India Studies in Business and Economics

Keshab Das
Bhabani Shankar Prasad Mishra
Madhabananda Das *Editors*

The Digitalization Conundrum in India

Applications, Access and Aberrations

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ISSN 2198-0012 ISSN 2198-0020 (electronic)
India Studies in Business and Economics
ISBN 978-981-15-6906-7 ISBN 978-981-15-6907-4 (eBook)
https://doi.org/10.1007/978-981-15-6907-4

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

In the process of economic development, late industrializing countries are both burdened and freed by new technological developments. Non-capitalist social relations, strong legacies of colonial institutions, and underdeveloped state capacity hamper the narrowing of technological gap with the front runners. At the same time, late entry could be an advantage in skipping reinventions and avoiding large infrastructural investments in bygone technologies. Thus, leapfrogging some technologies becomes a reality. Yet the conundrum faced by the Global South is the unequal access and the continued coexistence of obsolete and advanced technologies in the socio-economic system. Of course, this should not come as a surprise if we read into the techno-economic paradigm literature where a specific carrier technology is not completely dissipated before the birth of a new carrier technology.

To take a simple contemporary example, within the automotive industry, the presence of internal combustion engine (ICE)-driven vehicles coexists with electric cars. Neither radical innovations nor the innards of these products resemble the earlier vintages since the application of a new carrier technology, namely digitization and information technology, has thoroughly transformed these products even if the basic function remains moving from point A to point B (D'Costa 2019). To stretch the example further, the development of self-driving cars or autonomous vehicles is a further development of the product. It represents the convergence of technologies with the application of advanced electric motors, battery innovations, software, GPS-based communication systems, and big data analytics. As self-driven vehicles become shared, the concept of a personal vehicle itself is transformed to platform-based operations such as Uber.

What is missing from the above example is the social context in which new technologies are adopted, including but not limited to social and economic domains in which they are applied. Other factors such as the degree of accessibility, cultural receptivity, global competitive pressure, importance of the regulatory environment to obtain the most favorable outcomes for social well-being, and the design of institutions that facilitate the diffusion of such technologies are also part of the social-institutional milieu. In the absence of critical social and political economy analysis of innovations, the grand narrative of technological change remains rose tinted. In the real world, and certainly in the Global South, where multiple communities with widely varying economic, educational, and social and political standing coexist, it is obvious that new technologies will have a differential impact, both enabling and detrimental on society and polity.

As an observer of digital technologies in the 1990s, I have had the opportunity to work with a number of scholars to document both the global ascendancy of Indian information technology (D'Costa and Sridharan 2004, D'Costa 2002), the application of such technologies in the 'new economy' (D'Costa 2006), and the uneven impact and the social divides associated with digital technologies (D'Costa 2003a, b) despite the wide diffusion of such technologies. Today, we are under the spell of a different carrier technology (still unnamed and unformed completely), combining a plethora of interrelated innovations such as internet of things (IoT), artificial intelligence (AI), big data, 3-D printing, and cloud computing to name a few. These are radical innovations by the standards of the 1990s. These promise liberating humankind from the drudgery of work reduce despair from disease and ill-health, enhance food insecurity for the poor, and ensure reliable delivery of government services, among others. Yet each one of these promising applications is replete with challenges such as inadequate incomes to access such technologies, illiteracy let alone IT literacy that constrains the effective use of new technologies, massive backlog in physical, educational, and ICT infrastructure, poor quality of education, and shortfall in public sector administrative capacity to manage the challenges faced by the poor, the disadvantaged, and the vulnerable. In many ways, despite the rise of new technologies old problems do not disappear, instead new challenges surface.

In this edited volume, Keshab Das, Bhabani Mishra, and Madhabananda Das have mobilized a group of fine young Indian researchers to reflect precisely on these types of issues and anticipate the uneven impact and social challenges in adopting new digital technologies across multiple themes and sectors. Their broad focus is on the digitalization of the Indian economy with the added emphasis on social inclusion and equity. In the true spirit of interdisciplinary scholarship on technological change and social impact, the contributors have combined their collective expertise from computer and information sciences, the social sciences, development studies, and management. Their investigation is multifaceted with wide-ranging implications for critical analysis and policy interventions such as oligopolistic tendency of new digital technology firms and thus the significance of competition policy and regulatory institutions for technology diffusion, data management and its privacy, and legal frameworks to ensure consumer protection with the rise of e-commerce. With these thematic areas the authors in this volume reveal the complex technology-society interfaces and policy implications in a number of sectoral and project domains. To list a few, they cover Indian agriculture and public health services covering pest control and degenerative diseases, telemedicine, disaster management, and signature verification in vernacular languages for reliable access to and efficient distribution of social security services.

As the various chapters in this volume suggest, technological change is like a double-edged sword; it is disruptive and enabling. It is a harbinger of *achhe din* (good days) just as it is a threat to employment and social justice. New technologies create and destroy jobs. They allow the few well-educated and skilled to join the new world of cutting-edge innovations while the many already confined to precarious jobs face the threat of automation. It is hard to imagine how the digitalization of the Indian economy will meet the employment needs of 16 million new workers entering the workforce every year. After all, not all new digital jobs are glamorous. In fact, many like their low-wage informal sector counterpart are also low-wage, white collar service sector jobs. Even as technology democratizes certain types of consumption, in others it reproduces and exacerbates pre-existing inequality. The dilemma facing late industrializing countries is that new technologies are attractive and available for economic advancement. However, the institutional context as it exists be it weak social predisposition to scientific temper, lack of political commitment to uplift the downtrodden, short-sighted leadership in policy making, and the growing power of big foreign and domestic business is not conducive to a democratically-inspired technology-society interface. This widely-known cautionary tale needs retelling, as this volume does, so that the conundrums and disruptions posed by new technologies become public knowledge for better social decision-making. This collection of essays on digitalization of India rises forcefully to that expectation.

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Acknowledgements

The idea of this book emerged out of an interesting conversation between the co-editors at KIIT University, Bhubaneswar, wherein the intensive and extensive presence of the information and communication technology in day-to-day activities and larger sectoral level in the Indian context seemed an important subject to delve deeper. As it was a classic phenomenon of science-technology-society interface we thought of creating a platform where engineering scholars would share their science-based analyses with those from social scientists and development practitioners towards enriching our understanding of technological applications in real-life societal and policy spheres. This was a bit complex process as there were issues which needed to be deliberated upon with an approach and semantics that would be intelligible to any interested reader irrespective of profession or *core* discipline. Contributors to this volume come from diverse intellectual and professional pursuits and that is the newness and strength of this output.

The co-editors place on record their gratitude and sincere appreciation for every contributor of this volume for her/his efforts, patience and kindness throughout this arduous journey.

We are earnestly grateful to Professor Anthony P. D'Costa, Eminent Scholar in Global Studies at the University of Alabama, USA, for writing a deeply perceptive 'Foreword' for this volume. Some of his observations merit detailed research in the context of late industrializing economies including India.

Thanks are due to the Management of KIIT University, Bhubaneswar and the Library staff at the Gujarat Institute of Development Research, Ahmedabad for all their support at various stages of preparation of the manuscript.

We are immensely thankful to the wonderful team at Springer for their support and pleasant dealings in turning the manuscript to this book. We specially thank Sagarika Ghosh, Nupoor Singh, Ashok Kumar, Ravivarman Selvaraj, Gowrishankar Ayyasamy and Vishnu Muthuswamy for their pleasant engagement all through.

We all contributors are hopeful that this book would be of interest to a wide variety of readers and might spark an idea or two with some to undertake more intensive and socially-useful research or action in the future.

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Contents

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Chapter 1
The Digitalization Conundrum in India: Context and Concerns

Keshab Das, Bhabani Shankar Prasad Mishra, and Madhabananda Das

1 Introduction

Since the turn of the millennium, the pace and spread of digitalization in India—whether promoted or spearheaded through the state, private sector or global capital—have come to be recognized as a significant phenomenon not merely in the sphere of information and communication technology (ICT) perse but its multifarious applications spreading across almost all aspects of production, services and institutions. Digitalization in its myriad forms has had profound implications for the transformation of the society and economy at the micro, meso and macro levels. Digitalization encompasses the whole range of processes from basic computerization of information (including data analysis, storage, management and sharing) to automation of manufacturing processes (or 'tasks') to engaging robots for various utilities in both work and living spaces.

In India, the ICT sector has risen remarkably and the globe has recognized its prominent position in terms of contribution to software development as also participation in the global business process or management outsourcing (Das and Sagara 2017). During the last decade or more, there have been momentous transformations in the digitalization field which are collectively denoted as 'disruptive technologies'. These include such transformative technologies as artificial intelligence (AI), cloud computing, big data analytics and algorithms, internet of things (IoT), automation, e-commerce, delivery robots, driverless cars and 3D printing to mention only the prominent ones. Unlike heavy machines (embodied technology), most of these technologies defy physical space, conventional infrastructure like transportation, pace of

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_1

mobility and inoperability between technologies. From an economic development perspective, these special characteristics/properties of the new technologies would imply massive changes in the nature and extent of demand for certain kinds of physical infrastructure as well as skill sets. The very global nature of these seamless technologies where inter-operability remains the quintessential advantage of digitalization the Indian economy and society are unlikely to stay insulated from changes in the technological and concomitant spheres of finance, labour and trade.

As the changes occurring and those waiting to happen have been posing new challenges to governance and economic development of India (Sagara and Das 2019), it is important to form an idea about the nature and implications of such changes as these would impact the micro, meso and macro levels of resources, organizations and activities.

Given the complexities of the nature of interface between the new technology and the socio-economics of India, the present volume explicitly draws upon interdisciplinary scholarship and diverse professional pursuits; contributors and editors belong to computer and information sciences as also social sciences, management and development studies. This is probably for the first time that articles from engineering/technical professionals have been carried together with those with a predominantly social science or development studies persuasion towards addressing discrete various relevant issues in the process of digitalization in India.

It is realized that technological innovation, economic growth and overall human wellbeing are intricately linked (Mishra et al. 2011). The relationship between the customers, workers and employers is redefined by the modern digital platform. As computing power improves significantly and more people are participating in the digital economy, attention should be given to design new policies which will exploit the advantage of information and technology by minimizing the error (O'Sullivan 2019). The digital revolution is global, and the pace of adaption and policy reactions are largely national reflecting different economic structure and social preferences (Muhleisen 2018). IT industry and researchers are mostly working towards using disruptive techniques effectively and efficiently in the fields of agriculture, and healthcare, banking, transport and numerous critical services which will improve the quality of the common people.

2 A Compendious View on the Contributions

The chapters in this volume have been carried in two broad segments mainly to distinguish chapters with a greater emphasis on technical applications from those dealing with the interface of technology with the socio-economic dynamics in the Indian context.

2.1 Part I: Technical/Engineering Applications and Infrastructure

Weaving together the literature on technology evolution, information/network society and digital economy, Francis (Chap. 2) argues that several structural features built into many digital markets make them inherently exclusionary. It discusses different strategies used by innovators and fast followers in the digital era to consolidate their monopoly positions (including their proprietary ownership of platforms and control over data) and for erecting barriers to make entry for new entrants. These cause the adverse incorporation of developing country economies into these markets and lead to asymmetric benefits for them. Lead firms are also integrating new digital technologies into the production of goods and services in myriad ways. This presents new challenges to the Indian economy in the ability of its firms to survive against the onslaught of imported digital products and services across sectors. With data as the prime driver of many of the new digital technology systems, policy choices in the digital space will decidedly influence India's digital transformation trajectories in the services and the industrial or agricultural production spaces, as well as the overall societal outcomes. Therefore, India's 'digital development trajectory' needs to be guided by the government by quickly putting in place adequate regulatory systems and policies related to data ownership and data protection as well as privacy and security standards. Reformulating competition policies as well as our trade and investment policies to reflect the emergent concerns also come within the ambit of the regulatory shake-up that is urgently needed to allow secure and sustainable digital catching up by India.

Growth of information technology has attracted many researchers to use various computational techniques in different domain to optimize the objectives which may fall under single or multiple criteria. The efficiency of an algorithm depends upon different factors, and one of the major factors is the computation or processing speed of the system where the algorithm is going to be executed. In the current trend quantum computing has attracted many researchers to use it for solving problems which are more complex and do not give the result even within a considerable amount of time. Pattnaik et al. (Chap. 3) present fundamental aspects of quantum computing and its application in the area of healthcare and agriculture. They have touched inform different challenges to be addressed in the area of quantum computing which would act as a foundation for young researchers to address new issues in the domain.

In the domain of healthcare, constant health monitoring of the aged, post-surgical monitoring, prediction of degenerative diseases like cancer, tumour, heart disease, Alzheimers, dementia and so on, there exist numerous applications of the wireless body area networks (WBANs), which are based on big data analytics. The long-term data hugely facilitate medical practitioners to analyse patients' health status to arrive at appropriate diagnosis and provide immediate and effective healthcare solutions. As the continuous monitoring of the physiological parameters such as sugar level, heartbeat and respiration rate results in the generation of large volume of information, big data analytics along with the IoT technology would help the medical professional to analyse better and make efficient decisions in eHealth and mHealth scenarios. Bhanumathi and Sangeetha (Chap. 4) examine the decision-making architecture for the degenerative disease, namely the Alzheimer's Health Management and Analysis (AHMA), with the help of sensors, big data and IoT. This degenerative disease is one which would kill a patient in the long run and would typically remain asymptomatic for long. With this advancing technology, the disease analytics are becoming easier and time-saving in analysing the disease profile. As these patients cannot be interviewed for a longer duration, the big data derived from the system remain extremely useful for taking decisions.

Efforts to transform the healthcare system from the clinic-centric environment to personalized information-allied environment have involved the usage of IoT technologies for automated and efficient monitoring of daily activities of patients of all age groups. By bringing physicians and the ailing onto a single platform, the new technology provides 'one stop' service to people at remote locations by network architecture that undertakes continuous monitoring of body signals based on sensors. Considering the rapid developments in the sphere of IoT in healthcare technology, Swapna Rekha et al. (Chap. 5), through an extensive survey of literature, trace the antecedents, assessment standards and progress in research made of the emerging technologies. This review, thus, provides clues to cope with challenges such as management of data, compatibility, security, adaptable and privacy.

Focusing on the farm sector, Mallick et al. (Chap. 6) discuss the implementation of newer technologies in creating smarter ways towards judiciously using available energy resources. Through three major case studies this chapter addresses diverse problems faced in agricultural practices. The first case relates to the facial recognition technique which helps in detecting presence of the worker who was assigned a certain job and as per the requirement, the machine would start. In case of occurrence of air pollution, the sensor would detect and activate the air purifier. The second case depicts the design for a smart greenhouse equipped with monitoring systems and temperature, moisture and light sensors that would create a self-regulating environment to provide an optimal condition for the plants to grow and efficiently save energy at the same time. The third case addresses the issue of detecting coffee plants infested with bugs which produce a characteristic noise and cause stem rot in the plants. An amalgamation of a noise detecting sensor, drone with GPS facility and a robot equipped with cutting of the infested plant has been suggested. The potential of undertaking such challenging projects lies in the fact that these would pave the way for spearheading technological advancements in India at the global platform.

