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Chapter

The Fourth Industrial Revolution: A Technological Wave of Change

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Abstract

This chapter focuses on the technological wave of change called the fourth industrial revolution (4IR), which is also known as the information age or industry 4.0. It starts off with a brief history of the concept, describing the evolution through the ages, from the age of industrialization to the current technological age. The chapter then presents industry 4.0 through three lenses, which are i) the key enabling technologies that serve as its foundational pillars, such as the Internet and Cloud Computing; ii) technologies and concepts that emanate from 4IR, as well as their applications, which are discussed using use-cases; iii) the impacts of industry 4.0 on the wider society (both positive and negative). Finally, the chapter closes with a discussion on some open challenges that need to be considered in future research works to enhance the widespread adaptation and/or implementation of industry 4.0.

Keywords: big data, cloud computing, cyber-physical systems, information and communication technology, industry 4.0, industrial revolution, internet of things

1. Introduction

The phrase “industrial revolution” (IR) is often associated with progressive transitions in the way things are done, specifically as a result of technological enhancement or enlightenment. Within any given society, IR reshapes the processes therein through several waves of changes that directly impact the people’s general way of life. Manual and laborious processes are replaced with automated and mechanized systems, while antique processes are replaced with contemporary solutions.

Till date there have been four (4) industrial revolutions. Though historians refer to the “industrial revolution” as the first industrial revolution (1IR), this chapter makes a distinction between both, by referring to “industrial revolution” as the wave of technological advancements that bring about changes to societies, while 1IR is the first of such revolutions. The four IRs, their respective timelines and impacts are well documented in literature, hence not elaborately repeated in this work, but concisely highlighted on Table 1.

The third and fourth industrial revolutions are interwoven, with many of the offerings of the third industrial revolution (3IR), including pervasive computing and
The fourth industrial revolution (4IR) can thus be considered a logical extension or continuation of the 3IR, as it builds on many of the same concepts and technologies that enabled the 3IR.

This chapter focuses on the 4IR, which is also known as the information age or industry 4.0. It discusses the 4IR through three lenses, viz., the key enabling technologies that form the foundational pillars of the 4IR, technologies and concepts that emanate from 4IR, and the impacts of 4IR on society, both positive and negative.

2. Enabling technologies of 4IR

This section would discuss five foundational technologies that enable the 4IR. These are: ICT & Networking, Internet of Things & Sensor Networks, Big Data & Data Analytics, Cloud, Fog & Edge Computing, and Artificial Intelligence & Machine Learning.
2.1 ICT and networking

2.1.1 Information and communication technology (ICT)

The phrase Information and Communication Technology (ICT) consists of two parts: Information that refers to processed data and Communication or Telecommunication (Telecoms) and that can be defined as the transmission of information over wired or wireless media, and often over a considerable distance. Communication in itself often connotes the exchange of information between two or more parties; hence, the above definition is apt. Advancements in technology, particularly during the 3IR, led to the rapid growth of ICT. The key enablers of this unprecedented growth were transistor chips and the Internet (and its associated world wide web or www), as shown on Table 1. Transistors revolutionized computers, while the Internet “shrunk” the world and made it a global village.

The 4IR is characterized by rapid digitization, growth of pervasive & ubiquitous devices, and prevalence of connected devices – both personal and industrial. A relatable example is the “smartphone”. Figure 1 shows the growth of smartphone usage in the closing 5 years of the 3IR versus the last 5 years of the 4IR. The figure shows a steady rise in smartphone sales between 2007 and 2010, with the numbers escalating from around year 2011. Coincidentally, 2011 is arguably often regarded as the beginning of the fourth industrial revolution (4IR) by some authors. Another example is the Internet, with its increased penetration especially in the global south countries of the world. Figure 2 shows the global percentage of users with access to the Internet in various regions of the world grouped based on level of development. In the figure, “developed” includes countries of the western world, “developing” includes countries in Africa, Asia, and South America, and “Least developed countries” (LDC) include rural remote regions of the world. Internet accessibility in LDC and developing countries is shown to have more than doubled in 2019 compared to 2009.

