Mohammad Dastbaz
Peter Cochrane
Editors

Industry 4.0 and Engineering for a Sustainable Future

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ISBN 978-3-030-12952-1 ISBN 978-3-030-12953-8 (eBook)
https://doi.org/10.1007/978-3-030-12953-8

Library of Congress Control Number: 2019936003

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This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Acknowledgements

We would like to thank all the contributing authors for their tireless work and for providing us with their valuable research work which has made this edited volume possible. We would also like to thank the Springer editorial and production team, Amanda Quinn, Brian Halm and Brinda Megasyamalan, for their patience and valuable advice and support.

Special thanks go to Atlanta Blair who worked tirelessly in organising our almost impossible schedules, getting all the necessary forms done and sending numerous e-mails and gentle reminders when necessary, and also to Jane Cochrane, for helping Peter and I to get together for some key discussions around the book and its key concepts.

Finally, our thanks go to all our colleagues at the University of Suffolk; BT Research Centre at Adastral Park; Matrixx; Ericsson; BMW; Maastricht University; Saïd Business School, University of Oxford; Cracow University of Economics; TRADE Research Advisory (Pty) Ltd; the University of East Anglia; the University of Northumbria; Leeds Beckett University; and Qatar Computing Research Institute that have made significant contribution to our work and have informed the ideas and core discussions, which are presented in this edited volume.

Mohammad Dastbaz
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Chapter 1
Industry 4.0 (i4.0): The Hype, the Reality, and the Challenges Ahead

Mohammad Dastbaz

Introduction

In the aftermath of the 2008 global financial crises, a debate around how to recover from the crises and ensure future growth, as well as the role of technology in the future of this growth, is pursued. In a report titled "Industrie 4.0" (Industry 4.0), the German government through its "Ministry of Education and Research" and the "Ministry for Economic Affairs and Energy" proposed a national strategic initiative focused on building a digital society and pushing digital manufacturing into an ever-expanding interconnection of products, value chains and business models (European Commission Report 2017).

While the report generated a lot of interest and it was followed by the German government initiating ten "Future Projects", the reality is that 7 years later and despite numerous debate and position papers both from industry and academia, the full concept and potential of Industry 4.0 remain largely poorly understood and not widely implemented or exploited.

In a report published by Deloitte on "Industry 4: Are you ready", in January 2018, Punit Renjen, its global CEO, writes: "… Wristwatches monitoring vital signs to warn of impending heart attacks. Factories running at optimal capacity, with every process monitored and adjusted in real time. With the emergence of big data, cloud computing, the Internet of Things, 3D printing, and more, this is the world being ushered in by the fourth industrial revolution (Industry 4.0)" (Deloitte Review 2018).

The report highlights the fact that only 14% of CXOs are confident that their organisations are ready to fully harness and benefit from what i4.0 has to offer.

Before attempting to provide a framework of what i4.0 in its current stage of development is, what are the key areas of technology that define i4.0 and how we can move beyond the jargons and the hype, it will be useful to provide a historical context to i.4.0 and its predecessors and how they impacted our development over the past 250 years.

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M. Dastbaz, P. Cochrane (eds.), *Industry 4.0 and Engineering for a Sustainable Future*, https://doi.org/10.1007/978-3-030-12953-8_1

Historical Context

The extant literature indicates that the Industrial Revolution started in the 1760s in Britain. With the emergence of steam engine and steam power at the dawn of the first Industrial Revolution (and from now on i.1.0), a significant shift in the mode of production from cottage industry production to large-scale mechanisation took place. The dawn of the Industrial Revolution and the shift from framing/cottage-based production to large-scale factories also signalled the beginning of an era of significant scientific discoveries and innovation (Dastbaz et al. 2016).

From “the spinning jenny” that increased wool mills productivity in 1764 to James Watt’s first reliable steam engine in 1775, the “telegraph communications” in the early 1800, and finally Joseph Aspdin who, in 1824, devised and patented a chemical process for making “Portland cement”, the world rapidly changed, in both producing manufactured goods to how we rapidly developed population centres (town and cities). According to Eric McLamb (2011), following the Industrial Revolution in the late 1700s, the world’s population grew by 57% to 700 million and then quickly reached the billion mark by 1800, and within the first 100 years of the Industrial Revolution, it grew by a further 600 million to reach 1.6 billion (MacLam 2011) (Fig. 1.1).