Acknowledging that most of the developed countries have invested in disruptive technologies in the farm sector to achieve excellent results, Salma and Narasegouda (Chap. 7) present a comparative case study of agricultural IoT in India and the USA with the central purpose of providing details related to the impact of the technology on the socio-economic life of farmers and its impact on the growth of the agriculture sector. This has been attempted by discussing various statistical and technical details related to IoT in agriculture. It explains the current agricultural practices carried out in India and its impact on sectoral income in the GDP growth, while emphasizing the role of IoT, its applications and benefits in the context of Indian agriculture.

Based on a detailed survey of literature on digitized handwritten signature verification system, Rohilla and Bawa (Chap. 8) take us through one of the discrete complexities of the digital world, namely, the problem of recognizing a person through various biometric applications. In order to recognize an individual, even as various unique physical biometric patterns like face, iris, fingerprints, and so on exist along with some of the behavioural biometric patterns like signatures, voice, gait, and so on, handwritten signatures play a major role in our daily life. This chapter discusses the recent work done on online and offline modes which are the two ways of digitizing handwritten signatures. A comparison of these studies has been attempted on the basis of various features and techniques used. The raw features such as the image of signature and position coordinates, time and pressure have been considered in the offline and online signature verification, respectively. For matching the signature pattern many artificial intelligence-based techniques and machine learning algorithms, like support vector machine, hidden Markov model, neural network, fuzzy logic, deep learning, etc., have been used in developing different handwritten signature verification systems. The authors also highlight some signature verification systems which have considered handwritten signatures of different languages like Arabic, Chinese, Japanese, Bangla, Hindi and English. The performances of such signature verification systems would pave the way for conducting more intense work using other Indic scripts-based signatures.

2.2 Part II: Access/Use, Aberrations and Obstacles

With the phenomenal rise in e-commerce and consumer internet industry in India whether in retail, grocery delivery and food tech, the spread of the technology could be observed much beyond the metro cities in tier II and III cities. However, the space ceded from traditional businesses to online commerce has policy implications for consumer trust and confidence—one of the foundations in a market economy. A legal solution to this problem is found in the concept and device of consumer rights so that factors such as information asymmetry, collusion between manufacturers and retailers, fraud, cheating and unfair trade practices do not disadvantage consumers, vis-à-vis sellers, or become a hindrance in expansion of businesses. Gupta (Chap. 9) addresses these dimensions, initially, through a brief overview of the architecture for protection of consumer rights in e-commerce in India. This includes the Consumer Protection Act 1986 and 2019. The author then examines a few consumer cases filed in e-commerce category at the district, state and national consumer forums in India so as to answer certain pertinent questions in this field which might engage the attention of policymakers and researchers alike. This enquiry delves into a series of concerns. First, what are some of the major consumer issues and frequency in e-commerce in India? Second, is the current three-tier framework of consumer courts at the national state and district levels, sufficient to address the growing volume of consumer complaints in this area? Third, do consumer courts have adequate capacity to deal with questions involving consumer interests in a field that requires technological knowledge apart from the legal know-how? The chapter proffers alternatives and policy suggestions towards strengthening consumer protection to achieve the twin goals of swiftness and fairness of decisions on consumer complaints and cases in the e-commerce domain in India.

Digital technology has transformed the financial services sector in revolutionary ways. All facets of financial service provision and consumption have been affected by disruptive innovations, making it difficult to systematically assess its actual impact and develop appropriate regulatory responses. In India, the great push for adoption of digital technology in the financial services sphere coincided with the launching of the ambitious project of Aadhaar in 2010, and the accelerated diffusion of smartphones and internet connectivity. The second wave of financial inclusion that started around 2015 leveraged the Aadhaar infrastructure to open bank accounts (under the Jan Dhan Yojana) on a mass scale and make all government benefit payments digital and direct-to-account. The financial inclusion programme currently rides on what is known as the JAM (Jan Dhan-Aadhaar-Mobile) trinity. Nair (Chap. 10) examines how the digital technology-aided financial inclusion drive has performed in India over the decade 2010–2020.

Data science is the new buzzword in the information technology industry. The skill of a data scientist is currently in high demand and is also one of the highest paying jobs in the service sector. Analytics using IoT and data science is slowly becoming an allied industry of the IT sector in India. The IBM has predicted that demand for data scientists will soar by 28 per cent by 2020. More than 50 per cent of this demand would be in finance and insurance, IT and professional services. The trade-off in the creation of decent work and automated work in the sector remaining an area of concern. Trade-offs also exists between the profitability of IT firms and costs of deployment of automation in the sector. Emergence of the new knowledge economy has called for changes in the labour regulations of the industry as the nature of work in such industries is distinctly different from the traditional industries. Using both primary and secondary data, Nizami (Chap. 11) examines the nature of work in IT analytics industry and the labour regulations required to improve and reform the working conditions. An attempt has been made to understand the possible skill gaps in the labour market. Reflections on the nature of transformation of the technology–work interface would have implications for policymakers and labour analysts to gauze the future of work in the industry.

Policy efforts at mitigating systemic barriers to widespread socio-economic deprivation, especially in rural India, have led to the introduction of a variety of social security measures. However, the implementation of these measures has often been constrained by and criticized for leakages in the system and lack of granular information essential for the smooth functioning of these schemes. Despite taking recourse to ICT to improve their public outreach, technology did not prove to be the silver bullet that it was expected to be. Varying degrees of digital development, access to ICT, differentiated informational requirements and the digital divide have posed challenges to the same. Taking cognizance of these challenges as well as India's rising internet user base, many platforms like Haqdarshak, Schemopedia and India

Iris were developed. As discussed at length by Patel et al. (Chap. 12), the GIS-enabled entitlement tracking (GEET) system is a similar effort undertaken by the Foundation for Ecological Security in association with the Ministry of Rural Development and United Nations Development Programme, to promote information democracy. The platform is an interesting example of enabling better first mile (usually termed as the last mile) delivery of social security schemes through a strategic mix of online as well as offline activities like collation of information about benefits, eligibility criteria as well as concerned authorities related to various state and centrally sponsored schemes, capacity building and promotion of local leadership.

The role of mobile application in agricultural development in India has been explored by Kumar (Chap. 13) with an emphasis on challenges of implementation. Mobile technology is being used in the collection of ground data, infrastructure facilities, asset mapping, disaster management, incident alerting, and so on. Moreover, recent advancements in smartphones, GPS, wireless networks and web GIS have facilitated the development of customized mobile applications for domain-specific attribute data collection with geo-tagging and field photographs. The mobile applications not only help in standardizing the data collection process but also help the user to collect the field information at ease and in a systematic manner through the rich graphical user interface (GUI). Constraints, nevertheless, abound in actual application and access by farmers who may be disadvantaged, for instance, by illiteracy or even unable to afford a mobile phone. In order to enhance the use of mobile phone-based information by farmers, especially for the small and marginal and those loacted in remote areas there is a need to create awareness and provide training and subsidize costs related to mobile services. There is also a need for a platform where all actors involved in the system, whether producers and sellers, shares and uses data and experience.

With the open science momentum gaining momentum ever since the launching of the preprint repository Arxiv.org in 1991 and the signing up of the global declaration Budapest Open Access Initiative in 2002, free online scholarships have been receiving support from research funding agencies while they are committed to the dissemination of results of public-funded research studies to common citizens. The global South, particularly, the BRICS nations are leading the developing nations in producing open access scholarship. In India, many universities and research institutions have established their respective open knowledge and research data repositories. At the same time, scholarly periodicals published by many of the public institutions have also been made accessible online freely; this is in keeping with the salience of open research data within the open science ecosystem. Globally, FAIR Data Principles have been adopted by the scientific community to make research data findable, accessible, interoperable and reusable (FAIR). The FAIR Data Principles were published in 2016, while the term was coined in 2014. Das (Chap. 14) discusses the key features of FAIR Data Principles and highlights issues and challenges in an open research data ecosystem in the Indian context. It also compares the availability of open research data in India vis-à-vis that in the global South through examples of a few success stories.

Since about the late of 1990s there have been massive transformative changes in the computer and information science (CIS) discipline requiring substantive overhauling of existing systems of technical education—curricula, courses offered, teaching skills, supportive infrastructure and, importantly, placement possibilities. Even as the Indian CIS education system (in terms of number of institutions offering such courses, enrolment, placement, etc.) has been on a growth path at least since the mid-1980s or so, in recent decade a series of *disruptive* technologies have necessitated a complete revamping of the existing curricula and methods of imparting education under the CIS discipline. This has led to different educational institutions responding differently—some seeing this as beyond their capabilities while others hoping to catch up with the new dispensation. Addressing the major churning taking place in the sphere of professional education in CIS in India, Sagara and Das (Chap. 15) have made an attempt at empirically tracking the contours and extent of changes as may be surmised from the All India Council of Technical Education (AICTE) data, mainly. The study takes into account a wide variety of CIS courses and those are/were offered in technical institutions in India over about the last couple of decades and analyses implications of such performance of the CIS education in India. State-level disaggregated data are analysed and are supplemented with policy measures at the national and subnational levels in addressing the challenges of disruptive technologies in education.

By presenting a set of studies largely dealing with the issues and concerns of digitalization in India, this volume is an attempt towards appreciating the policy challenges at the ground level. While technological applications may have opened up several economy and social possibilities their actual access by users could be dependent on the institutional framework within which these function. Moreover, there exist aberrations within the socio-economic context which could act as potential barriers to obtain the benefits of a transformative technological advancement. To the extent this volume is able to raise those underlying concerns and invoke inclusive policy thinking, much of the efforts of the contributors would not go in vain. Hopefully, this volume would encourage deeper engagement with these and related new issues by scholars, policy specialists, development practitioners and, especially, young minds.

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Part I
Technical/Engineering Applications and Infrastructure

Chapter 2
Digital Transformations and Structural Exclusion Risks: Towards Policy Coherence for Enabling Inclusive Trajectories

Smitha Francis

1 Introduction[1]

We are increasingly experiencing the transformative impact of information and communication technologies (ICT) in myriad ways across most areas of social and economic life. The greater ICT-led transformations that we are witnessing now across sectors (compared to the earlier internet phase) follow the emergence of the interrelated technology systems driven by cloud computing, automation, digital platforms, the internet of things(IOT), artificial intelligence (AI), and so on. The increased dynamism is reflected in the emergence of several developing country start-ups. In India, these are the most prominent in service sector activities such as retail, finance, transport, restaurants, hospitality, health and education. Seemingly leveraging India's strength in the IT software domain and driven by new business models facilitated by the new technology systems, these sectors are undergoing significant digital transformation.

Despite the large spectrum of new opportunities offered by such digital technologies for levelling the playing field for developing country firms, digital technologies can entrench some of the existing inequalities in technology access and use, leading to differential benefits from the diffusion of technological advances. The focus in this chapter is on how digital technologies may entrench existing inequalities between developed and developing countries through the latter's adverse incorporation into the global digital economy due to several inherent structural characteristics of the emerging dominant digital markets and the many strategies used by digital innovators and fast followers to sustain their competitive advantages and prevent new entry.

[1]This chapter draws from a working paper (Francis 2018) of the author published by Centre for WTO Studies, Indian Institute for Foreign Trade, New Delhi, and is re-used here with permission.

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_2

The chapter strives for a systematic understanding of technological change in the digital era and the dynamics of the accompanying competitive processes and transformations. There has been a significant evolution in the theoretical understanding of the processes underlying technological change from the time early neoclassical growth theories conceived technological progress as exogenous to firms. As technologies evolve in a complex process influenced by a variety of factors, the nature of competition in the market changes through the different phases, and the changed market structure, in turn, impacts the nature of innovation and diffusion of new technologies. Accordingly, as technologies and products evolve and mature, they present different opportunities and challenges to innovating firms and first movers, as well as for new entrants and fast followers. The rate and effectiveness of the changes in firm and industry structures, as well as the pace and effectiveness of efforts to adopt and master new technologies, depend on the institutional structures enveloping the socio-economic spheres—in particular, on the extent to which state policies facilitate productive transformation through each phase of a technological revolution. All these micro, meso and macro level processes of technological evolution and diffusion involving complex interactions have been captured within the framework of evolutionary (or neo-Schumpeterian) economics, which is found in the most synthesised form in the Venezuelan-British scholar Carlota Perez's techno-economic paradigm.

After briefly explaining this framework in Sect. 2, the chapter analyses the features and phases of the ongoing ICT revolution, including the current digital era, in Sect. 3. It also discusses how transformations being brought about by digital technologies have to be understood at three levels: (i) those in the digital space itself; (ii) those associated with the digital transformation of services; and (iii) those associated with digital transformations in the production space whether in the manufacturing or agricultural sector. Subsequently, Sect. 4 discusses the opportunities and challenges presented at the firm level during each phase of the product/technological lifecycle, to innovators, fast followers and incumbents. Against this backdrop, Sect. 5 discusses different strategies used by innovators and fast followers in the digital era to increase their market share and to erect entry barriers for new entrants from developing countries. This leads to asymmetric benefits from digital transformations for the latter. Against the backdrop of these analyses, in the last section, the chapter discusses the various economic policy changes needed in India to enable inclusive digital transformation trajectories across sectors.

2 The Techno-Economic Paradigm (TEP)

2.1 A Brief Overview of the TEP

Perez synthesised the perspectives from the historical framework of Schumpeter and the Russian economist Kondratiev on cycles and long wave theories of economic development, as well as the neo-Schumpeterian research on innovation, technological trajectories, national innovation systems, and institutions. The latter stream is associated with the names of Richard Nelson, Bengt-Åke Lundvall, Giovanni Dosi, Luc Soete, and so on, and in particular, Chris Freeman and Francisco Louçã.[2] For all these neo-Schumpeterian economists, the description of technological revolutions as processes of "creative destruction" applies not only to the economy but also to policies and institutions. However, as highlighted by Kattel et al. (2009), Perez has gone further than all of them by bringing in the fundamental role of financing in technological change. Perez's framework incorporates the financial infrastructure interplay with innovations and economic activities. Thus, she is able to relate microeconomic innovations with macroeconomic policies and activities, by marrying the historical account with institutional change and macroeconomic and financial issues (Kattel et al. 2009).

Perez (2001) observed that even though there are specific differences between technologies, most technologies tend to follow a similar trajectory as regards the rate and direction of change, from initial innovation to maturity. The lifecycle of a technology commences with the introduction of a new product based on an emerging technology. According to her, after a radical innovation gives rise to the appearance of a new product capable of generating a new industry, there is an initial period of intensive innovation and optimisation, until the product gains acceptance in the corresponding market segment. Once market acceptance is achieved, they are subjected to a series of incremental innovations following the changing rhythm of a logistic curve. While new investment and economic growth are triggered by a radical innovation, investment expansion depends on numerous incremental innovations in product enhancement and process improvement that follow. These incremental innovations have an important impact on productivity increases and market growth. Changes occur slowly at first, while producers, designers/engineers, distributors and consumers engage in feedback learning processes, which become rapid and intensive once a dominant design is established in the market. This process culminates in the product reaching maturity, and changes begin to slow down once again as new investment begins to have diminishing returns (Perez 2001: 113–114; Perez 2009: 3).