2.1.2 Next generation networks

Over the years communication networks have evolved through five generations. The first generation was mostly analogue based fixed telephone lines supporting voice calls.

Figure 1. Comparison of Smartphone sales between 2007 and 2011 and 2017–2021. Adapted from reference [8].
only. The second generation introduced digitisation and mobile networks, as well as support for SMS and MMS through GPRS. The third generation introduced better support for multimedia including video streaming and social media, while the fourth brought improved download speeds and reduced latency. The 5th Generation (5G), which is the latest communication standard is still in its deployment stages. It promises several features including up to 10 Gb/s connection speed, lower energy utilization (up to 90% conservation), better availability and coverage, support for a significantly higher number of simultaneous connections, lower network latency (in the order of milliseconds), as well as support for multi-tenancy and modular programmability.

**Figure 3** reveals some key application areas that will be significantly enhanced by the 5G mobile network such as i) residential use, ii) Internet-of-things, iii) infrastructure connection, iv) inter-vehicle connection, and v) augmented and virtual reality. These enhancements would leverage on the increased coverage, high bandwidth, low latency of 5G, coupled with cross-integration of multiple networks including terrestrial networks and aerial networks [10].

### 2.2 Internet of things and sensor networks

Internet of Things (IoT) can simply be described as fitting everyday objects with Internet connectivity feature. These objects or things might include TVs, air...
conditioners, doors/windows, vehicles, and heavy machinery etc. and are embedded with uniquely identifiable computing nodes. Key components of this IoT definition are “connectivity”, which refers to networking; “embedded”, which refers to the infusion of miniaturized devices with built-in sensing and actuation capabilities; and “uniquely identifiable”, which implies distinct addresses either via IPv6 or Media Access Control address (MAC). Figure 4 shows a depiction of the constituent features of IoT.

The simplicity, openness, and the fact that IoT builds upon existing network infrastructure and protocols, accelerates its growth and widespread adoption. It is widely estimated that the number of connected devices would grow exponential to close to 50 billion in the next few years [11]. Though several unique (closed) communication protocols exist for interconnecting IoT “things”, recent years have seen a push for openness or interoperability between these protocols. Table 2 shows the IoT stack (loosely based on [14]) compared to the classic network stack, as well as several IoT specific protocols and their respective operating layer.

2.3 Big data and analytics

Big data is a term used to describe large volume of data in different formats (variety), generated at a fast pace (velocity), are of good quality (veracity) and holds significant value. Big data emanates from different sources, including social media, streamed media (videos, images and audio), web pages, and IoT telemetry data; and can be structured, semi-structured, quasi-structured, or unstructured. Storage and processing can be challenging, because big data does not conform to the traditional notions of data structure, and often exceeds the storage and processing capacities of conventional computer systems. Federated CPS that relies on a federation of physical systems (such as those proposed in [15, 16]), and/or federation of virtual entities techniques (such as proposed in [17]) could be potential solutions to these issues.
Typical big data processing pipeline include i) Data sourcing; ii) Data collection and ingestion; iii) Data storage & warehousing; iv) data preparation, including pre-processing, de-duplication, filtration etc.; v) Data processing and mining, which are the process of discovering patterns, trends, and/or valuable information from large data using statistical and/or machine learning models [18]; vi) Data analytics, vii) Data visualization; viii) result evaluation and application. These processes are summarized in Figure 5. By combining qualitative & quantitative analyses, visualization
& dash-boarding, with data mining performed on big data, big data analytics can
improve processes in diverse domains including agriculture [19], education [20],
health [21], etc.

2.4 Cloud, fog and edge computing

In simple terms and from the end-user's perspective, Cloud computing (CC) is a
model that shifts computing from physical devices to a service [22]. It allows users
to transfer the “headaches” of managing computing infrastructure to a third party
(Cloud service provider (CSP)), and instead focus on their core business or goal. On
the other hand, the CSPs (with expertise in computing) ensure satisfactory service
delivery at agreed price points, using virtual machines [23, 24]. Services offered by CC
include but are not limited to storage, high performance computing (HPC), and
software/hardware on demand, making CC a key backbone of many of today’s dis-
ruptive industries.

