [13] have demonstrated, transformation from one technological system into another was long delayed and far from automatic business.

In fact, we know very little about Industry 4.0 and the Fourth Industrial Revolution. What we know is more about the vision for the future than about actual analysis of the current situation. Conclusions about the future are drawn from the past experience and for this purpose the "Industrial Revolution" is a credible concept. However, it is worth remembering that originally the concept was used, when trying to understand the multiple consequences of industrial production. Today, the advocates of the Industry 4.0 and the Fourth Industrial Revolution try to harness the future, which is unpredictable and chaotic. If the concept of Industry 4.0 is placed in this context, it becomes more of a political and an ideological concept, than a blueprint of the technological future.

3 Implications of Industry 4.0 Beyond Technology

What are the social implications of the Industry 4.0.? If this question is viewed from the historical point of view, the answer is less than certain. Industrial revolutions from the late eighteenth century to today have caused massive and mostly unpredictable social changes. Industrial production is based on the interaction between machines and humans, which takes place in the factory. It is a carefully designed space for productive manufacturing of industrial goods. Factory is an artificial environment, which reflects the functions of machines. Manufacturing systems, on the other hand, are both abstract and concrete blueprints, which describe how the flows of raw materials and energy are turned into products. Human labor collaborates with the work of the machines. Machines are able to work without breaks almost 24/7, but human labor must be scheduled differently. How this is done, and who has the power to decide about the division of labor within the factory walls has been, and still is, one of the most heated political, social, and ideological issues [14].

The interplay between machines and human labor started slowly, but escalated during the Second Industrial Revolution. According to von Tunzelman [15], the Second Industrial Revolution integrated useful scientific knowledge into technological developments and brought the results from the collaboration into the factory. Radical innovations in energy technology allowed long distance transfer of electricity to factories. Consumption traditions changed and standardized and inexpensive industrial goods replaced uniquely crafted hand-made products. Factories were organized to follow the philosophies of economies of scale and throughput. The best example of this was the mass production system, which is based on the American System of Manufacturing. Continuous moving belts moved interchangeable parts on the belt, where they were assembled into standardized industrial goods. This production system integrated the human work and the machine work into a seamless web. Production systems required a great deal of coordination and understanding on how human physiology and psychology could be optimized to serve the manufacturing system.

The use of human labor in the manufacturing system has been a permanent challenge since the beginning of the industrial era. Human skills are important and skilled workers are needed to supervise the production and to manage complicated issues. However, human labor is the irrational part of the manufacturing system. Every worker is different and the capacity of workers changes from day to day and from year to year. On the other hand, machine work can be standardized and if managed properly, machines operate without disruptions. Hence, the manufacturing systems have tried to minimize and even eliminate human labor from the system. Fredrik W. Taylor introduced scientific management into factories in order to standardize work and to find the "right man for the right work". During latter part of the twentieth century, automated machines and robots started to take over human work. Information technology and advanced ICT applications have escalated this development and many factories are currently operating almost without human assistance [16].

The Industry 4.0 promises to make even more radical changes in the human-machine collaboration. It is not so far in the past, when the automobile factories employed more human workers than machines. Now the balance has shifted and less and less human labor is needed in the shop-floor level. The technologies of Industry 4.0 have the potential to erase the labor issue by substituting human workforce with an army of robots, automated systems, and algorithms. This applies equally to the semi-skilled and qualified workers, who must compete against intelligent machines and smart systems.

Industry 4.0 will also change the future of professional work. According to Richard and Daniel Susskind [17]: "*In relation to our current professions, we argue that the professions will undergo two parallel sets of changes. The first will be dominated by automation. Traditional ways of working will be streamlined and optimized through the application of technology. The second will be dominated by innovation. Increasingly capable systems will transform the work of professionals, giving birth to new ways of sharing practical expertise. In the long run this second future will prevail, and our professions will be dismantled incrementally.*"

What happens to the social structures and social cohesion, if the Industry 4.0 fulfills its promises? Most European countries have adopted the welfare state model, which builds on high employment, high taxation, and active public participation in social, political, and economic life. In order to sustain the welfare state, industrial societies must maintain economic growth and high employment rates in both public and private sectors. In addition, modern professions are the foundation of modern societies. They foster social mobility and hold the middle-class in place. If modern professions collapse or disappear, the social structures will also collapse. There are already signs of political and social unrest which reflect the fears and frustrations of the middle-class [18].

The link between manufacturing systems and social systems is intimate and historically constructed. Changes in manufacturing systems have always generated social problems, which influence the political discourse. Daniel Buhr points to Elvis Hozdic and observes that the development of Industry 4.0 cannot be isolated from the social and cultural development of industrial societies. Internet, wireless networks, and the uninterrupted flow of information have already diluted borders and created a new social order, where the needs of individual citizens and customers are met by smart factories and flexible production methods. Individualization and the changing prospects of work put new challenges on the welfare state. According to the definition, a welfare state is supposed to counteract inequalities by redistribution and protecting against a set of risks. Industry 4.0 will produce new risks, which will penetrate in the very core of the welfare state. The welfare state is also based on social stratification, which more or less makes gainful employment a privilege. Again, the Industry 4.0 and digitalization puts this principal in jeopardy [19].

Hence, there are two ways to read the current visions of the future of manufacturing. Technological enthusiasm gets the most out of the technological promises that will bring a completely new concept to the industrial production. The Fourth Industrial revolution will bring a set of globally networked economic actors, who will reorganize and restructure the way work is conducted in post-industrial factories. The concept is simultaneously local, national, and transnational. Digital technologies and expanded Internet will allow companies to utilize global value chains and produce digitally manufactured goods to the global markets. Industrial structures are locally based, but they are designed to operate without local connections or regional expertise or labor market regulations. This model will create a globally standardized, networked production and service structures [12].

The other way to approach the Industry 4.0 is to place the concept in the historical context. This takes a relativist stand on the technological enthusiasm and puts light on the complex environment, where the new concept should operate. All industrial revolutions have promised dramatic changes and radical improvements in productivity. None of these visions have materialized, at least in the short period of time. As economic historians, based on the empirical evidence, have demonstrated, technological advances improve economic growth, but the improvements in productivity only come after long delay.

According to Paul David [20], the main cause to the productivity paradox be found in the manufacturing system itself. Factory owners and managers optimize production and they are reluctant to accept radical innovations, which will disrupt organization and working conditions. The other reason is found in the knowledge capacity, which is built into manufacturing systems over a long period of time. Skilled workers, managers and corporate leaders are unwilling to have to learn and adopt new knowledge and new methods—there is a lock-in to what is already known [21]. Hence, the diffusion of new knowledge and innovations slows down.

There is a rich literature explaining why innovations and new manufacturing systems don't break through the old systems. Without going deeper into the discussion, it is worth reminding that manufacturing systems are organic systems, which are managed by people. Although automated systems, robots, and digitalization will take over much of the routine tasks, the foundation of the systems will remain in the hands of skilled managers. Historical examples demonstrate that the change from old to new is always difficult and it involves a complex set of social and cultural factors. It is certain, that Industry 4.0 and the Fourth Industrial Revolution is coming. However, if the development follows historical examples, it is unlikely that Industry 4.0 will fulfill its strategic goals. Technological innovations will affect society, but society will affect technology. What comes out of this interplay is still an open question.

In vein with the above, this book is a collection of articles in the original spirit of the term "Industry 4.0", *focused on manufacturing* and presenting a holistic view of modern manufacturing. "Manufacturing 4.0" is presented, discussed, and analyzed in light of the technical, the economic, and the societal through visiting the past, the status quo, and imagining the future.

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