The evolution of technology, therefore, is not random or isolated in Perez's sequence model—it is a collective process involving different agents (producers, suppliers, distributors and many others, including consumers). Further, technologies interconnect and tend to appear in the neighbourhood of other innovations. Thus *technological systems* consist of successive new products, services and related industries that build upon the innovative space inaugurated by an initial radical innovation (leading to a new product/technology) and which is widened by followers (Perez 2001). Just as individual innovations are interconnected in technology systems, these are in turn interconnected in technological revolutions. The process of multiplication of innovations and technological systems, both up and downstream from the industries based on radical breakthroughs, forms the core of each technological

[2] See the detailed discussion in Francis (2018).

revolution. In the whole process of diffusion and social assimilation of each successive technological revolution, from big-bang to maturity, there is the recurrence of a sequence—"irruption, frenzy, synergy and maturity" (see, Francis 2018 for a detailed discussion).

Successive technological revolutions and their TEPs are, as Perez showed, the fundamental feature of capitalism after the Industrial Revolution. Accordingly, there have been five distinct technological revolutions and five associated development surges during the last 250 years: (i) the eighteenth century Industrial Revolution; (ii) the age of steam and railways of the early nineteenth century; (iii) the age of steel, electricity and heavy engineering in the late nineteenth century; (iv) the age of oil, the automobile and mass production of the early twentieth century; and (v) the age of information and telecommunication from the second part of the twentieth century.[3]

As mentioned, one of the salient features of Perez's framework is the incorporation of finance into the technology cycle. Under the TEP, the propagation of a techno-economic paradigm is divided into the installation period and the deployment period. In the installation period lasting 20–30 years or more, wherein a new technological revolution acts as the instigator of a new surge of development, financial capital plays a critical role in investments in new technologies. Finance is the handmaiden that allows the new TEP to be explored, exploited and installed before it is fully deployed (Kregel 2009). However, with yet limited scope in these new technologies, overinvestment in them and increased focus on financial profits eventually lead the way to the hyperinflation of asset values and creation of a major market bubble (Kregel 2009). The subsequent inevitable crash leads to the 'Turning Point' in the middle of the propagation of a TEP.

It is clear from Perez's paradigm that it is only once the financial sector is reined in by regulation, and the incentives for investments have been tilted in favour of production simultaneously, the new technologies tend to spread their transformative power across the whole economy over the next two decades or so. The latter constitutes the deployment period (Perez 2017).[4] Unleashing the growth potential of each technological revolution in the deployment period requires overcoming the basic tensions inherited from the installation period. According to Perez (2007: 24), this means:

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[3]It is now popular to use the Fourth Industrial Revolution or Industrie 4.0 to refer to the current transformations. According to Carlota Perez, this different numbering of the Industrial Revolutions sometimes arises from the conflating of the mechanisation era and the steam and railways era. Further, unlike Klaus Schwab's conceptualization of Industrie 4.0, we consider that microprocessors, which led to the eruption of the ICT revolution, continue to be the kernel of most of the technology systems that we see today, while others like biotechnology are generic industrial technologies that have sprung up since the frenzy phase of the ICT revolution (detailed discussion follows in Sect. 3). Also, the Klaus Schwab argument about Industrie 4.0 does not take into account the socio-institutional processes of assimilation of new technologies, which is central in Perez's TEP.

As Perez (2002) highlighted, while the dominant TEP moves through its mature phases (late deployment and decline), a new paradigm is gestating and moving into the early phase of installation.

[4]See https://beyondthetechrevolution.com/blog/second-machine-age-or-fifth-technological-revolution-part-3/.

- favouring long-term over short-term investment;
- stimulating productive investment and employment creation, rather than feeding the financial casino or housing bubbles;
- aiming at innovations for true market expansion and not for quick financial gains, and inducing the search for profits from real production and not from manipulating money.

Each TEP gives rise to a great surge of growth initially in the core group of industrialised countries, where, in addition to the explosive expansion of new industries, new technologies also encompass and gradually rejuvenate most of the existing industries. Perez argues that it is towards the end of the process of deployment of a TEP, when the primary industries of a particular technological revolution face maturity and market saturation that the process spreads to the periphery, while in the core countries the next great surge is already irrupting.[5]

2.2 *Catching-Up Opportunities for the Followers*

Under Perez's TEP, apart from the mature phase of technologies, the other moment when weaker players confront surmountable barriers is not in phases two or three, rather in the phase one of irruption. This is because catching-up supposes a dynamic development process that is fuelled by local innovation and growing markets, and this requires an entry as early as feasible. The irruption phase, thus, happens to be the most promising entry point.

In contrast to how the industries of the mass production paradigm were deployed nationally first before moving internationally, many industries in the ICT paradigm have operated globally from phase one. This has been, in large part, owing to the transformation of the business organisation from the rigid hierarchical pyramids of the mass production age into flexible organisation and adaptable networks in the fifth paradigm based on ICT. This opened up the possibility of participating

[5]Citing the case of countries which had little success in promoting their development during the mass production age, even though they applied "similar" procedures for making use of imported technology like the newly industrialised East Asian developing countries (such as South Korea and Taiwan), Perez (2001) argued that the reasons for the different outcomes are "connected with the nature of the windows of opportunity created by the technological evolution of the leading countries and the capacity for consciously or intuitively taking advantage of them." During the late 1950s to the late 1970s, catch-up development strategies adopted by several developing countries were successful owing to the nature of the techno-economic paradigm in place at the time. While relocation of production from the mature industries in the advanced countries which were faced with "technological exhaustion and market saturation" in their countries provided the push factor, developing country governments adopted different models of import-substitution industrialisation strategies to attract relocation of production by multinational corporations (MNCs). The eruption of the ICT revolution along with the changes in the international trade rules that "penalise" import-substitution industrialisation strategies and promote export-led growth strategies that pushed several developing countries simultaneously into the export markets for similar products have together meant that these conditions have radically changed (Francis 2018).

in global value chains (GVCs) in many roles and with varied arrangements. Even though there are differences in network structures across industries, and crucially between manufacturing, services and natural resources, the ICT revolution has seen oligopolistic/monopolistic innovating firms from the developed countries (and subsequently, a few developing countries) externalising non-strategic activities through various network formations to reduce costs and to coordinate and rationalise various linkages in these network formations.[6] At the same time, strategically, this allows them to increase barriers and alter market structures to their advantage.

However, the experiences of different countries concerning the degree of integration into value chains and net benefits drawn by them have varied. A significant body of empirical research has established that in the relatively strong catching-up region of East Asia (including China), the state has had a strong influence in each case, in particular by protecting the learning efforts (see the detailed discussion in Francis 2019b). It is because of such industrial policy-led learning efforts that these economies have managed to create sustainable links to global production and innovation networks as well as manage the rise of indigenous firms as market leaders.

Given that access to key ingredients or raw materials for technological progress is widely available, ultimately the capabilities to use them—technological knowledge, applications and production facilities—become the critical deciding factor in catching-up strategies. Thus, whether follower firms can "catch-up from behind" (phase four) or forge ahead from the frontlines (phase one), industrial policy has played differing roles in fostering and managing national technological development processes by protecting the learning efforts.

Further, the nature of specialisation or the kind of activities that a country is engaged in during each TEP also determines the factors influencing its ability to catch-up. This is something classical and development economists had pointed out long ago—the presence of increasing returns activities and synergies between different types of economic activities positively influence a country's development trajectory (Reinert and Kattel 2010; Francis 2019b). Interestingly, Hausmann and Klinger (2006) has brought this idea back to conventional economics literature through the 'product space' concept. Note that Perez's conceptualisation of *technology systems,* wherein new technologies, products and services tend to appear in the neighbourhood of earlier innovations, clearly contains the implication that catching-up would involve building up capabilities in the earlier and/or related technologies.

A country's ability to catchup and use new technologies successfully also depends on the existence of certain important complementary factors such as dynamic advantages and different types of externalities, especially the physical, social and technological infrastructure, and often, the existence of competent and demanding local clients. These elements may have been built-up before with mature technologies, or they can be acquired through intensive learning processes and investments in the improvement of the social and economic environment.

[6] See also Ernst (2016).

It must be noted that since the early 1980s, evolutionary economists have emphasized that the characteristics of technology such as path dependencies, linkages, spill-overs, externalities, winner-takes-all markets and highly imperfect and dynamic competition engender long-term structural changes in economies in the form of technology trajectories, paradigms and geographical agglomerations (Karo and Kattel 2011: 182). While these trends and patterns from the earlier TEP will form the base, the uneven and varied response of governments, firms and industries to the threats and opportunities posed by a new wave of technologies will decide whether the new trajectories will tend to accentuate or even out the uneven processes of development globally and within specific economies and societies.

3 Phases and Features of the ICT Revolution

As observed by Perez (2001, 2007), the current ICT revolution had erupted in the early 1970s with its first technology system around microprocessors, their specialised suppliers and their initial uses. Many products of the microelectronics technology system reached phase two at the beginning of the 1980s. The 1990s were marked by the vigorous development of the new telecommunications infrastructure, the wider adoption of the internet leading to the structuring of the emerging industries, and the modernisation of the existing ones. Subsequently, there was an overlapping sequence of minicomputers and personal computers, software, telecoms and the internet, each of which opened new technology systems trajectories through the 2000s, while being strongly inter-related and inter-dependent. As they appeared, these systems interconnected with intense feedback loops in both technologies and markets.

The inter-related upstream and downstream technology systems that have evolved under the current fifth technological revolution—the ICT revolution (variously referred to in the literature as information technology/IT revolution, information revolution, etc.)—are captured in Fig. 1.

The 2008 global financial crisis was initially considered the Perezian turning point for the ICT TEP (Drechsler et al. 2009). However, as Carlota Perez emphasizes, although there have been some post-crisis efforts to regulate speculative finance, policy efforts aimed at redirecting finance towards productive investments have not been intensive enough nor uniform across countries to make a difference.[7] Similarly, despite the urgent need for a drastic change in development models towards environmentally sustainable ones, there is the persistence of the old fossil fuel-based technologies. Perez, thus, considers that we are in a "long turning point" of the ICT revolution.

[7]The author is grateful to Carlota Perez for highlighting this important point over a private email discussion.

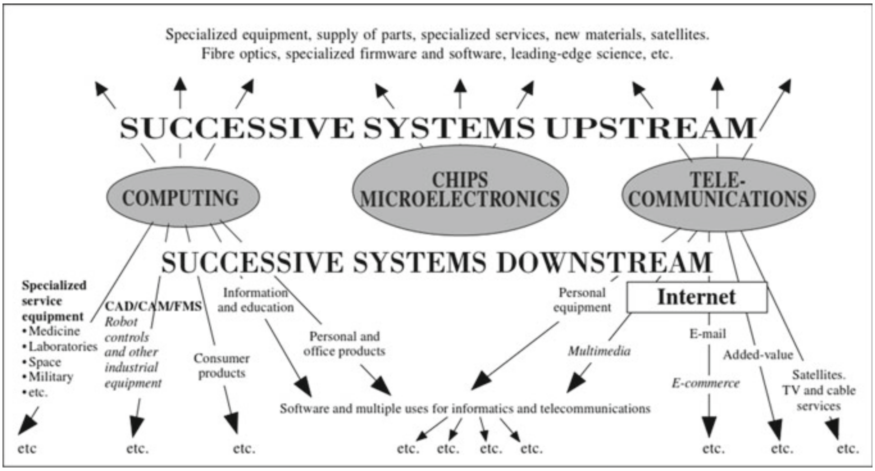

Fig. 1 Technology systems under the ICT revolution *Source* Perez (2001: 116)

3.1 *Digital Era and the Digitalisation of Services, Industry and Agriculture*

The 2010s have seen the emergence of new technological systems within the ICT revolution, which we refer to as the digital era. These have been driven by simultaneous intertwining innovations in the areas of networking, interfacing and services/content/knowledge creation through Web 2.0. These advances have led to the emergence of the inter-related technological systems of cloud computing, automation, online platforms, the IOT, and AI (Fig. 2). In all these cases, the shift from the old simple internet technologies to Web 2.0 having interoperability (wherein the

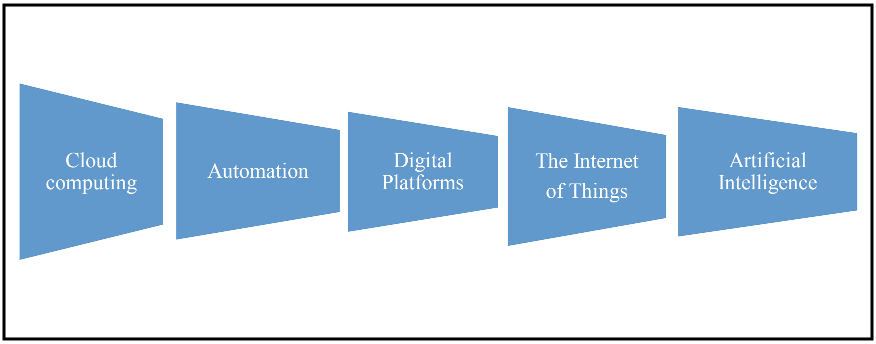

Fig. 2 The digital technology systems of the ICT evolution—The 2010s *Source* Author's illustration

website or computing system can work smoothly with other products, systems and devices)[8] has enabled information processes to be organised differently (Soete 2015).

Cloud computing delivers computing services—data storage, computation and networking—to users at the time, to the location and in the quantity, they wish to consume, with costs based only on the resources used (Zysman and Kenney 2016: 7). This means that powerful computing resources can be assembled more easily and deployed as needed. In other words, cloud computing expands the availability of computing while lowering the cost of access to computing resources. Value in computing moves up the value chain from the provision of the basic data infrastructure to the creation and deployment of applications based on the same. And since computing can be moved from a capital expense to an operating expense, the ability to create, experiment with, and launch new products, platforms, and so on, is radically improved (Zysman and Kenney 2016: 7).

Thus digital technologies are themselves moving at an accelerating pace giving rise to new possibilities while having the capacity to continue transforming the old.

Simultaneously, we have been witnessing critical innovations in generic industrial technologies through the turning point and into the deployment period of the ICT revolution. Called "Advanced Manufacturing Technologies" in the US and "Key Enabling Technologies" in Europe, the latter allows for new ways of manufacturing existing products, as well as for manufacturing new products (Ernst 2016).

According to Montalvo (2014), Ernst (2016), Ross (2016) and Schwab (2016) the new enabling industrial technologies encompass, for instance:

- Continuous manufacturing of pharmaceuticals and bio-manufacturing
- Environmental and renewable energy technologies for sustainable manufacturing
- Photonics[9]
- Industrial biotechnology
- Nanotechnology
- Additive manufacturing (or 3D printing), etc.

With service activities converted into codifiable, computable processes, there has been progressive digitalisation of business processes and transactions (Ernst 2016). Manufacturing is, thus, getting further transformed through radical innovations in production organisation, product and business processes. Driven by advances in digital technologies, direct ICT application areas include control technologies, advanced visual and physical human–machine interfaces, navigation and perception technologies, monitoring and diagnostics devices, locomotion technologies and integrated product-process-production system design and simulation techniques (Alcorta 2014). Innovations in all these enabling technologies together with synthesised

[8]Interestingly, the term Semantic Web (sometimes referred to as Web 3.0) has already been coined by Berners-Lee to refer to a web of content where the meaning can be processed by machines.