Cloud computing offers several services, common amongst which are infrastruc-
ture as a service (IAAS), wherein HPC are dynamically provisioned for data
warehousing, analytics, or machine learning tasks. When developing web, mobile or
desktop applications, the platform as a service (PAAS) Cloud service model provides
bespoke application development toolkits, which can significantly reduce application
development time. Finally, the Software as a service (SAAS), avails Cloud users with
ready-made software solutions, thus eliminating the need to install software on per-
sonal computer systems. CC can arguably be considered as the foundational enabler of
the 4IR. The true power of the Cloud as an enabler of the 4IR comes in form of
everything-as-a-service (or XAAS). Where X can be cars, as is the case of on-demand
car services provided by the likes of Bolt and Uber; or X = Multimedia or video on
demand, such as Netflix and Apple TV; or X = houses - Airbnb; or X = storage - Google
Drive and One Drive; or X = Data, which incorporates elements of data analytics, data
warehousing, visualization and dash-boarding; or X = productivity/office, where
products such as Office 365, Zoho, SAP, and Salesforce, offer remote work and
productivity solutions to billions of users globally; and X = Education, with
Massive Open Online Courses (MOOC) and Learning Management Systems, such
as Sakai, Udemy and EdX which offer remote teaching/learning and education
management [25].

2.4.1 Fog and edge computing

Certain Cloud application domains, such as dynamic traffic routing, e-Logistics,
ambulance routing, self-driving cars, require fast, on-demand and real-time informa-
tion from processed data. CC, though capable, is ill-suited for such application areas
due to latency emanating from the distance between the Cloud data centre and the
data source. Fog and Edge computing have been proposed as potential solutions to this
challenge. Fog Computing is a form of distributed CC, where portions of the compu-
tational processing that would typically have been done in the Cloud are handled by
smaller computing nodes. The Fog layer thus serves as a middle layer between the
Cloud layer and the data source. The proximity of the Fog nodes to the data source
helps reduce latency emanating from network congestion, bottlenecks, and band-
width limitations [26]. Being a HPC node, the Fog can perform high intensity com-
putations in real-time and only forwards data meant for long-term storage, batch
processing and/or advanced computations to the remote Cloud.
On the other hand, Edge computing devices are low powered computing nodes placed next to the data source. These devices are responsible to routing, collecting, filtering, and aggregating data collected at the source. They might include network gateways, such as wireless access points, network switches, network routers, single board computers (such as the Raspberry Pi or Asus Tinker board), or micro-controllers (such as the Arduino or ESP32).

Figure 6 shows a depiction of the Cloud, Fog, and Edge computing layers in a generic Cyber-Physical network. The image shows the Fog and Edge layers being sandwiched in between the physical/device layer (data source) and the Cloud computing layer.

2.5 Artificial intelligence and machine learning

Artificial Intelligence (AI) is a technique for building systems that mimic human behaviour or decision-making. Machine Learning (ML) is a subset of AI that uses pre-existing data to learn and automatically classify or make predictions. There are four main types of ML methods, which are: Supervised ML, which learns by example and yields output based on provided data; Unsupervised ML, which seeks to identify patterns in raw data without the need for examples; Reinforcement Learning, which learns using reward-based system, in which good decisions are rewarded, while incorrect decisions are penalised; Deep Learning, which is a special subset of ML that relies on multi-layered artificial neural networks to solve complex tasks. AI and ML have been used to identify faces and objects, detect tumours, navigate self-driving cars, and in language processing to analyse, understand, and generate human language, whether written or spoken.