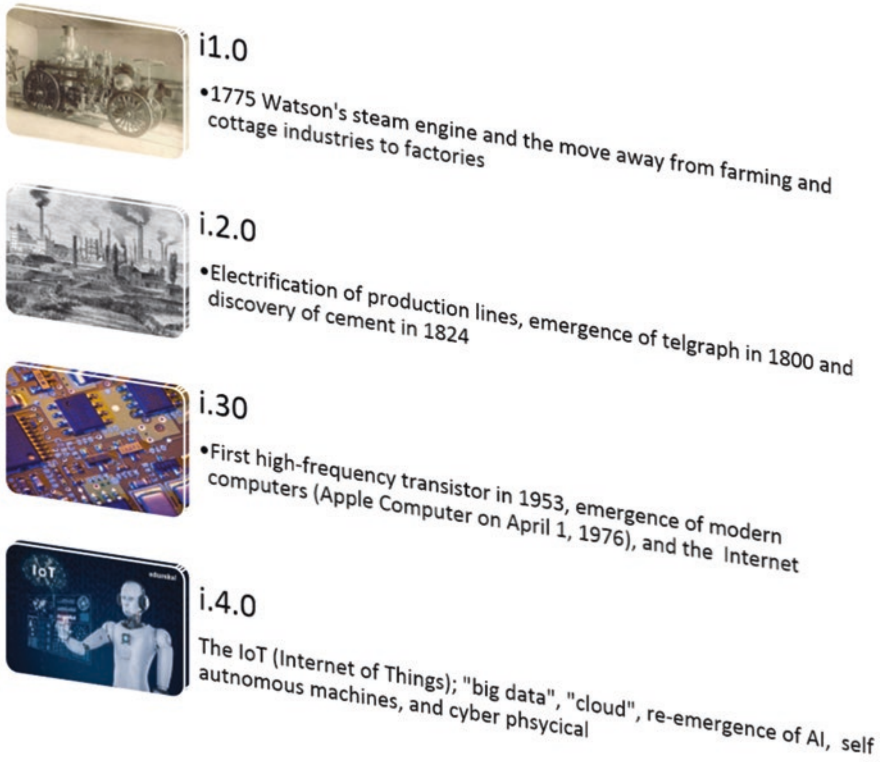

Fig. 1.1 Time line for Industrial Revolution 4.0

Key Technical Advances: High-Frequency Transistors, IC, and ARPANET

Looking at the how our current technological advances have been affected, one could identify a number of key technical advances that all happened within a span of two decades following the end of the World War II.

According to historic documents, the transistor was invented by three American physicists, John Bardeen, Walter H. Brattain and William B. Shockley, at the American Telephone and Telegraph Company's Bell Laboratories in 1947–1948 (Development of Transistors n.d). The transistor's high reliability and low consumption as compared to the electron tube, as well as its capacity to compress complex circuitry into a small device, made significant changes to the development of modern electronics (Fig. 1.2).

Following the invention of the transistor, it was the emergence of integrated circuit (IC), first successfully tested in September 1958, by Jack Kilby, that paved the way for the emergence of the modern computing.

In his patent application on 6 February 1959, Kilby described his new device as "a body of semiconductor material … wherein all the components of the electronic circuit are completely integrated"(Winston 1998).

Fig. 1.2 An old Motorola television from 1948 with electron tubes. (Image sources: https://www.antiqueradio.org/motvt73.htm)

The capability provided by the IC to produce microchips with large number of transistors, diodes and resistors made possible the production of both powerful mainframe (large-scale) computers and microcomputers with higher operating speeds.

At the same period that rapid changes were taking place in the hardware industry and companies like Intel (1968) and Apple (1976) were developing new products not aimed at large military or scientific labs but for the mass market, there was significant developments made in creating systems solutions (software) to work with the emerging new power of these computers. The emergence of companies such as Microsoft (1975) and the development of new “operating systems” [such as DOS (disk operating system)] which provided a more manageable, user-friendly interface with the new microcomputers can be viewed as a revolution and the dawn of the digital age.

Gordon Moore, the co-founder of Fairchild Semiconductor and CEO of Intel Corporation, noted in 1965 that there was the strong possibility of doubling the number of components per integrated circuit every 2 years (this is now referred to as “Moore’s law” although this was only an observation). In his paper “Cramming More Components onto Integrated Circuits”, Moore wrote: “The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas”(Moore 1965) (Fig. 1.3).