[9]Photonics is a space where information signals carried by electrons are converted to photons and vice versa. It allows for optical transmission of information and applications cover a range of areas, including lasers, consumer electronics, telecommunications, data storage, biotechnology, medicine, illumination and defence. The main developments are being driven by the telecommunications industry for smartphones and increasing bandwidth for internet transmission (Alcorta 2014).

advanced materials and custom-designed and recycled materials are expected to act as enablers of new products and services that might create new niches and new industries. All these are also expected to lead to transformations in the supply chain dynamics.

The abundance of data storage, computing power and networking abilities—enabling the analysis of data on a scale never imagined before and cross-sectoral coordination—permits the reorganisation and transformation of not only services and manufacturing but also agriculture. As described by Ross (2016), huge masses of real-time data on weather, water, air quality, soil nutrient levels, diseases—specific not just to each farm or acre, but precise at the level of each inch of the farmland—can be collected through sensors located on and off the farm. Big data is evaluating these real-time data accumulated in the cloud combined with GPS and satellite-driven weather data, and is beginning to transform agriculture into "precision agriculture". Algorithms based on such real-time analysis enable the customised delivery of fertiliser mix to each defined portion of the farmland. Evidently, ICT technologies are refining and re-defining existing industries as well as introducing new technologies and industries, while transforming the material conditions of societies and driving new governance and institutional formats. Thus, from a purely technological view point—as pointed out in Francis (2018)—the current phase may appear to be the synergy phase of the ICT revolution as it moves into the deployment period of the ICT paradigm (Francis 2018). These trends have accelerated globally after the COVID-19 pandemic struck. Yet, this is how states are able to re-orient their financial sectors towards the real economy and resolve the many challenges related to ecologically sustainable development, which will critically influence how the synergy phase of the ICT revolution moves forward and brings wide-spread and inclusive benefits from the deployment of the ICT revolution.

Arguably, the digital *technology systems* of cloud computing automation and digital platforms are going through the phase of incremental innovations. Currently, the other technology systems like IOT and AI seem to be in their initial optimisation phases immediately following introduction. However, given their inter-related nature which enables them to build on each other, advances in any or some of these and other related technology systems can accelerate their movement through the intermediate phase.

3.2 The Platforms

Service sector digitalisation has been occurring at many levels; sometimes through distinct innovations (say, electronic payment), and at other times, transforming the old with advances originating in other technology systems.[10] Zysman and Kenney (2016) observed that such digital/algorithmic transformation of services, which was

[10] A good example for the latter is bot or chatbot, which is a computer program that provides a chat-based interface, where clients can interact with a company through text chats or voice commands. It

initially observed in the early internet phase of ICT-enabled business processes in communications, finance, media, and so on, but which has since spread further across other services through digitisation, underpins the "platform phase" of the digital era.

According to the computational understanding of the term, the platform is an infrastructure that enables the development and deployment of applications. But from an economic point of view, platforms refer to intermediaries of multi-sided[11] digital markets (credited to Evans 2003; Rochet and Tirole 2006), which create value by facilitating, shaping and intermediating the terms on which economic agents (often, but not always buyers and sellers of services or products) interact with one another in a manner that makes everyone better off (Ross 2016: 91; Evans and Schmalensee 2013). Companies operating a platform create products or services that facilitate value-creating exchanges between different types of market participants, and create new markets by doing so. Figure 3 presents several different types of platform markets that have been in operation.

The products that facilitate these markets where distinct user groups interact are the internet platform services themselves: a search platform enables transactions between users, content providers and advertisers; and a social media platform helps users, advertisers and application developers to meet (Lehtiniemi 2016). The platform increases the value for these economic agents by solving a coordination problem between these groups and by reducing the transactions costs they must incur in order to interact (Evans and Schmalensee 2013: 7). In the process, platforms replace and rematerialize markets, restructuring both economic exchange and patterns of information flow (Cohen 2017, as cited in Gurumurthy and Bhathur 2018).

In terms of the TEP, within the platform technology system, while e-commerce, sharing service platforms, electronic payment platforms and streaming entertainment services appear to be in the incremental innovations phase of their evolution, blockchain is in the initial optimisation phase following introduction.

Three defining characteristics of platform companies can be considered to be the following:

- Platforms are characterised by the existence of indirect network effects, whereby the presence of end-users on one side of the market creates a positive externality

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can be embedded and used through any major messaging application. This is an AI-based automation of the business process service provided by a customer service assistant.

[11] A market is typically called two-sided or multi-sided if indirect network effects (or cross-side network effects) are of major importance. Indirect network effects are distinguished from the so-called direct network effects. Direct network effects mean that the utility that a user receives from a particular service directly increases with an increase in the number of other users. For example, a service such as Skype is more attractive for users the larger the number of other Skype users, as the possibility to communicate increases with the number of users. In contrast, indirect network effects arise indirectly if the number of users on one side of the market attracts more users on the other market side, as the larger the number of users on one side of the market, the larger the expected gains on the other market side (Haucap and Heimeshoff 2013, p. 3). Thus the participation of at least one of the user groups in the market impacts the value of participation for the other group. Some of the key papers discussing theoretical and empirical issues relating to multi-sided markets are Caillaud and Jullien (2003), Rochet and Tirole (2006), Evans and Schmalensee (2013), Amelio et al. (2017). See also Lehtiniemi (2016).

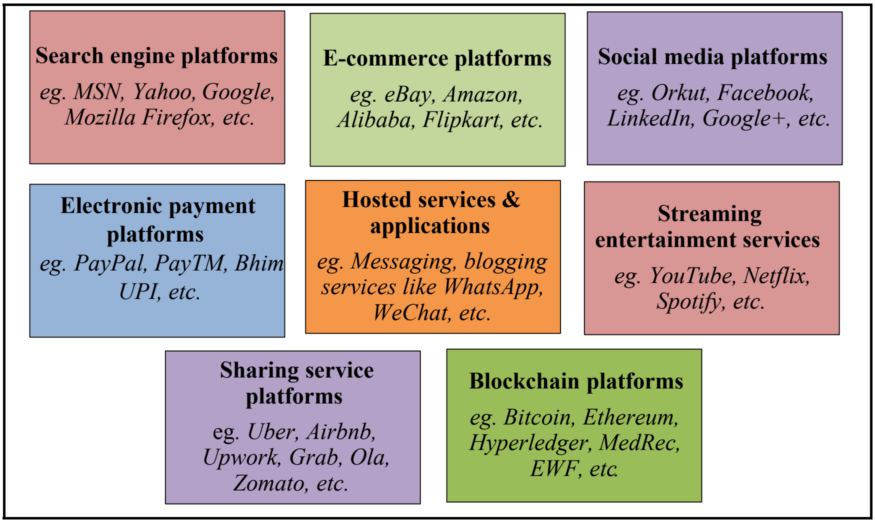

Fig. 3 Platforms—The multi-sided markets *Source* Author's illustration

that makes participation for the other more attractive, and vice versa (Amelio et al. 2017).

- The services provided to both end-users and customers and their terms (pricing/fee structures, etc.) are based on the collection and leveraging of data about users on all sides of the market; and
- Based on the data-based manoeuvring of their algorithmic design, platforms use their fee/pricing structures to influence transactions between different users and maximise platform value (see Amelio et al. 2017; Evans and Schmalensee 2013; Rochet and Tirole 2006).

These characteristics arise from the fact that the multi-sided platform literature assumes the presence of multiple customer groups with demand that is interdependent in various ways (Evans and Schmalensee 2013; Rochet and Tirole 2006). Indirect network effects, thus, function something like economies of scale on the demand side and increase the value that economic agents can realise from the platform (Evans and Schmalensee 2013). The interdependence of demand and indirect network effects also mean that the prices charged on one side of the market need not reflect the costs incurred to serve that side of the market. If we define one side of the market as the buyer side and the other as the seller side, then the price charged to one side (say, the buyer side) will tend to be lower when either:

- each additional buyer generates significant extra revenue on the seller side; or
- it is difficult to persuade buyers to join the platform.

While the consumer end-users get the services of platforms free of charge, the profit-turning side of the market consists of paying businesses which often pay both a membership fee and a usage fee (Haucap and Heimeshoff 2013; Evans and Schmalensee 2013; Lehtiniemi 2016; Amelio et al. 2017). Thus, the businesses of online platforms are made possible by "datafication", or the transformation of the social actions of their users into quantified data (Mayer-Schönberger and Cukier 2013, cited in Lehtiniemi 2016), which is used to capture value. The access-in-exchange-for-data regime of platforms has been variously referred to as a form of governmentality (Cova et al. 2011) involving disciplining, and as extractive and surveillance capitalism (Zuboff 2015).

4 Firm-Level Opportunities and Challenges

It must be emphasised that the opportunities available to different categories of firms in a particular market—innovators/first movers, fast followers and existing firms—differ in various stages of the evolution of a technology (see Francis 2018 for a detailed discussion). In the earlier technological revolutions, because mature technologies did not generally require much prior know-how and the processes could use unskilled labour, for example, in electronics final product assembly, the determining advantage was the comparative cost profile. Therefore, phase 4 had offered opportunities for follower firms from developing countries. However, in the current phase of the ICT revolution, technological change is occurring at a more rapid pace than before. Thus, the targets for catching up and development are constantly moving and market opportunities change quickly in today's world. Accordingly, the requirements to access and apply new technologies and to capture market opportunities may be more difficult to meet than before. This is all the more so, given the distinctive features of digital markets.

4.1 Unique Characteristics of Digital Markets

Digital technologies are characterised by specific unique features. As pointed out by Soete (2000), electronic markets by their very nature are wrought with problems of non-excludability, non-rivalry, and often, non-transparency. Owners of digital commodities selling their products/services on the market will have difficulty in preventing buyers, or anyone else for that matter, from copying and reselling it. The creation and enforcement of excludability is, therefore, an absolute and first condition for such markets to exist. Consequently, a central response by innovators and fast followers has been to create artificial excludability by focusing on encryption, watermarks and various other forms of tracing and monitoring property rights. The creation and strengthening of property rules have of course immediate implications for market structure and the degree of competition in such markets. High levels of property protection create significant challenges for new entrants and lead to less than optimal competition in a market (Soete 2000). Apart from a focus on intellectual property rights, innovators in digital markets create excludability and erect entry barriers through various anti-competitive business strategies, as we will see in detail in Sect. 5. Here, the focus is on the innate characteristics of the digital markets.

Despite the tremendous opening up of trading possibilities and the seeming increase in market transparency, the actual exchange of a digital commodity also involves, almost by definition, a high degree of information asymmetry between sellers and buyers (Haucap and Heimeshoff 2013). Many of the new forms of internet markets—including the platform companies (generating value out of providing intermediation services)—are considered innovative responses to this problem of non-transparency. However, as discussed in the ensuing section, the anti-competitive business strategies of platforms often aim at leveraging and entrenching the information asymmetry between different sides of the markets they intermediate.

Here, it is useful to examine how platform companies deal with the issue of non-excludability. As pointed out in Caillaud and Jullienne (2003), intermediation services usually are not exclusive as users often rely on services of several intermediation providers. For instance, a web-surfer looking for some specific good or service will usually visit and register with several intermediation service providers, to increase his chances of finding a match. Similarly, firms offering various services register with different intermediaries—in their segment or on multi-sectoral platforms, to benefit from their different user bases. Literature refers to the parallel usage of different platforms as multi-homing.

Excludability is often imposed by intermediaries to ensure that their efforts in processing users' demands end up with a transaction, or because registration involves the specific building of a profile that the intermediary may consider proprietary. Caillaud and Jullienne (2003) pointed out that the use of transaction fees is central in these pricing and business strategies. Platform matchmakers rely on two pricing instruments: registration fee, which is user-specific and paid *ex-ante*, and a transaction fee paid *ex-post* when a transaction takes place between two matched parties. The Ease of multi-homing depends, among other things, on (a) switching costs (if they exist) between platforms; and (b) whether usage-based tariffs or positive flat rates are charged on the platform (Haucap and Heimeshoff 2013). Even though switching costs between search engines are very modest for consumers, new firm entry into the search engine business is not easy due to the indirect network effects and the associated economies of scale.

While ruling out transaction fees raises intermediation profits most of the time, the fact that the user's specific profile and usage patterns become controlled as the platform's proprietary asset leads to the other central pillar of excludability for new entrants—the control over data and data-based intelligence (or digital intelligence) by the leaders. We will discuss this in detail soon.

4.2 Indirect Network effects and Control Over Digital Intelligence

It is evident that at one level, platform companies (search engine services such as Google, Bing or Baidu; e-commerce firms like Amazon, Alibaba, eBay, Flipkart, etc.) have increased competition. The entry of new firms is facilitated by the fact that their coded nature makes these markets available even to the smallest vendors/participants (Ross 2016). Many online markets have been characterised by a large degree of Schumpeterian competition, where one temporary monopoly is followed by another (Haucap and Heimeshoff 2013).[12]

At another level, however, in many of the digital markets, we see a highly concentrated structure with a monopoly or a duopoly (Caillaud and Jullienne 2003). The reasons for these high concentration levels are the excludability conditions imposed by platforms to capitalise on the indirect network effects that characterise platform companies as discussed in the previous section, as well as the economies of scale that the former gives rise to.

At one level, increasing returns to scale arises from the fact that typically, multi-sided markets are characterised by a falling average cost structure due to the relatively high proportion of fixed costs and relatively low variable costs. Most of the fixed costs arise from the technical infrastructure (servers, cloud, etc.) required for managing the respective databases, such that additional transactions within the capacity of the databases usually cause hardly any additional cost (Haucap and Heimeshoff 2013: 6–8).

At a more critical level, increasing returns to scale arise from the digital intelligence the proprietary platforms claim control over. This is again linked to the presence of network effects in platforms. For instance, when Uber increases the number of cars under its pool and under-prices its rentals, it incentivises more users to register on that platform. The latter in turn draws more car owners (and advertisers) to it. Benefits of this network effect get multiplied for the platform owning company through the greater amount of data that gets generated for analytics (i.e., for learning from the data) and predictive modelling, which enable the platform-owning company to improve its algorithm further. Greater the usage base (which is increased by imposing excludability conditions on new entrants), greater is the revenue potential that accrues to the company "owning" the data (Francis 2019d). Digital platform businesses, such as Swiggy/Zomato, Ola/Uber and Facebook/LinkedIn, generate their revenues by selling the data generated from the user interactions on their platforms to third parties. Equally important is the potential for future revenue generation from the innovations based on data analytics—both for the "original" data "owning" company as well as the third party who can buy data or data intelligence from it (Francis 2019d).

In the case of e-commerce, while the entry of new firms and new growth opportunities will depend on the substitution possibilities of physical commerce with electronic

[12] A notable exception has been eBay which has managed to hold on to its dominant position for long (Haucap and Heimeshoff 2013).

commerce, followers' business strategies invariably focus on entering and expanding the market by differentiating the kind and variety of products and services offered. Whether in e-commerce or other platform companies, the higher the degree of heterogeneity among potential users and the easier it is for platforms to differentiate among users, the more diverse the platforms that emerge, and the lower the level of concentration and therefore barriers to entry for followers. Consequently, despite indirect network effects, every digital platform market is not automatically highly concentrated. For example, several competing platforms coexist in case of online real estate brokers, travel agents, online-dating sites, etc. (Haucap and Heimeshoff 2013).