Perhaps the most obvious/real life examples of AI are the ever so popular digital assistants – Amazon’s Alexa, Apple’s Siri, and Google’s Assistant. These assistants are now seemingly commonplace and integrated into numerous “smart” products, including speakers, TVs, watches, and phones. With these assistants, users can order items from stores, control home appliances, pay bills or book flights by simply starting their voice command with “Alexa ...” or “Siri ...”. 

Figure 6. The 4 Layers of a generic cyber-physical network based on ITU architecture [14].
3. Emergent technologies, concepts and applications

This section discusses several derivative solutions or systems of industry 4.0. The systems are presented as use-cases which showcase the various applications of technologies of the 4IR. For each system, a high-level description of the use-case is presented, followed by a brief discuss of the underlying 4IR technology. Building on Figures 6 and 7 shows a CPS orchestration framework which encompasses both the physical and cyber worlds, through the integration of various 4IR technologies, particularly IoT, Cloud Computing, data analysis, storage, machine learning, and insights.

Many concepts emerging from industry 4.0 are largely deployed using the orchestration framework shown in Figure 7. The physical consists of appliances, machines, or human entities that need to be monitored or tracked. This is achieved using sensors which measure environmental and/or physiological variables such as temperature, humidity, oil level, running time, heart rate, oxygen level etc. These parameters are then collected at the edge, where pre-processing (aggregated and/or filtration) takes place, before being forwarded to the Fog or Cloud for advanced processing, storage, and analysis. The final output is inference, which can be used to make informed decisions and/or make necessary adjustments at the physical level. The entire process can be described as a data pipeline flowing from the physical space to the cyber-space and back to the physical, as described in [27]. Figure 7 would be used as a guide to discuss the selected use-cases, while Table 3 summaries the various components of each level.

3.1 Use-case 1: health monitoring system

This is an application of 4IR wherein wearable devices fitted with sensors are used to actively monitor physiological parameters. These devices collect relevant data and are connected to software applications, through which the wearer or professional, such as healthcare officers (doctors) or fitness coaches, can monitor relevant information. Applications include sports and fitness trackers, cardio and respiratory

![Figure 7. CPS orchestration framework.](http://dx.doi.org/10.5772/intechopen.106209)
<table>
<thead>
<tr>
<th>Use-case</th>
<th>Physical</th>
<th>Edge</th>
<th>Fog</th>
<th>Cloud</th>
<th>Inference</th>
<th>Actuation</th>
</tr>
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</table>

Table 3.
CPS orchestration framework components for each use-case.
monitors, child minders and infant trackers etc. Several health and fitness monitoring systems were discussed in [15, 21, 28].

In context of the CPS orchestration framework, relevant sensors are used at the physical levels. Protocols, such as the Health Level 7 (HL7) and servers are considered at the Edge and Fog levels respectively, while hospital management systems can be deployed as SaaS solutions in the Cloud. Inference might include health conditions, sleep patterns, emergencies, etc. for which relevant actions, such as doctor’s appointments, medical prescriptions, or ambulance could be dispatched. One such system is described in [29], where cyber-healthcare kiosks were proposed to support healthcare systems in developing countries.

3.2 Use-case 2: smart traffic and road systems

Smart traffic and road systems (STRS) include smart roads, driver assistant, traffic congestion monitoring, smart traffic and streetlights, smart parking, smart transportation etc., some of which are briefly described as follows.

Smart roads and intelligent highways are classic road networks which have sensors installed to monitor various road conditions and report same to commuters. Smart traffic and streetlights are improved versions of their traditional counterparts. Smart traffic lights are fitted with sensors to measure traffic intensity at road intersections and dynamically control traffic flow accordingly [30, 31], while Smart streetlights measure ambient light to autonomously switch themselves on or off. Driver assistant systems provide real time information on traffic situation to drivers and can also include drowsiness detection. Smart parking systems allow communities make optimal use of parking spaces while enabling drivers reserve or locate parking spots [32]. Other road-based solutions that have emerged from 4IR, including driver monitoring, smart mobility & carpooling, Bus Rapid Transport (BRT), traffic surveillance & license plate detection, electric vehicles, etc. as reviewed in [33]. Table 3 summaries the technologies at play at each level of the CPS orchestration framework w.r.t. STRS.