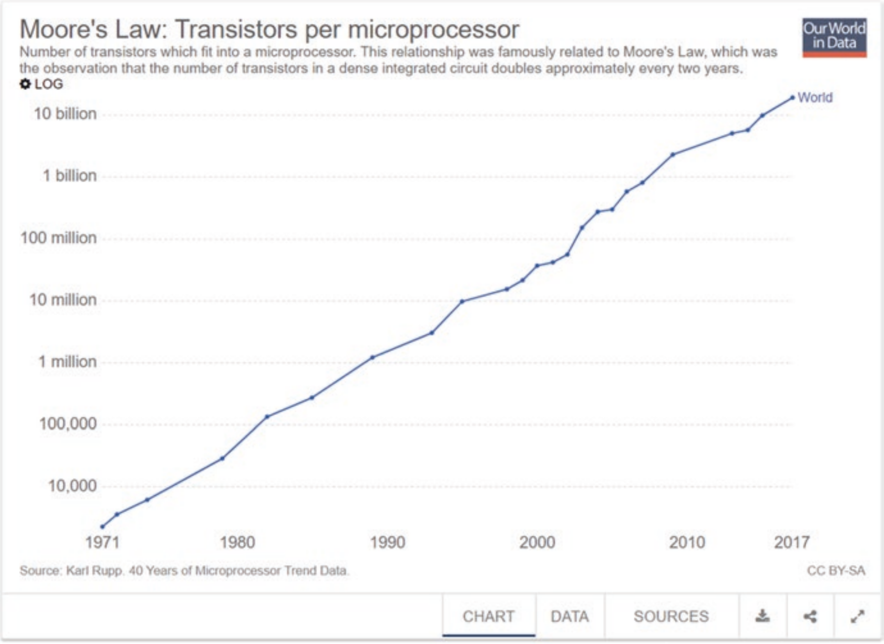

Fig. 1.3 Increasing number of transistors per microprocessor over the last four and a half decades. (Source: https://ourworldindata.org/technological-progress)

An important part of the current information revolution relates to the concept of creating "networks" of machines that exchange data across long distances. Perhaps the most notable of network projects that prepared the ground for the emergence of the Internet was Advanced Research Projects Agency Network (ARPANET). The first network structure that used an innovative packet switching data exchange protocol was called "Transmission Control Protocol (TCP)". On 29 October, 1969, the first message was sent over the ARPANET link from Leonard Kleinrock in UCLA to a second node at Stanford Research Institute in Menlo Park, California. The message was simply "Lo" instead of the intended word "login" ("Charley Kline Sends the First Message Over the ARPANET" n.d.)

It was this combination of advances in hardware and software design as well as the emergence of network technologies that provided the building blocks of the new digital universe with its billions of connected users and yottabytes (YB) of data being exchanged (1 YB = 10^{24}bytes = 1 000 000 000 000 000 000 000 000 bytes = 1000 zettabytes (ZB) = 1 trillion terabytes (TB)).

Industry 4.0: Hype or Reality?

The rapid changes in the power of computing and the wide reach of the technology, which almost covers the entire planet and every aspect of our lives, fundamentally changed the way the industries worked, businesses operated and how we live and communicate.

It's also worth noting that while there has been some justified criticism about hyping the concept of i4.0 to sell products and solutions that are hardly anything significantly different to what has been around for a while, there are significant new products and solutions following the technological advances that we have seen over the last decade that will bring significant changes.

A report by KPMG titled "Beyond the hype: Separating ambition from reality in Industry 4.0" warns against unrealistic expectations and warns: "Everyone wants to talk about i4.0. From industry conferences and magazines through to boardroom tables and shareholder meetings, i4.0 is at the top of the agenda. The pressure on executives to adapt and compete is tremendous. But there is also a lot of hype. Projections for the i4.0 market run into the trillions. Forecasts for potential value creation are eyewatering. Revenue expectations at manufacturers and at service providers — are flying high. Depending on who you talk to, the disruption for value chains, employees and business models may be fundamental…" (KPMG Report 2017).

In response to the sceptics, it is fair to point out that the modern computing technology, as already stated, has been around for over six decades, but the pace of change and the hardware and software power to enable this change are not comparable to anything we have seen before. Therefore, it is safe to assume that we have entered a new era of an Industrial Revolution that is as significant as the first one and will no doubt change the future of humanity for good. While it is important to note that we are at the beginning of this road, and there are still significant challenges ahead, we also acknowledge the opportunity and look to see how i4.0 will impact our future.