That is, while on the one hand, indirect network effects, increasing returns to scale and the proprietary ownership of technology platforms, the extracted data, and the digital intelligence will drive increasing concentration in multi-sided markets, on the other, capacity limits (and the associated the risk of platform overload),[13] product differentiation and the potential for multi-homing will decrease concentration levels (Evans and Schmalensee 2008, cited in Haucap and Heimeshoff 2013. See also Martens 2016).

Hackl et al. (2014) have shown that while entry and exit of e-commerce firms are very prevalent, newcomers are more likely than in well-established physical markets to be able to influence the market structure at the core. This is because of the cheap and easy establishment of online shops, and the fact that many such shops operate only online, without a brick-and-mortar store or physical storehouse. Investigating the impact of the number of firms on mark-ups and price dispersion in e-commerce using data from an Austrian online price-comparison site (price search engine) for digital cameras, they found that the number of firms had a highly significant and strong negative effect on mark-ups. Having one more firm in the market reduced the mark-up of the price leader by the same amount as the competition between existing firms in three additional weeks in the product lifecycle. This was found to be especially true for markets for consumer electronics, where product lifecycles are particularly short.

Even so, the success of new entrants in e-commerce is not guaranteed. This is partly because indirect network externalities give rise to a "chicken & egg" problem: to attract buyers, an intermediary should have a large base of registered sellers, but these will be willing to register only if they expect many buyers to show up (Caillaud and Jullien 2003: 310). This is related to the fact that as Haucap and Heimeshoff (2013) argue, it is not easy for sellers (or buyers) to use competing online trading platforms simultaneously—that is, to engage in multi-homing. This creates a fundamental bias against new e-commerce entrants. First of all, multi-homing is difficult for small sellers because they often sell unique items and heavily benefit from a large group of customers to find buyers for their products. Additionally, it is difficult to build up a reputation on several platforms, as reputation depends on the number of transactions

[13] Advertising space is often restricted since too much advertising is often perceived as a nuisance by users, and therefore, as decreasing the platform's value in the recipients' eyes (Haucap and Heimeshoff 2013: 6).

a seller has already honestly completed on a given network.[14] Investment into one's reputation is typically platform-specific so that there are significant costs involved in switching to another e-commerce platform. Furthermore, selling on smaller platforms bears the risk of selling the product at prices below its market value, as the price mechanism works best with a sufficiently large number of market participants on both sides of the market, that is, with sufficient market liquidity or "thickness". As long as sellers do not switch to other trading platforms, there is only a very limited benefit for consumers in starting to visit and to search through other trading platforms (Haucap and Heimeshoff (2013).

In this context, it must also be kept in mind that lower search costs and lower switching costs for internet users increase price elasticity (Smith et al. 1999a). That is, all strategies and techniques which increase the cost of switching to another platform lower price elasticity and simultaneously provide premium pricing opportunities for innovators and become entry barriers for followers. By reducing actual or potential competition, such high market entry costs make it possible for existing market players to sustain price premiums. This is helped along by the fact that customers' search costs (which in turn reduces information asymmetry) and sellers' menu costs are both lower online than in conventional outlets.[15] Retailers may also be able to charge a price premium by leveraging customers' switching costs.

Various types of loyalty programs are one such strategy used by platform companies to increase switching costs of the participants and to build in excludability. Towards this, goods might be offered for free, or paid for by advertising or by subsequent upgrades; or a limited preview of the goods might be offered for free; and so on (Soete 2000; Lehtiniemi 2016). Citing Rochet and Tirole (2006), Lehtiniemi (2016) also points out how platform companies' pricing strategy often entails selling products on one market segment below cost. Losses on one market segment are incurred to stimulate the sales of products in other, profit-turning market segments, which subsidise the loss-incurring segment (see also Rieder and Sire 2014).[16] This is also called the "divide and conquer" strategy (Evans and Schmalensee 2013: 10).

Such strategies whereby one group of buyers is locked in by the incumbent with very favourable offers, to prevent a potential entrant from reaching the critical scale, allow the incumbent to monopolise the rest of the market (Amelio et al. 2017). This exclusionary strategy deployed by the incumbent in a multi-sided market is identified in the literature as "naked exclusion" (Amelio et al. 2017). Caillaud and

[14] It has been documented by many studies that a good reputation on eBay translates into higher prices for sellers (Haucap and Heimeshoff 2013).

[15] Menu costs are the costs incurred by retailers when they make price changes. In online markets, it is comprised primarily of the cost to make a single price change in a central database, rather than physically changing price labels on shelves. Offline retailers will only make a price change when the benefit of the price change exceeds the cost. Lower online menu costs allow Internet retailers to make significantly more, small price changes than conventional retailers (Smith et al. 1999a).

[16] Varian had pointed to such complex and diversified set of exchange methods in which the value of the content offered by a seller is likely to differ strongly amongst individual consumers (Varian 1997 cited in Soete 2000). This so-called versioning can be seen to be influencing switching costs, and in turn, multi-homing.

Jullien (2003: 310) had argued that in the case of exclusive services, an incumbent might forego all potential profits to protect a monopoly position. However, with non-exclusive services, intermediaries may avoid fierce price competition and make positive intermediation profits.

The integration of various forms of verticals may be seen as another strategy to generate customer loyalty. This, for instance, is visible in Amazon or Flipkart's strategy to process a large part of their payments directly. They push their payment applications—Amazon Pay and PhonePe, respectively—with steep cashback and incentives for shoppers, which serves to increase switching costs.

Thus, at the firm level, growth in e-commerce will depend on how it can advantageously monetise the trade-offs involved in not only replacing the particular features and relative merits of physical commerce over electronic communication and exchange, including the payments of money, but also in the ability to build loyalty (and therefore, significant switching costs) through various strategies.

Perez had pointed out that once innovators' and early adaptors' experience accumulated with product, process and markets reach a high point, this speeds up their incorporation of subsequent innovations so that it is even more difficult for latecomers to catch up with the leaders. We can observe this in the case of digital technologies too. Amazon is a case in point. The value creation models of large-scale internet platforms can be observed in Amazon's strategies to maintain lead market share, which has involved several of the above kind of innovative strategies. These have led to Amazon's transformation from an online bookseller to a marketplace for third-party sellers with a premier membership program. As reported by LaVecchia and Mitchell (2016), already half of all US households were subscribed to the membership program Amazon Prime, half of all online shopping searches started directly on Amazon, and Amazon captured nearly one in every two dollars that Americans spend online. Amazon sells more books, toys, apparel and consumer electronics than any retailer online or offline, and is also investing heavily in its grocery business.[17] Beyond acquiring Whole Foods, the US grocery store chain, Amazon has now shown that it is serious in expanding its physical presence by moving further into "offline" stores. Using computer vision, machine learning algorithms and sensors to figure out what people are grabbing off its store shelves, which are added to a virtual cart,[18] it had also launched its Amazon Go concept in Seattle, which lets shoppers take goods off its shelves and just walk out. Amazon's technology charges customers after they leave by charging the customer's credit or debit card to a smartphone. There are no cashiers, no registers and no cash in this new business model of Amazon for store shopping.

Social networks such as Facebook also share many characteristics with other online platforms. To assess the potential for competition and potential barriers to entry for followers, here again, it is important to understand: (a) whether switching

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[17] For more on Amazon's market power and anti-competitive practices, see also Budzinski and Köhler (2015).

[18] https://economictimes.indiatimes.com/small-biz/startups/newsbuzz/get-your-stuff-and-go-amazon-opens-store-with-no-cashiers/articleshow/62617852.cms.

costs play a major role or not, and (b) how easy it is for consumers to engage in multi-homing (Haucap and Heimeshoff 2013). Overall, the market for social networks shows lower concentration levels than other internet markets because user preferences are more heterogeneous and, secondly, it is not very costly for users to be present on two social networks, that is, to engage in multi-homing. For example, one network (such as Facebook) may be used for social contacts, while a second network (e.g., LinkedIn) may be used for business-related contacts and exchanges. Given this market segmentation, the degree of competition between various business-related networks and various social networks may decline to some extent, as direct network effects are rather strong for social networks. The main value of the network lies in the number of members subscribed to the network. However, new networks (as Google+ did in 2011) can still emerge, as multi-homing is rather easy and switching costs are not too substantial (Haucap and Heimeshoff 2013).

In Perez's framework, passing successfully through phases two and three (of frenzy and synergy) of a technological revolution requires growing support to the innovators or leads firms from the economic environment—especially, the physical, social and technological infrastructure/capabilities, constant innovation and the existence of competent and demanding local clients and consumers (see also Parthasarathy 2013). While state policy has a central role to play in enabling many of these—as will be discussed in Sect. 6, equally crucially, capital-intensive investments and great manoeuvrability in terms of markets and alliances also play major roles (Perez 2001). Meanwhile, innovators and fast followers are making use of various ingenious strategies to entrench their monopoly positions. Such anti-competitive strategies are being used to leverage various synergies enabled by digital technologies as well as to generate new synergies based on new business/organisational models and other innovations. We will discuss this in detail in Sect. 5.

4.3 Differing Value Propositions for Leaders and Followers

It is crucial to understand that through its deployment period, the ICT revolution indeed offers immense opportunities to fast followers and new disruptors/innovators. There are also opportunities for incumbent firms facilitating their reincarnations through digital transformations. The availability of platforms, cloud, data analytics, AI, blockchain, and so on as infrastructural utility services and an increasing array of other digitised services being offered through all of them, along with the availability of risk capital (from venture capital and other funds) enable fast followers and new disruptors to self-organise, scale up rapidly and generate rapid financial returns. As Teece (1986) has pointed out, sometimes greater profits from the original innovation may accrue to fast followers or imitators with certain complementary assets and successful business strategies for integration and collaborations, rather than to the original developers of intellectual property. This, together with their dynamic capabilities, can enable some of the fast followers to overtake the original innovators in some markets.

However, in the ongoing deployment phase of the ICT TEP, continuing interactions between the evolving technological systems and the subsequent ones that may emerge mean that lifecycles of the related new upstream and downstream products/services may involve much shorter phases of maturity than under the previous TEP. Some products may atrophy and die out before even reaching maturity. Further, the immense opportunities to small businesses do not usually lead to the same wealth generation capabilities for them as the owners of the platforms or cloud or AI or blockchain, since the value gets concentrated due to the latter's proprietary ownership of platform design and monetisation of the data generated, as well as other anti-competitive strategies. This is dealt in detail in the following section.

5 Competitive Strategies by Innovators and Fast Followers

As discussed earlier, overlapping and inter-linked innovations, rapidly falling average total costs, zero marginal costs, strong network externalities, standards battles and path dependence (Ernst 2016) as well and intelligentsification are the hallmarks of digital technologies. Arguably, internet markets are no more as frictionless as suggested two decades ago by Smith et al. (1999b). At the time, they had attributed the former to low search costs, strong price competition, low margins, and low deadweight loss in internet markets for consumer goods. However, other characteristics peculiar to digital technologies (in particular, platform companies) discussed in the previous section and speeding waves of creative disruptions are creating increased concentration and greater friction in these markets. Therefore, challenges to competitors and followers have become more complex in the digital arena.

In the ensuing discussion, the main strategies adopted by innovators/fast followers to extend their market power for generating sustained competitive advantages and consolidating monopoly positions are grouped under four major categories. All of these put up significant entry barriers and challenges to other follower firms from developing countries.

5.1 Expansion of Private Property Rights to New Spheres and Standards-Setting

Various IP-related tactics followed by innovators aimed at extending, broadening, and leveraging their monopoly power involve strategic patenting as well as other strategies leading to patent thickets and patent trolling. Since innovation often requires the use of currently existing IP, high-tech companies are often unable to innovate without violating other companies' intellectual property rights. This leads to blocks (sometimes called a patent thicket) that delay and reduce innovation because of the long and costly negotiations involved in obtaining the multiple permissions needed (Baker et al. 2017). Clearly, the greater the IP protection, the narrower the scope and opportunities for competitors and followers to “invent around or for innovating on the shoulders of the patent holder” (Burlamaqui 2006: 6). Thus overly high IP protection goes hand-in-hand with high entry barriers.

Some firms are also involved in “strategic patenting”, that is, acquiring patents that the firm has no intention of using/exploiting, but patenting it solely to prevent others from using and profiting from it (Burlamaqui 2006; Block and Keller 2011). Large corporations have been aggressive in acquiring substantial portfolios of strategic patents as a defensive manoeuvre (Block and Keller 2011). If they are sued by another firm for infringing an existing patent, they might use some of the patents in their portfolio to mount a countersuit against the other firm (remember the Apple *vs* Samsung battles not so long ago) to arrive at a negotiated settlement (Francis 2018). Sometimes, private equity (PE) firms, which make strategic investments in competing start-ups, also play a role. When the winner firm eventually takes over any of the competitors (often manoeuvred by the PE fund), this transfers the ownership of the acquired firm’s patents also to the acquirer, to be leveraged by them for entrenching their market position. Companies also invest large sums of money into emerging technologies that have not yet been deployed, not solely for the patents, but because they will also give them room to influence the setting of standards, which give them a long-term competitive advantage in several related markets (Francis 2018). This is currently the case with 5G, shorthand for fifth-generation wireless technology. Given the use cases being forecast for 5G, including in the spheres of autonomous cars and the internet of things IoT, and so on, setting standards also becomes a barrier to entry.

5.2 Increasing Embeddedness of Software in Hardware and Networked Products

In the ongoing deployment period of the ICT technological revolution with the widespread application of digital technologies across sectors and spheres, the maximum size of the market for digital products is defined by the possession of the hardware by users and the existence of communications links. Given that hardware possession would be determined by incomes and telecom network penetration which requires gigantic investments, the diffusion of digital technologies might not happen equitably, whether between developed and developing countries or within countries. As pointed out by Perez (2007: 22), this means that hardware and telecom networks penetration (that determines the extent and quality of internet access) are the true market frontiers for the ICT industries. This, we argue, is an important reason why global software companies are increasingly investing in hardware technologies, and vice versa, as a strategy to retain monopoly rents. Lead platform-owing firms are, thus, entering into several sectoral verticals in the production space. The fact that Alphabet—Google’s parent company, has an autonomous car technology on which it has invested hundreds of millions of dollars over nearly a decade, is just one such instance of this attempt to maintain leadership by entering hardware segments that will see growth due to advances in the emerging technological systems. There are also ride-sharing platform firms like Uber that sees its future as dependent on self-driving cars and is investing in the same.

Advances in data analytics combined with greater sets of data such companies gain access to through their various products and business strategies enable them to develop and offer new products. These can displace existing products in industrial segments different from the digital space that the firms originally inhabited, and even traditional sectors (e.g., through the emergence of precision agriculture). It will also create a demand for new networked products. In manufacturing, this has begun to happen in a variety of industries, starting with the electronics industry. In the electronics industry, rather than being stand-alone pieces of electronics with capabilities that were limited to the hardware and software inside the unit (Ross 2016), several new networked products are being launched.