3.3 Use-case 3: e-Logistics

e-Logistics is multi-faceted and incorporates several complementary solutions, including transportation, real-time tracking, geo-location, courier, and cargo delivery services. Delivery services, encompasses the entire process flow required to transport cargo from pickup to delivery points. The technical requirements for each delivery differ and depend on the size, weight, type, and content of the cargo being transported. To instance, high valued items might require real-time tracking using GPS receivers, while sensitive and/or delicate cargo might require maintaining certain ambient conditions such as temperature and humidity.

For the CPS orchestration, the physical layer might require RFID or NFC modules for cargo tagging and identification, as well as sensors to gather data on the cargo and its surrounding environment. The Edge would include data aggregators and network gateways, through which telemetry data are sent to the Cloud, while the Cloud layer could house software for visualization, mapping, and customer engagement.

3.4 Use-case 4: smart factories and manufacturing

Perhaps the most direct impact of industry 4.0 is the automation of manufacturing processes. Gartner describes smart factories as new forms of efficient and flexible
manufacturing, powered by the interconnection of processes, diverse real-time data sources, and individuals (operators, maintenance officers, etc.) who interact with these systems [34].

Smart factories connect the physical and cyber world together in a bid to monitor (and control) end-to-end manufacturing processes. These processes begin with the procurement of raw materials, tracking their shipment, monitoring parameters from various machines, packaging of finished produce, and the delivery of finished goods. Parameters of interest within the smart manufacturing process might include fuel levels and usage estimation, ambient temperatures, air quality, levels of CO$_2$ and other gases, oil levels etc. These data parameters are then fed into CPS, where ML and data analytics are used to obtain relevant inferences, such as failure metrics (Mean Time Between Failures - MTBF, Mean Time To Repair - MTTR, and Mean Time To Failure - MTTF). With this information, preventive and corrective maintenance can be scheduled, avoiding the need to shut down the factory (stopping production and revenue generation) due to faulty equipment.

3.5 Use-case 5: smart energy and grids

Traditional electric grids are based on a closed system of production, transmission, distribution, and consumption, with no provision for the exchange, visualization and security of information and energy flows between operators and customers [35, 36]. These classic grids adopted a top-down architecture, with a centralized producer supplying the necessary energy to consumers. Smart grids (SG) in contrast, are made up of decentralized power sources, mostly renewable or “green” energy, which rely on ICT to control the flow of energy and information in real-time to customers. Being made up of several decentralized power sources, SGs employ bi-directional architectures consisting of both the top-down and bottom-up architectures. The bottom-up architecture is one in which the consumers can also produce energy which is fed into the grid, thus, becoming “prosumers”. Beyond the grid, sustainable energy usage is an ever-present concern in today’s energy market. Several solutions have been proposed including energy efficient appliances and smart appliances, which learn usage patterns through machine learning, and automatically switch themselves on or off [37, 38].

Regarding the CPS orchestration framework, the physical layer might include solar panels, smart meters, adaptive lighting, and motion sensors. Gateway appliances running protocols such as Bluetooth Low Energy (BLE) and ZigBee might be found at the Edge layer, while the Fog and Cloud are merged to provide solutions for remote appliance control and monitoring, as well as billing and metering solutions. Finally, drawn inferences might include energy consumption patterns, while actuations involve remote appliance control.