Understanding Industry 4.0

The extant literature provides a range of definitions and identifies several key components and challenges where i4.0 is concerned. For the purpose of this book, the key features and technological enablers for Industry 4.0 are summarised as below:

1. *Internet of Things (IoT)* – The backbone of the ever more connected world where various devices be it personal or industrial are connected through the Internet, thus creating a new digitally connected world with billions of users and providing new possibilities for knowledge, data and process sharing and exchange.
2. *Cloud Computing* – According to Microsoft, "cloud computing is the delivery of computing services – servers, storage, databases, networking, software, analytics, intelligence and more – over the Internet ("the cloud") to offer faster innovation, flexible resources and economies of scale" (Microsoft n.d.). Everything from our "Gmail" to our Internet search and financial exchanges online uses cloud-based services. According to Statistica: 2018, approximately 3.6 billion Internet users are projected to access cloud computing services, up from 2.4 billion users in 2013.
3. *Big Data* – Over the past decade, there has been a significant amount of data produced, stored and shared across the Internet. The concept of "big data" deals with volumes of data storage and traffic unparalleled before the age of Industry 4.0. While it is difficult to provide an accurate estimate to the amount of data stored and trafficked across our digital universe (as this is a constantly changing volume), one way to provide an estimate for data currently stored on the Internet or on various cloud services is to look at data held by all the big online storage and service companies such as Google, Amazon, Microsoft and Facebook. Estimates are that the big four hold at least 1,200 petabytes between them, that is, 1.2 million terabytes of data.
4. *Digital Manufacturing/Production (Factory 2.0)* – From the emergence of 3D printers to laser machinery, and robots replacing humans in factories, it is not difficult to see how manufacturing has changed in the twenty-first century. There are several interesting case studies where it can be demonstrated how technological advances have changed the design and production process of goods. The car industry is one such case study where the old production lines, with hundreds of thousands industrial workers, have been replaced with robots (Fig. 1.4).
5. *Industry 4.0 Logistics* – One of the key discussion areas around Industry 4.0, besides its usage in manufacturing and production, has been around logistics and how traditional warehouse operations have been revolutionised.

Fig. 1.4 BMW plant in Spartanburg, South Carolina. (Source: https://www.bmwblog.com/2015/10/30/behind-the-scenes-in-a-rare-factory-tour-of-the-bmw-spartanburg/)

Logistics 4.0 and Supply Chain Management 4.0 deals with the use of a combination of i4.0 technological enablers to provide for various aspects of end-to-end logistics and supply chain management. A good example of i4.0 in logistics and supply chain management is the ever-growing operations of Amazon, one of the world's largest online retailers that has replaced its traditional warehouse and managing delivery operations with advanced computer systems and robots (Fig. 1.5).

6. *Cyber-physical Systems (CPS)* – It is the concept of integrating physical processes with computation and networking power, where intelligent software process, monitor and control physical processes. An interesting example of CPS can be found in research around "Smart Living" where the movement of elderly people living alone can be monitored for potential problems and then provide support by raising an alarm automatically.
7. *Re-emergence of Artificial Intelligence (AI) and Autonomous Systems* – One of the most striking technological developments over the past decades has been around AI and the potential new areas of application and development. While AI systems have been around for decades and as a young graduate doing information systems engineering in the 1980s and programming with languages such as PROLOG (programming in logic) and LISP (list processor), the reality was that mainframe systems such as DEC10 could not provide enough processing power to develop the complex systems that we are able to develop today. Using very powerful parallel processing systems, we are now able to develop ever more complex systems, tackling difficult problems in medicine, engineering, etc. and

Fig. 1.5 Amazon bots in action in their warehouse. (Source: https://qz.com/709541/amazon-is-just-beginning-to-use-robots-in-its-warehouses-and-theyre-already-making-a-huge-difference/)

Fig. 1.6 Erica Aoi the first android employee on Nippon TV. (Source: https://www.broadcastingcable.com/post-type-the-wire/nippontvericaaoi)

finding new solutions. The use of AI as a research and development tool has opened a whole new era of innovation, and with it several difficult philosophical questions and challenges were solved. It is worth noting that in April 2018, it was announced that "Nippon Television Network Corporation" (Nippon TV) will be welcoming its new "anchor Erica Aoi" as its first android employee (Fig. 1.6).

8. *Augmented Reality* – The extant literature points to the ever-growing use of augmented reality in smart manufacturing, medical research and engineering. Volker Paelke (2014) presented "an augmented reality system" that supported human workers in a rapidly changing production environment. The system provided