Another example is where proprietary owners of personal assistant software are releasing their hardware as a strategy to increase integration of their software and create new product ecosystems and control the standards and markets. Reportedly, Google's strategy is to get people used to talking to the Google Assistant, whether it is on their products or the ever-growing list of third-party products that leverage their Virtual Personal Assistant (VPA). Google wants the Assistant to be to devices what its search is to the web (Pahwa 2018). In October 2018, Google announced the integration of its Assistant with the Pixel handsets and Google Home (an audio-based device which can be used to search and play music, book services, and integrate with supporting devices such as Chromecast), and indicated how these would work with multiple services, including YouTube, Maps, Street View, among others. The home also allows using voice control for TV and audio via Chromecast, allowing one to pause content, or change the volume through "handsfree voice control". Partners can integrate with the Google Assistant. To begin with, it supports external services like Nest, IFTTT, Philips and Samsung Smarthings. It is essentially becoming a single control device for a connected smart home. Google announced an open developer platform, which will allow anyone to build for the Google Assistant. Amazon has not lagged integrating its Alexa with its Echo. As a result, for instance, in the consumer electronics industry, smart speakers and other electronics are being powered by personal assistants and voice interfaces owned by Google (Google Assistant), and Amazon (Alexa), or both. Apple is also releasing its voice-controlled speaker, the HomePod—its first Siri-enabled smart speaker.

Fast followers are attempting to copy such strategies at their level. To fight the continuing risk of commoditisation in the consumer electronics space and to deal with competition from the leaders, the media streaming company Roku, for instance, is developing its virtual assistant and plans to license it to smart speaker manufacturers in an attempt to own the entertainment experience more fully.[19]

The transformation being brought about by digital technologies is not limited to the electronics industry. In the automobile industry, for instance, many cars (and other

[19] https://codeburst.io/3-takeaways-from-ces-2018-ca239c903ace.

vehicles soon) are coming into the market with pre-installed IoT apps and devices, which capture huge amounts of data related to the vehicle, user, traffic, pollution, and so on (Francis 2019a).

The competition to make differentiated offers to consumers is also driving integration strategies being adopted at multiple levels such as product, software, services and marketing.

5.3 Acquisition of Competitors and Innovator Start-Ups

There have been several instances of mergers or acquisitions of competitors and start-ups by leading firms to protect their dominant market position. Many leading firms have cut back their R&D efforts or shifted funds towards product development because the financial orientation of top executives means that they see new technologies as simply another asset that can be acquired (Block and Keller 2011; Ernst 2016). Acquisitions enable the leading firms to achieve many advantages: (i) to transfer the ownership of patents on the latest technological advances; (ii) to absorb the capabilities, and (iii) to crush the competition and often significantly delay new competition until the leader can garner the premium profits in a new product/new market.

Buying other companies' technology is widespread among innovator firms in the digital economy. For example, Google purchased Boston Dynamics, a leading robotics design company with Pentagon contracts, in 2013. It also bought DeepMind, a London-based artificial intelligence company founded by wonderkid Demis Hassabis, which had taught computers how to think in much the same way that humans do. Google has been applying its expertise in machine learning and systems neuroscience to power the algorithms as it expands beyond internet search into robotics (Ross 2016: 25).

Similarly, Apple bought up the technologies it needed to launch its iPhone X with face-tracking technology and Animoji, years before its eventual launch in 2017. Apple had bought up PrimeSense, maker of some of the best 3-D sensors on the market, as well as Perceptio, Metaio, and Faceshift, companies that developed image recognition, augmented reality, and motion capture technology, respectively. These technologies enabled Apple to eventually come out with the face tracking technology which allows users to unlock the phone with their face or to lend their expressions to a dozen or so emoji with Animoji (Stinson 2017).

A related strategy for lead innovator firms, especially when they enter emerging markets like China and India[20] with specific domestic market requirements (such as stringent government regulations in China), is to acquire local start-ups. For instance, when it entered China, Amazon bought up an online book retailer Joyo.com. Sometimes acquisitions take place at the personal level of top-level executives of lead firms. An example is that of John Chambers, executive chairman of Cisco Inc. picking up

[20]Parthasarathy (2016) discussed these strategies as a form of frugal innovation.

a 10 per cent stake in the Chennai-based speech recognition solutions company Uniphore Software Systems Pvt. Ltd.[21] In addition to their technologies, acquisitions in developing countries also provide global firms with valuable insights into the business models used by domestic firms.

More recently, companies have also been signalling interest in blockchain technology through strategic acquisitions. In 2016 and 2017, Airbnb, Daimler, Rakuten, and several others acquired blockchain-related start-ups, while the investment arms of Jaguar Land Rover, JetBlue, Verizon, and others made blockchain-related strategic investments.

It must be noted that such acquisitions are becoming strategically important in varied sectors, including agriculture, and transforming agri-business firms to ICT firms. Ross (2016) discusses how major investments are being undertaken by the largest agribusinesses such as Monsanto, DuPont and John Deere. Convinced about the opportunities in the use of big data to agriculture, Monsanto has gone on a buying spree of farm data analytics companies. Even if hardware costs on sensors, smartphones and tablets come down, the business model likely to be pushed by big agribusinesses will mean that costs, and, therefore challenges to followers will come from the cost of precision agriculture software as a service.

5.4 Proprietary Ownership of Technology Platforms and Networked Data

The central barriers to new entrants in the platform markets are the incumbent leader's emphasis on proprietary technology platforms and its "ownership" of networked data. The platform companies own the proprietary platforms used for the peer-to-peer "intermediating" functions. Also, in the absence of data protection policies, they become de facto "owners" over the data assets that are extracted over a wide range of users and data sources.

The monetisation of the surplus-value produced by platforms is exclusionary, as the platform owners control the monetisation of the extracted data assets through its platform design and keep the users/producers out of that process. All decisions about what kind of data is extracted and what is learned from it are shaped by the underlying institutional market form of platform companies (Kostakis et al. 2016). They are embedded in ways platform companies organise their markets, and collect, store and use personal data about their users (Zuboff 2015). That is, digital platforms are regulatory structures, which set the rules and parameters of action for participants, whether it is Uber/Lyft, Google, Facebook, Airbnb or others (Zysman and Kenney

[21]"Uniphore's products help government and companies reach rural customers by interacting with them in vernacular languages", *Hindustan Times*, December 1, 2017. This monopoly power also enables Amazon to formulate new "business strategies" around setting the terms for government support, which go beyond the externalities they gain from publicly-funded research and development in the US. See the discussion in Section 5.1.6 in Francis (2018).

2016: 23). The governance rules of such sharing platforms are, as Larry Lessig argued years ago, an outcome of the code itself, and therefore, deeply exclusionary (Lessig 2015; Kostakis et al. 2016).

According to Zuboff (2015), the value creation process in the platform-based markets takes place in three phases: data extraction, behaviour prediction and monetisation of predictions. In the first phase, the company provides products or services for people to use, and targets the users with ubiquitous extraction processes to collect data about them. The users become the sources of what Zuboff calls surveillance assets, a raw material for later phases of production. In the next phase, the company uses the extracted data as input material to produce prediction products from surveillance assets. The conversion of surveillance assets to prediction products happens by employing highly specialised analysis capabilities. Predictions include qualities, preferences, characteristics, intentions, needs and wants of users. The third phase is about converting prediction products into revenue. Accordingly, revenues come from beneficiaries of prediction products, who are not limited to only advertisers. Thus the very revenue model of platform companies is to produce "objective and subjective data about individuals and their habits for the purpose of knowing, controlling, and modifying behaviour to produce new varieties of commodification, monetisation, and control" (Zuboff 2015: 85). As observed by Ross (2016: 93), how the intermediary company redirects each of the transactions between multiple user groups through their proprietary technology platform leads to greater concentration, because revenue flows to the owners of the platform rather than the participants of the transaction.

Further, the greater the volume of data (in terms of both breadth of data from a single user as well as the breadth of user base), the greater is its predictive power through analysis, and therefore, its revenue potential. Therefore, as Rieder and Sire (2013) have argued, these companies have incentives to collect as much information as possible from the users. Moreover, when extraction and analysis of data about user behaviour improves service quality, extracting more data leads to more users and advertisers choosing the particular service, which in turn leads to even better service (Lehtiniemi 2016, p. 4). Data-based intelligence on user behaviour is also leveraged by incumbent firms for various exclusionary practices in order to attract agents on each side of these multi-sided markets and reach a viable scale. These include strategies such as "divide and conquer" (Evans and Schmalensee 2013) or "limit pricing" (Dixit 1980). Such exclusionary strategies also allow the incumbent to monopolise the rest of the market. In the case of exclusive services, an incumbent might forego all potential profits in order to protect a monopoly position (Caillaud and Jullienne 2003).

The leadership position of the innovator tends to get entrenched due to the advantageous access to the capabilities of data collection and analysis. The material and knowledge asymmetries—both in the data extraction phase and the analysis phase—institutionalise the leader's position in multi-sided markets. This asymmetry has been rightly described as the "big data divide" by Andrejevic (see Zuboff 2015). This is reflected in the fact that Facebook and Google now control 73% of US revenue in the digital ad market.

LaVecchia and Mitchell (2016) shows how Amazon too increasingly controls the underlying infrastructure of the economy through its advantageous position as the innovator/leader. Its marketplace for third-party sellers has now become the dominant platform for digital commerce. On the other side, its Amazon Web Services division provides the cloud computing backbone for much of the country, powering everyone from Netflix to the CIA. Its distribution network includes warehouses and delivery stations in nearly every major US city, and it is rapidly moving into shipping and package delivery for both itself and others (LaVecchia and Mitchell 2016).

By controlling the critical infrastructure across various sectors (and not just verticals), Amazon both competes with other companies and sets the terms by which these same rivals can enter the market in each and all of these segments. Moreover, redirecting all these transactions through its proprietary technology platforms also enables this company to entrench its market leader position further through "ownership" of data collected from across sectors and benefit from the digital intelligence thus generated.[22]

6 Towards Policy Coherence for Inclusive Digital Transformations

In the rapidly evolving digital technology space, it is evident that there will be continuous inter-related innovations in technology systems, markets and organisational forms. They bring together synergies in ICT hardware and software capabilities together with access to data of all kinds (Francis 2019a). Digital technologies will be integrated into the production of most goods and services in myriad ways. India, therefore, faces critical policy choices in shaping her development trajectory in the context of such transformations. Policies have to take into account the following three kinds of ongoing transformations:

(i) those in the digital space itself;
(ii) those associated with the transformation of services; and
(iii) those related to transformations in the manufacturing and agricultural production spaces.

Increasingly, policy choices in the digital space will influence the trajectories of digital transformations in the services, manufacturing and agricultural production spaces, as well as their societal outcomes (Francis 2018).

Data and digital intelligence have become the prime drivers of many of the new technology systems in the digital economy. With the capital and knowledge asymmetries between lead firms and follower firms from countries like India getting

[22]This monopoly power also enables Amazon to formulate new "business strategies" around setting the terms for government support, which go beyond the externalities they gain from publicly-funded research and development in the US. See the discussion in Section 5.1.6 in Francis (2018).

entrenched through the former's control over extracted data, value also gets concentrated, especially given the latter's proprietary ownership of platform design and monetisation of the data extracted. As observed earlier, greater the data for analytics and predictive modelling, the greater is the revenue potential for the owners of data as well as the innovation that follows it for future revenue generation. This also means that the immense opportunities to small businesses that utilise these platforms do not usually lead to the same wealth generation capabilities for them as the owners of the platforms or cloud (or Blockchain or AI).

The increased use of sensors in devices and application-driven machines, and equally importantly, the growth in networked devices are continuously increasing the scale and scope of real-time data extraction. All kinds of public data—whether of utility usage, traffic, domestic and international trade and financial sector transactions, health, farming practices or the weather, environment or ecosystems—are also the raw material for analytics-based innovation.[23] Thus how access to data is managed by the public policy will have critical implications for the "digital development trajectory" and for ensuring that the new technologies can be used widely for solving the many development problems facing the country (Francis 2019d).

Additionally, across sectors, whether it is retail, health, finance and insurance, education, and so on, or in manufacturing, extensive foreign ownership, especially of platform businesses, may imply their de facto *ownership* of humungous volumes of data, which can be used to build digital intelligence. Advancements in the new technological systems such as AI, network technologies, robotic process automation and cloud robotics, blockchains, and so on are all also contingent on digital intelligence. This makes it crucial to ensure that various monopolistic tendencies and predatory pricing practices in the digital spheres, and particularly in the platform business segments, are reined by regulations. Otherwise, such practices will result in heavily concentrated sectors, with concentrated "data ownership". This will have anti-competitive implications for not just the respective digital sectors, but also the "not-yet-digital" sectors and innovative potential in the economy as a whole. This is why protecting data is critical for the needs of an inclusive digital development trajectory.

Thus, digital transformations need to be guided by the government by quickly putting in place adequate regulatory systems and policies related to data ownership, privacy and security standards. We must not have a policy of first introducing the technologies and then imposing standards. Unfortunately, this is how things have been proceeding. Unlike the previous generation of internet, linked products, lack of security standards for the emerging generation of networked products is a call to disastrous consequences for national security given the vast range of channels through which security may be compromised (Francis 2019c). Further, to capture the broad synergies that will become available through ICT deployment, IP rules must strike a balance in favour of technology diffusion.

All these entail a challenging policy task to strike a balance between data needs for innovation on the one hand, and issues surrounding privacy, data protection and

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[23] See Singh (2019) for an extremely useful framework for formulating non-personal data policies.

the ethics of data use (including for AI, for example) on the other. India's draft Personal Data Protection Bill 2018, the draft national e-commerce policy and the one in the making on Non-Personal Data all have data localisation rules that address the flow of data outside the country's borders. India must resist the pressures to dilute them. Further, India must not take up legal commitments in bilateral, regional or multilateral trade negotiations on e-commerce, cross-border data flow, and so on, before it develops its digital competitiveness.

Acknowledging and protecting data as the source of competitive advantage and inclusive digital development trajectories while securing strategic national interests, public digital infrastructure provision will also be critical in finance, energy, water supply, transportation, health, education, and so on. This will go a long way in ensuring equitable access to digital infrastructural layers and the broadest sharing of the benefits flowing from digital technologies by reducing overhead and transaction costs. This is also crucial for creating new competitive advantages for domestic firms in existing and emerging new technologies.

One of the arguments made against data localisation requirement has been that the cost of localisation measures will hit start-ups and small businesses disproportionately. To help enable smaller entrepreneurs over such entry barriers, fully secure, public cloud and local data storage rentals can be provisioned, similar to what the Chinese state of Guizhou has done by setting up the Guizhou Cloud Big Data Industry Co. Ltd. Europe is also offering useful examples from which India can learn (Singh 2018; Scholz 2016). Moreover, given that digital intelligence is becoming the focus of economic value generation even in agriculture, with global seed and agricultural machinery companies transforming themselves into digital companies, continuing along the current path could have adverse implications for India's food sovereignty too.