3.6 Other emergent technologies

**Digital Twin:** A Digital Twin (DT) is a digital replica of a physical object or concept in the real world. The replica which receives data from the real world is able to mimic and “act” in a manner similar to its real world instance. This ability makes DT technology ideal for prototyping and simulating world events and settings to develop appropriate responses to external stimuli. It is a technology that infuses IoT, AI and Data analytics, as data received from IoT sensors in the real world are fed into AI, mathematical, and/or statistical models from which decisions and useful inferences are obtained.
Blockchain: A blockchain is a sequence of “blocks”, each containing a list of transaction records, stored cryptographically in linked distributed databases (chain) [39]. In essence, Blockchain is an immutable way of storing information. It is characterized by high security, as it uses unique digital signatures and cryptography; and decentralized control, through a peer-to-peer network of consenting users, who control and authorize transactions. It has been applied in numerous fields including finance (cryptocurrency) [40], trading [41], health [42], logistics, construction engineering [43], and in almost any area where secure and accurate record keeping is required.

4. Impacts of the 4IR

This section discusses some of the direct impacts of Industry 4.0 on the lives of people and societies in general.

4.1 E-commerce

E-Commerce or electronic commerce is a system of trading carried out via the Internet. The growth of the Internet during the 3IR could be considered one of the catalysts for the wide adoption of e-commerce. This adoption has since risen astronomically, particularly in the 4IR era, with the proliferation of smartphones, tablets, and other mobile devices. Amazon, Alibaba, Best Buy, and eBay are some well-known global online retail stores, most of which accept payment through various means including physical cash, credit/debit cards and NFC-based payment [44] such as Apple Pay, Samsung pay and Google Pay.

The impact of e-Commerce became more apparent during the recent Covid-19 global pandemic, which called for isolation and physical distancing to reduce its spread. People relied heavily on technology to shop for necessities, contactless deliveries, and payments. Figure 8 shows the monthly year-on-year growth of...
e-Commerce in 2019 vs. 2020. As of April 2020, the number of orders placed on e-Commerce platforms had almost doubled the number from the year before at 96% increase.

Hybrid stores or “Just Walk Out” or “till-free” stores are becoming increasingly popular. As the name implies, a “just walk out” store is one wherein a buyer, after picking any item of interest, simply walks out of the shop without visiting the counter/till to pay. These stores use artificial intelligence, weight sensors on shelves, and cameras to monitor buyers, automatically determine which items were selected and bill the customer. Examples of these stores are Amazon Go and Telesco GetGo stores.

4.2 Remote workers

An indirect impact of technologies of the 4IR is remote working or tele-working. This is a system wherein employees carry out their tasks or jobs from locations different from the physical building of the employer. Industry 4.0 technologies including high speed Internet (5G), tele-conferencing solutions (such as Zoom, Microsoft Teams), augmented/virtual realities, and collaboration tools (Github, SharePoint), have greatly enabled remote work. The Covid-19 pandemic also popularized remote work as “working from home” became a norm between late 2019 and 2021. These years saw tele-conferencing solutions including Google Meeting, Zoom Microsoft Teams etc. replace in-contact meetings.

4.3 Education

The education sector has also been greatly impacted by the 4IR. Like with remote workers, the education sector has also seen a surge in the number of remote teaching and learning especially through Massive Open Online Classes (MOOC). In the era of Industry 4.0 the traditional brick and mortar classrooms are either being complemented by or replaced by online alternatives. MOOC, such as Udemy and Coursera, offer teaching and learning solutions that are completely independent of physical classroom environments. In cases where traditional classrooms are being augmented, 4IR offerings, particularly virtual and mixed reality, allow students immerse themselves in a virtual world, giving them first-hand experiences of the concepts being taught. Immersive technologies are commonly used in specialized industries where training equipment are either too expensive or delicate to leave in the hands of trainees. These include the aviation industry, where augmented reality is used to teach pilots and astronauts [45], in medicine to train medical students [46], in agriculture to teach farmers the concept of crop rotations and use of tractors [47], etc.

Though the Internet has been the major catalysts of change, other factors have also played their roles in reshaping the education sector. For instance, smart television and touch screens now enable interactive learning for kids and toddlers, while Podcasts, Webinars and MOOC allow a single lesson to reach billions of globally disperse learners in an on-demand fashion. The authors in [25] discussed several considerations for remote teaching and learning especially from the perspective of developing countries.