Policy responses to evolving corporate strategies for value appropriation in the digital economy will determine the direction and impact of digital transformations and the associated income distribution effects on aggregate demand in the economy. To ensure that emerging digital economy players promote competition and entail broader economy-wide benefits, policies need to evolve quickly to support indigenous digital companies by reigning in monopolistic tendencies and practices in the digital space. Our competition policy should also discourage the takeover of Indian technology firms in different sectors by foreign technology companies and foreign private equity funds. This calls for a reformulation of the metrics used in merger reviews[24] by adopting a more strategic approach to ensuring competition within and across sectors. Building up the national ecosystem for an inclusive digital economy also calls for a level-playing field for firms and start-ups founded in India by Indian entrepreneurs. Access to capital from the government through the setting up of ingenious financing methods is the dire need of the hour so that they do not have to depend on foreign venture capitalists and foreign private equity firms.

[24]See Saraswathy (2019) for a critical analysis of the Competition Commission of India (CCI)'s assessment of the 2019 Flipkart-Walmart deal.

It must also be acknowledged that without improving indigenous capabilities in electronics hardware production rapidly to leverage as well as forge synergies with India's software capabilities, India faces the risk of witnessing another wave of import surge with adverse macroeconomic implications. Lack of rapid indigenous technological improvements could lead to dwindling of its manufacturing base across several other industries, as the use cases of the new digital technologies expand in sectors as varied as healthcare and education to industrial automation, renewable energy, public safety, smart cities, finance and agriculture. Such an impact will vary depending on:

- the existing levels of capabilities in various industries;
- indigenous entrepreneurs' abilities to foresee the synergies and leverage capabilities across different areas and activities; and
- the government's abilities to put in place the necessary ecosystem to improve the first two capabilities through a systemic approach (Francis 2019a).

Within the ICT sector, there is a critical need to support the domestic telecom equipment manufacturing segment as it provides the network connectivity and access for the digital economy. Depending on foreign equipment manufacturers for this critical digital infrastructure layer will leave India dangerously vulnerable as the country's strategic sectors become more and more digitalised and integrated. Equally importantly, India must ensure that critical digital infrastructure network layer—telecommunications networks—are not kept open to foreign companies. This calls for tweaking of India's FDI rules (Francis 2020).

Ensuring equitable access to data through data protection and security policies, building up secured ICT hardware/software synergies domestically and evolving adequate public digital infrastructure provision support are some of the most urgent inter-related interventions that India needs to take on a priority basis. Acknowledging all these challenges and seeking solutions not only call for a significant leap in the capacity of bureaucracy and policymakers, but also a huge step up in the resources allocated to for educating and skilling the population and public funds allocated to SMEs, start-ups, and R&D in strategic high-technology fields. Thus, India faces a critical governance challenge to envision an inclusive digital development trajectory within the deployment phase of the ICT techno, economic paradigm and to effect a high level of coordination between the development of technological, financial, industrial and institutional capacities and capabilities needed for equitable digital transformations.

Acknowledgements This chapter mostly draws upon "Evolution of Technology in the Digital Arena: Theories, Firm-level Strategies and State Policies", Working Paper No. CWS/WP/200/47, Centre for WTO Studies, New Delhi; this was an extended pre-publication output to elicit comments from readers. This was the report of a study commissioned by the Centre for WTO Studies (CWS) and is available at https://wtocentre.iift.ac.in/workingpaper/WorkingPaper47.pdf. The author is very grateful to Abhijit Das, Head, Centre for WTO Studies for his valuable guidance and support, and to O. P. Wali, Professor, IIFT, Sanjay Bahl, Director General, CERT-In, and M. R. Anand, formerly, Principal Economic Advisor, Department of Telecom, for their very constructive suggestions on the original version of the paper, as well as to the participants at the seminar held at the Centre for WTO

Studies, for sharing their views. She is indebted to Carlota Perez for her most kind comments on the Working Paper. The author is also grateful to Smita Purushottam, Founder Chairperson of SITARA (Science, Indigenous Technology and Advanced Research Accelerator) and SITARA co-members for the insights they have shared. However, the author remains solely responsible for any omissions and errors.

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Chapter 3
Quantum Computing and Its Application in Healthcare and Agriculture

Kiranjit Pattnaik, Subhashree Mishra, and Bhabani Shankar Prasad Mishra

1 Introduction

Extensive use of digital computers for commercial purposes has been a fact of modern economies. The memory of a digital computer is made of bits and each bit is either a zero or one (off or on). The data in classical/digital computers are encoded into binary digits which are called bits and each bit has one of the two fixed states and that is either a zero or one.

There are some limitations in classical/digital computers. The computing power doubles every 2 years but this scenario is slowly coming to an end because of technological barriers and demand for smaller and better machines. Machines operating linearly by processing tasks one after another and parallelism can solve this problem. However, there are limitations to parallel calculations done by a machine as per Amdahl's law (Onyuksel and Hosseini 1995). Considering the above factors, dealing with complex real-world problems, unstructured big data, higher computing performance for machine learning and artificial intelligence models and so on would require a shift in computing paradigm.

Unlike digital computers which are based on transistors and have access to memory quantum computers are completely different when compared to the traditional methodologies; that is, they have access to quantum memory which are made of quantum particles assigned by zero, one, a state between zero and one, or both.

To solve a very complex problems and those which take too much time slowing down business decisions, quantum computing is one of the potential solutions

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(Narayanan 1999; Jain 2015; DiVincenzo 1995). Quantum computing operates on qubits which are also called as quantum bits. These qubits are affected by quantum effects such as entanglement and superposition and can omit Amdahl's law; that is all operations can be done at a time and not be bound by limited parallelism. Moreover, as the number of qubits increases, the power grows exponentially contrary to the linearity of classical computers.

Different groups of researchers have proved that certain quantum computing algorithms would provide an exponential speed-up to the existing classical ones but with an assumption that the qubits in quantum computers are stable and behave well under complex scenarios which are not at the current level of hardware. Presently, we are in the era where the quantum devices are noisy and unstable, and also termed as noisy intermediate scale quantum (NISQ) devices by some companies. Companies like IBM, Rigetti, Google, IonQare, D-Wave and Microsoft are trying to create their own enterprise-level NISQ devices.

2 Preliminaries of Quantum Computing

(1) ***Quantum***: The smallest possible unit (such as mass or energy) of any physical unit is termed a quantum. As proposed by Max Planck in 1900 the energy of a body is accommodated in distinct packets termed Quanta. Quantic particles have a wave-particle dual nature wherein depending on the environment these particles sometimes behave as a wave and at other times as particles. Quantum theory is distinguished by finding the probability of a particle at a given point in space and not the exact location of the particle.
(2) ***Qubit***: The qubit is the core component of quantum computing and also the smallest component of quantum information. It is a pair of composite vectors pointing to any spot on a unit sphere. Classical bits, that is 0 or 1, are used in classical computers to perform operations but the qubits can be 0, 1, any number between 0 and 1, or both 0 and 1. Qubits constitute a photon and an electron.
(3) ***Superposition***: When the qubit exists as both 0 and 1 this occurrence is called 'superposition'. Multiple quantum states can be possible for a particle but once the energy or position of the particle is measured, its superposition is lost and it drills down and exists in only one state.
(4) ***Entanglement***: The occurrence in which quantum particles interconnect with each other even though they are separated from each other by a long distance it is described as entanglement.

In a pair, if one entangled particle decides to be in the "down" spin state (that is when the electron is in alignment with its magnetic field or, in other words, the lowest energy state) during measurement time, then this decision is passed on to the other correlated particle which is in the "up" spin state. In short, even if the particles are far apart from each other, quantum entanglement allows qubits to interact with each other immediately.

Table 1 This table shows various sitting combinations for Person 1, Person 2 and Person 3 across Tables T1 and T2

Persons	Tables T1 and T2							
Person 1	T1	T1	T1	T1	T2	T2	T2	T2
Person 2	T1	T1	T2	T2	T1	T1	T2	T2
Person 3	T1	T2	T1	T2	T1	T2	T1	T2

Source https://hackernoon.com/quantum-computing-explained-its-rocket-science-55d7766edac2

A comparison of how quantum computers works using qubits and how its equivalent method uses classical computing would be useful.

As an example, say a dinner has been organised, and one is in charge of the seat arrangement of guests. To keep it simple for understanding, say, only three guests have arrived and there are only two tables in the room for them to sit but with a problem that some guests dislike each other and are enemies and some of them are friends. The following may be their inter-personal relationship:

- Persons 1 and 3 like each other and are friends.
- Persons 1 and 2 dislike each other and are enemies.
- Persons 2 and 3 dislike each other and are enemies.

In this situation, one wants to settle the guests in such a way that maximum number of friends sit together while having the lowest number of enemies together. In a classical computer how would this situation be resolved is mentioned below.

There are two tables (T1 and T2) and three guests (Person 1, Person 2 and Person 3), so that each pair may be assigned a table. For example, one combination of placements could be that Person 1 and Person 2 are placed on T1, and Person 3 is placed on T2 (Table 1). Similarly, here are all the possible combinations:

In order to optimise the results such that more friends can sit together rather than enemies sitting together, a scoring technique or algorithm to score the various sitting combinations is needed to get the best results. It could be something like this:

Score = (Number of Friends sitting together at a table) − (Number of Enemies sitting together at a table).

With this metric, the scores would be:

Looking at the scores in Table 2 it may be said that there are two arrangements which have the highest score 1, that is.

Arrangement 1: Person 1 and Person 3 sitting together at T1 and Person 2 sitting at T2.

Arrangement 2: Person 1 and Person 3 sitting together at T2 and Person 2 sitting at T1.

This shows that the best possible solution to the above-mentioned scenario would be if Person 1 and Person 3 sit together at a table and Person 2 sits separately at the other table.

Table 2 This table shows various sitting combinations for Person 1, Person 2 and Person 3 across Tables T1 and T2 along with the scores based on the algorithm. Score = Number of friends sitting together at a table − Number of enemies sitting together at a table

Persons	Tables T1 and T2							
Person 1	T1	T1	T1	T1	T2	T2	T2	T2
Person 2	T1	T1	T2	T2	T1	T1	T2	T2
Person 3	T1	T2	T1	T2	T1	T2	T1	T2
Score	−1	−1	1	−1	−1	1	−1	−1

Source https://hackernoon.com/quantum-computing-explained-its-rocket-science-55d7766edac2

In this situation, a conventional computer would require three bits to identify all three persons and each set would be executed separately to give the scores as per the scoring algorithm which sums up to eight times and then of selects the best score.

Since it is a very simple problem which would take very less time or one may say that almost no time would be taken on a conventional computer. However, what if the number of people is increased?

With 3 people, there will be 2^3 combinations, that is, 8 combinations**.**

With 20 people, there will be 2^{20} combinations, that is, 1,048,576 combinations.

The above cases are fine with conventional computers. Suppose the number is risen to 200 people, then there would have been 2^{200} combinations.

The fastest computers in the world can compute only 200,000 trillions calculations per second which means that it would take nearly 10^{46}s, which is too long when compared with the time that might be longer than the age of the universe.

Considering the above scenario with three persons and two tables, with a conventional computer three bits would be used and each combination has to be executed separately, one at a time; that is where quantum computers come into the picture. With a quantum computer, all of these eight combinations would be executed at one time instead of eight times, using three qubits. When a qubit is set to a superposition of both 0 and 1, two parallel realities are being unravelled and, hence, if it is done for all three qubits, there would be eight parallel realities. The combinations of qubits in each reality are different, which means that each combination exists in one of the parallel realities. When computations are applied to the qubits, the computation unravels all realities in parallel at the same time and this is how an exponential speed-up is achieved in quantum computing.

3 Quantum Computing Models

There are four models of quantum computing which are distinguished by the elements in which the computation is decomposed.

1. Quantum gate array: Computation is decomposed into a sequence of few qubit quantum gates which are reversible, contrary to the classical gates which are not reversible other than the NOT gate.
2. One-way quantum computer: Computation is decomposed into a sequence of one-qubit measurements applied to a highly entangled initial state or cluster state.
3. Adiabatic quantum computer: Computation is based on quantum annealing which is a high-level procedure to find the global minimum of an objective function over a given set of candidate states using quantum fluctuations.
4. Topological quantum computer: Computation is decomposed into the braiding of anyons which are two-dimensional quasiparticles in a 2D lattice wise world lines pass around one another to form braids in a 3D space/time which is one temporal and two spatial dimensions.

4 Application of Quantum Computing in Healthcare Sector

Quantum computing would help to increase the drug discovery speed exponentially in areas such as Genomics (Mathkour and Ahmad 2010) and Protein Simulation (Rapaport 1999).

1. Quantum machine learning (DeBenedictis 2018) algorithms are applied to work with multiple features at a time to identify specific diseases based on health reports. This can also be implemented on the live readings to forecast health conditions of patients and also probably to detect future complications and diseases.
2. Quantum computing helps in catalysing personalised medicine and simulates effects of potential treatments on individual and specific diseases. This enhances the possibility of increasing life by 5, 10 or even for more years based on the individual health conditions and its improvement with medication.
3. It can spark innovation in genomics to determine complete DNA sequences of an organism genome at a single time point considering various features.
4. It helps identify effects of individual drugs on the human body based on specific medical features of that particular body.
5. Using quantum computing the pre-approved drugs can be repurposed more easily to create new applications and permit computational chemists towards achieving discoveries faster; this would help in finding cures for a huge variety of diseases.
6. Quantum computing has the ability to process multiple computations at a time using qubits; this encourages chemists to invent different drugs by evaluating multiple proteins and chemicals and different molecular interaction to identify and improve certain medical conditions. It also helps in inventing a cure for those medical conditions and diseases.
7. Quantum computing facilitates faster sequencing and analysing of a person’s genes compared with the existing methods used today. Analysing personal drug development would be better performed through this.

5 Application of Quantum Computing in Agriculture Sector

1. Quantum machine learning algorithms are applied to create new protein structures of plants, that is, create new plants with much benefits to human health based on multiple combinations of DNA structure.
2. Weather forecasting requires some amount of guessing even after the results are achieved based on readings and different algorithms. Since quantum computing has the ability to process multiple computations at a time using qubits, meteorologists would have a much better idea of when bad weather will strike based on multiple live parameters all computed at a time to alert people to save money, lives and anguish when it hits the agriculture sector. Compared to existing climate models in the real world, quantum computers would prove to be a better option for computing, predicting and forecasting accurate climatic conditions. The sooner the climatic conditions are known, the better would decisions taken by the agriculture sector for the betterment of various form activities. Also various precautions can be taken to save crops.
3. Application of quantum computers in cellular agriculture (Patil and Kale 2016) can lead to conditions whereby different agriculture products are produced from cell structures with a combination of synthetic biology (Madec et al. 2009), tissue engineering (Desai 2012), molecular biology, biotechnology and bioinformatics (Jawdat 2006). These result in creation and design of new methods of tissues, proteins and fats production.

6 Challenges in Quantum Computing

Quantum computing is the future and is very much effective compared to digital computing but there are some challenges currently present in quantum computing. It is very hard to design and create systems that can accommodate a lot of qubits and execute all of them at the same time. Similarly, there is the fragility of the qubits in which there is a load of quantum coherence which is known as quantum de-coherence, and it is tough to track and understand the interactions between quantum systems. It is also very hard to optimise and reduce the requirement of qubits to do any algorithm and also develop advanced quantum error correction (QEC) capabilities to improve the error rate in quantum systems.