4.4 Media and entertainment

The impact of 4IR has also been felt in media and entertainment. The penetration of smartphones, smart-TVs, and reliable internet has increased the consumption of
high-quality, and often bandwidth heavy contents, such as 4K videos and game streaming. Industry 4.0 has brought about a major yearning for on-demand and ubiquitously accessible media contents. Classic videos on tapes, DVD and Blu rays have been replaced with on-demand streaming from online platforms such as Netflix, YouTube, Apple TV etc. Hard copies of photo albums have been replaced with Instagram and Snapchats, while classic hardware music players have been replaced with streaming services such as Spotify, Deezer and Apple Music. Recent statistics reveal that streamed contents accounted for over 83% of all consumed media, with Spotify accounting for about 33% (180 million subscribers), Apple music with 17.5% (or 90 million subscribers), Amazon music accounting for 14% (77 million), YouTube Premium with 50 million subscribers, and YouTube (free) with over 2 billion users monthly.

Furthermore, 4IR has also changed the way people socialize, with the shift from physical to online socialization. There are now a plethora of social media platforms including Facebook, Twitter, Instagram, Snapchat, WhatsApp etc., with built-in support for direct messages (chats), group messages, and voice & video calls. Using these solutions, friends and families can stay in touch with one another despite being globally disperse. Recent 2022 reports suggest that more than 58% of the world’s population (4.6 billion people) use social media, with most users spending an average of about 2.5 hours daily on these platforms [48]. Figure 9 shows that within the last decade, the number of social media users has tripled from about 1.5 billion in 2012 to over 4.6 in 2022.

4.5 Transportation

Smart transportation and mobility are another significant impact of the 4IR. Smart transportation encompasses a broad range of concepts including but not limited to vehicle-as-a-service (ride sharing/carpooling, riding hailing), bus rapid transit (BRT), smart roads, autonomous vehicles, electric cars and bicycles, transport monitoring and tracking, and car park management, most of which are accessible through a mobile device [33, 49]. Similarly, several 4IR technologies including IoT, Big data analytics, ML, Fog and Cloud computing are being fused together to achieve
autonomous vehicles navigation. Likewise, IoT, GPS, RFID and NFC are highly influential 4IR technologies in Logistics services and delivery services globally. Several smart transportation solutions, specifically variants of riding sharing, ride hailing, and courier/logistics services, have been deployed globally. These are mostly due to the increase in Internet and smartphone penetration rate in the last few years. For instance, online ordering and delivery of food, a form of logistics services, has become a norm in recent times [50, 51], while ride sharing services and ride hailing have continued to grow globally, even in developing countries [52, 53]. Leveraging on 4IR offering, insurance firms are able to monitoring driving behaviour [54, 55], while haulage companies can measuring fuel consumption in trucks [56].

5. Open challenges

The advantages and applications of industry 4.0 are numerous, some of which have been discussed above, however, there are several challenges hampering the widespread deployment of some of these applications. This section briefly discusses some of these open challenges.

5.1 Bandwidth and infrastructure requirement

With the plethora of social media applications, tele-conferencing solutions (Zoom, Teams), media streaming platforms (Netflix, Hulu), connected devices (smart appliances, connected homes), wearable technologies (smart watches, health monitors), the demand for reliable data access, greater network coverage, and bandwidth has sky-rocketed. Internet service providers (ISP) must be prepared to upgrade or perish. ISPs of today need to be flexible, dynamic, and agile enough to changes their mode of operations to suit dynamic customer demands, as well as, be ready to upgrade or replace ageing infrastructure with modern alternatives. For instance, classic active devices such as routers and switches might need to be replaced with those that support software defined networks, wherein the control and data planes are decoupled, and traffic flows are customised [57]. 5G and 6G are also on the horizon, hence, ISPs must make extensive plans and invest in capacity building. There is also the concern of seamless integration with existing solutions that must be considered, as the transition to 5G/6G would most likely be in phases. Adequately maintaining existing solutions while gradually adopting emerging ones is pivotal for the success of 4IR solutions providers. It is also important to note that Internet penetration in rural and less developed areas is on the rise and must be catered for. The utilization of Unmanned Aerial Vehicles (UAVs) to provide 5G network support in these locations might be viable solutions to consider [10].

5.2 Big data

By definition, “Big data” should implicitly spell trouble for data centres and ISPs, as they must process enormous volume of data (in petabytes) with minimal delays. Managing, processing, storing, and backing up these enormous amounts of data in batches or in real-time (streaming) can be a major challenge. Building data warehouses and HPC solutions to manage & process petabytes of data can be prohibitively expensive for most organizations. One solution could be cooperative Fog/Cloud federation, whereby small Cloud infrastructures are collaboratively operated, networked,
and managed by a group of organizations with common interest [16, 58]. Another alternative could be through partnership with third party solution providers such as Google (Google Cloud Services), Amazon (Amazon Web Services) and Microsoft (Azure).

5.3 Security and privacy concerns

Preservation of security and privacy is a major concern in today’s data-centric world. The IoT, despite its bells and whistles still has several privacy concerns. There is the ever-present threat of unauthorized access to smart systems (homes, buildings, cars) or hackers tapping into feeds from security cameras to spy on people. Moreover, in wearable technology where BLE is prevalent, performance degradation due to electromagnetic and inter-channel interference, specifically for medical devices, is also a major concern [59].

Beyond IoT, issues such as transboundary data ownership and jurisdictions are also major concerns. In many countries, legal, privacy and ethical issues relating to the use and access to sensitive data, such as those on health, judicial, and intellectual properties, remain open challenges, especially in instances where such data are stored on remote Cloud servers located in a different country [60]. Though policies are now in place to address some of these challenges, such as the Protection of Personal Information Act (POPIA) [61], and the General Data Protection Regulation (GDPR) [62], implementation and/or compliance remain a big challenge.

5.4 Interoperability

There are several protocols upon which 4IR technologies operate. These protocols enable the collection, storage, and exchange of data between various components. They include but are not limited to Li-Fi, Wi-Fi, 3G/4G/5G, ZigBee, Z-Wave, BLE, SigFox, NB-IoT, LTE-M etc. Unfortunately, many of these protocols are developed by different manufacturers and are used on their own appliances, hence, closed off to solutions from different manufacturers. This closed-source ecosystem limits the interplay between equipment and often forces users to be locked into using solutions from specific vendors. Currently, no single vendor can provide equipment to cater for all the phases of an integrated industry 4.0 system, and by operating in closed-source silos, manufacturers increase overall cost of ownership, limit vertical and horizontal scalability, and stifle innovation. Collaboration is thus paramount for scalability and growth. However, multiple studies have shown that proprietary technology, poor coordination, and lack of standards are primary factors limiting inter-operability and collaboration. To combat this, open industrial standards are required which allows for cross-vendor support and global interoperability. By providing APIs, standardized open-source messaging protocols (such as MQTT, HTTP) and RESTful solutions can be deployed to expand the application use-cases.

6. Conclusion

The fourth industrial revolution (4IR) or Industry 4.0 has indeed brought about a disruption to societal lives and the world in general. The world is now driven by data and the Internet, with some describing data as the new oil of the 21st century. Globally, data intensive activities, such as remote learning, gaming, video streaming,
and video conferencing, have grown dramatically in recent times and would probably keep growing.

This chapter has discussed the technological wave of change called the 4IR. It started off by defining the concept of Industry 4.0, and then its evolution, from the industrial age in the seventeenth century till date, was discussed. The foundational enabling technologies of the 4IR, including ICT, IoT & Big data, Cloud computing, etc. were presented; followed by a discussion on various application use cases using an orchestration framework. Finally, some societal impacts of industry 4.0 were given, including its impact on education and transportation. The chapter then concluded by discussing some open challenges facing the full-scale adoption and/or implementation of industry 4.0, and proposed plausible solutions to them, including cooperative collaborations and the need to embrace open standards.

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