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Chapter 4
Decision-Making Using Big Data in Predicting Degenerative Diseases

V. Bhanumathi and C. P. Sangeetha

1 Introduction

Most of the healthcare researches in recent years have been focused on the development and design of a human-related network, generally termed as body area networks (BANs) (Movassaghi et al. 2014). The advancement in the field of wireless communication technologies made it feasible to develop light-weight, low-power, intelligent wearable and implantable sensors and to implement wireless body sensor networks (WBSNs) or WBANs. The applications of WBANs include medical and non-medical activities, where several body sensors are placed in and around the human body (Yuce 2010). The most prevalent application of WBAN lies in the medical field like continuous health monitoring of aged people, post-surgical monitoring, prediction of degenerative diseases like cancer, tumour, heart disease, Alzheimer, dementia, and so on. Table 1 lists some of the applications of WBAN (Al-Janabi et al. 2017).

The most prominent objective of any WBAN is to provide a convenient, cost-effective, non-invasive method for human health monitoring or e-health patient monitoring and telemedicine applications. In this network, several miniaturized intelligent sensors are placed on the clothing or the body surface or even implanted within the human body. The sensors continuously sense the physiological parameters of the human body and communicate the measured data to the end-user using any of the suitable wireless technologies. The different types of bio-sensors and their working principles and specifications are listed in Table 2 (Malhotra et al. 2017).

The physiological parameters of the patient, continuously measured by the body sensors such as pressure, sugar level, heartbeat, respiration rate, and so on result in a big volume of data which comprise both structured and unstructured data. Big data

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_4

Table 1 Applications of WBAN

Application	Goal	Sensors used	Outcomes
Remote patient monitoring	Monitor patient's health and treatment outcomes	Accelerometers, EEG, ECG, blood pressure, temperature, respiration sensors	Specific detected events, such as an increase in heart rate
Rehabilitation	Assist with and improve rehabilitation of patients with mobility problems	Accelerometers, EEG, ECG, posture, gyroscopes, magnetometers	Patient's skills and level of impairment
Biofeedback	Assist with controlling emotional states, such as stress	EEG, ECG, blood pressure, posture sensor	Patient's environment or detected mental states
Assisted living	Improve the quality of life for people with disabilities	Accelerometers, EEG, ECG, blood pressure, temperature, location sensors	Environment, disease progression
Fitness, performance and wellness monitoring	Improve skills and detect deficiencies in athletes, military or workers. Improve user's quality of life	Accelerometers, EEG, ECG, blood pressure, temperature, respiration, posture, pedometers	Update training programs based on, e.g. fitness level, desired outcomes, stress detection, social interaction
Serious gaming	Improve the effectiveness of games, e.g. educational applications	EEG, EDR, heart rate sensor	Task difficulty increases/decreases based on detected stress levels

helps in analysing these data and also stores a huge volume of data. The advantages of big data are minimization of human error in the form of wrong medicines, dosage and reduced cost. In Bhanumathi and Kalaivanan (2019), application-specific sensor cloud architecture is detailed and it is observed that the integration of sensor networks, cloud computing and internet enables users to retrieve the resources whenever and wherever they like to access the same.

Figure 1 illustrates a basic and widely used WBAN architecture for a patient monitoring application, where the physiological parameters are sensed and communicated towards the end-user like a doctor, family members, medical server or emergency unit. It can provide seamless and secure connectivity among patients, doctors, healthcare centres and so on. When this WBAN architecture is applied to analyse patients in a hospital or a patient with multiple problems, the caretaker has to concentrate on large data sets of various patterns and trends. In this situation, the traditional analysis may mislead and become both inaccurate and inadequate in predicting the nature of the disease and the correct dosage. This is one of the reasons for moving towards big data, especially in the field of healthcare applications.

Table 2 Bio-sensor types and its applications

Sensor	Working principle	Data rate	Battery lifetime
ECG/EEG/EMG	Measures the potential difference across electrodes placed on different parts of the body	72/86.4 Kbps/1.5 Mbps	>7 days
Pulse oximetry SpO_2	Measures ratio of changing absorbance of the red and infrared light passing through the body	<10 Kbps	>7 days
Respiration	To measure the oxygen dissolved in a liquid using two electrodes	<10 Kbps	>7 days
Carbon dioxide	Uses the infrared light and measures the absorption of the gas presented	<10 Kbps	>7 days
Blood pressure	Measures the systolic pressure (peak pressure) and diastolic pressure (minimum pressure)	<10 Kbps	>7 days
Blood sugar	Uses non-invasive method like near-infrared spectroscopy, ultrasound, optical measurement at the eye, and breath analysis	<10 Kbps	>7 days
Humidity	Measures the conductivity changes in the level of humidity	<10 Kbps	>7 days
Temperature	Uses a silicon-integrated circuit to detect the temperature changes by measuring the resistance	<10 Kbps	>7 days

Source Malhotra et al. 2017

In this chapter, the main focus is on the prediction of degenerative diseases which is one of the most crucial applications of WBAN. Even though a WBAN for patient monitoring has been developed much faster, applications like detection or diagnosis of degenerative diseases are still progressing. Degenerative diseases are like slow poison and may lead to death in the long run. With technologies like big data (Lv et al. 2017; Kambatla et al. 2014; Mehta and Pandit 2018; Chen and Zhang 2014) and IoT (Farahani et al. 2018) the disease analytics are made easy and time-saving. The data set derived from the system is very much beneficial for making decisions. With the advent of new technologies, the scope of WBAN is proliferating into every walk of human life. This chapter deals with the decision-making of a degenerative disease called Alzheimer's disease (AD) based on big data and IoT. AD is one of the most common neurodegenerative diseases leading to progressive brain disorder

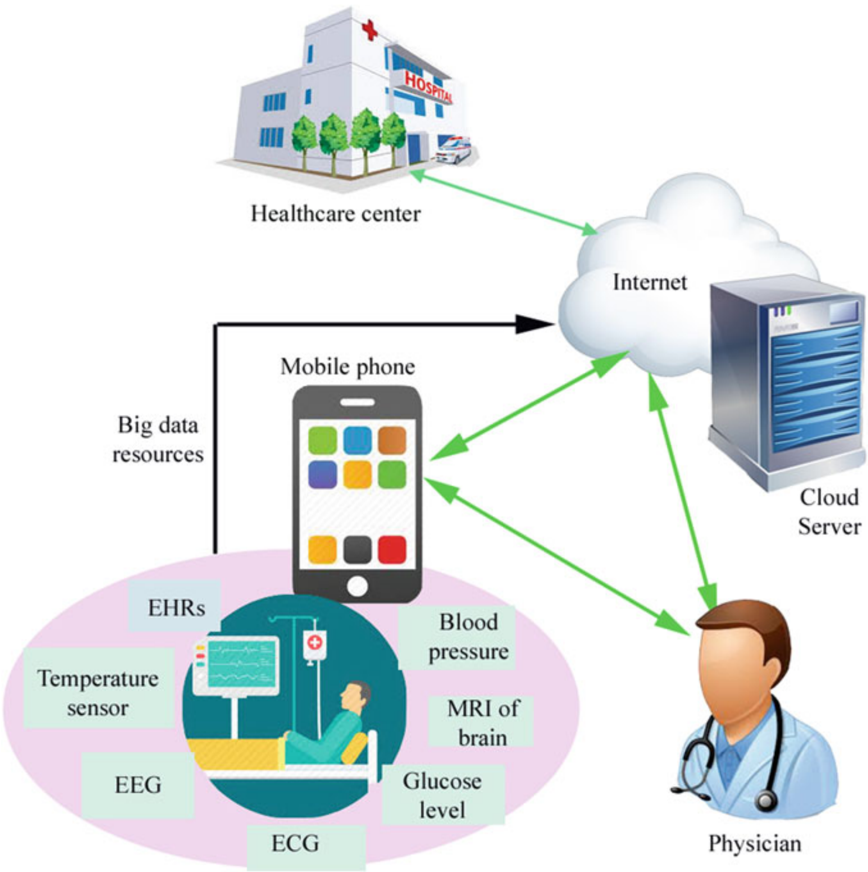

Fig. 1 WBAN architecture for healthcare application

that makes a person dependent on others (Alzheimer's Association 2018). As time passes, 60–70 per cent of AD affected people end up in dementia, which is also a degenerative disease affecting brain cells.

India had about 4.1 million people suffering from dementia, the second largest in the world, as per a report in *Hindustan Times* (October 29, 2018). Alzheimer disease is the most common type of dementia. It is also held that this count could double by 2035. This disease is common among elderly people, but this remains unaware by almost all people. Early detection of this disease is a challenge.

An attempt is made here to come up with an architecture that can predict the chance of occurrence and it can act as a tool for prevention of this disease with the support of newer technologies.

The main objectives of the chapter are:

- Analysing the importance of big data and IoT technologies in healthcare applications.
- Proposing a decision-making architectural framework to diagnose AD.
- Presenting research challenges in the field of healthcare using big data.

Section 2 gives a background of big data technology and IoT and their application in the healthcare sector. Section 3 briefs existing techniques for the evaluation of AD. Section 4 presents an outline of an architectural framework for decision-making of the disease. Benefits of integration of technologies are detailed in Sect. 5, and Sect. 6 concludes the chapter.

2 Background

2.1 IoT in Healthcare

With the advancement in the field of information and wireless network technologies, the communication methods have transformed into machine-to-machine communication from traditional methods like human-to-human or human-to-machine communications. The recent IoT technology is such a platform to support machine-to-machine communication technique (Miorandi et al. 2012; Bandyopadhyay and Sen 2011; Gubbi et al. 2013). Generally, IoT consists of several interconnected wired or wireless devices, systems and networks that can perceive, communicate and transfer information between anyone, anytime or anyplace. One of the most appealing applications of IoT lies in medical and healthcare services like patient health monitoring, fitness care and rehabilitation of the elderly (Bisio et al. 2017). Concerning these applications, medical objects, diagnostic devices, sensors, imaging equipment constitute the smart objects in IoT. These services are expected to reduce the overall cost and to improve the experience of users.

2.2 Big Data in Healthcare

Big data, in general, represents huge volumes of data. When the data is received from different sources it makes the system complex to solve and conclude. The system can be a human or a machine. The complexity of the received data cannot be processed by conventional technologies. The importance of intelligence comes into play in handling big data. For some applications, computational analysis is needed and this can be done with the help of big data technologies like Apache, Hadoop, Microsoft HDInsight, NoSQL, Hive and so on. In recent times big data is found to be the most opted solution for healthcare applications in analysing critical and degenerative diseases.

The healthcare industry is overwhelmed with data that includes clinical data, like doctors' prescriptions, laboratory data, hospital administrative notes, patient records, and so on. Due to the current trend of digitization in several fields the earlier hard copy clinical records are transformed into digital form with significant advantages like low cost and improved quality of healthcare services (Wang et al. 2018). The volume of such data has been increasing by the day, which is complex and difficult to manage by the conventional software tools. Hence, big data researchers are setting up a new goal called Big Data Analytics by considering the behaviour and trends within these data. This Big Data Analytics has the potential to enhance the quality of human life by predicting various degenerative diseases and providing immediate and effective treatment at an earlier stage with low overall cost (Hampel et al. 2017; Bates et al. 2014). Some of the benefits of Big Data Analytics in healthcare are that it can:

- Deal with any crisis in public health by dealing immediately and effectively.
- Reduce time for treatment and cost of disease diagnosis.
- Perform the research and development activities efficiently.
- Predict the occurrence of any hereditary disease.
- Analyse the chance of fraud cases and ensure the privacy of patient data.
- Offer individual patient analytics.

The analytics of big data in healthcare can be better explained with four expressions: i. volume refers to the amount of data; ii. velocity indicates the speed at which the data are managed; iii. variety means the data can be of various characteristics; and iv. the term veracity denotes the authenticity or accuracy at which the analytics is performed (Gandomi and Haider 2015). The architectural framework of big data analytics is the same as that of the conventional health informatics with a difference in the processing execution (Raghupathi and Raghupathi 2013; Marjani et al. 2017). A large amount of data is stored in repositories to analyse and make decisions regarding health-related issues. The block diagram of the framework is shown in Fig. 2.

The big data sources can be internal (e.g., electronic patient records) and external (e.g., laboratories and insurance agencies) whose outcomes may be in different formats or data types. This raw data must be transformed using components like web services, data warehousing, and so on. The processed data are then made available to big data analytics platforms and tools (Raghupathi and Raghupathi 2014) like Hadoop, Hive, Avro, and so on. The typical applications of big data analytics are queries, reports, data mining, and so on. Currently, several healthcare applications using big data analytics have been introduced and are still evolving. Table 3 lists some examples in real-time big data analytics.

2.2.1 Analytical Techniques for Big Data in Healthcare

The healthcare-related data were mostly multi-dimensional and heterogeneous, which makes the analysis very difficult due to its dynamic and complex features. Descriptive and comparative analytics that can enhance the quality of health service

Fig. 2 Big data framework

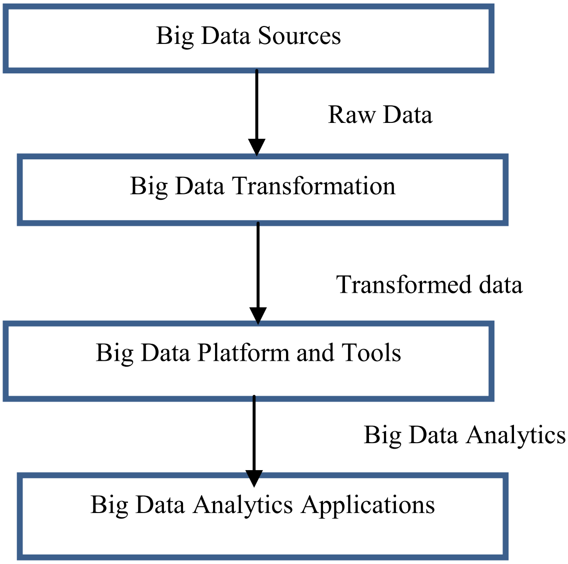

Table 3 Examples for some real-time big data analytics application

Healthcare end-user	Analytics application
North York general hospital, Canada	To enhance patient outcomes and overall operations like clinical, financial and administration
Columbia university medical centre	To analyse patients with brain injuries
Rizzoli orthopedic institute bologna, Italy	To study the role of genetic factors and to provide treatment
The hospital for sick children, Toronto	To improve the lives of kids prone to nosocomial infections
The university of michigan health system	To administrate blood transfusions
The national institute for health and clinical excellence, U.K	To verify the effect of new drugs or medicines in treatments
Harvard medical school and harvard pilgrim health care	To identify diabetes patients among the public for health surveillance
Blue cross blue shield of massachusetts	To find high-risk disease groups to reduce the risk and to improve patient outcomes

delivered by the organizations have been discussed (Asante-Korang and Jacobs 2016; Groves et al. 2013). It is stated that predictive analysis is better suited for long-term healthcare services like post-surgical critical monitoring, degenerative diseases like AD, dementia, cancer, and so on. Figure 3 explains some of the analytical techniques of big data in healthcare (Hu et al. 2014). It is observed from the figure that how the

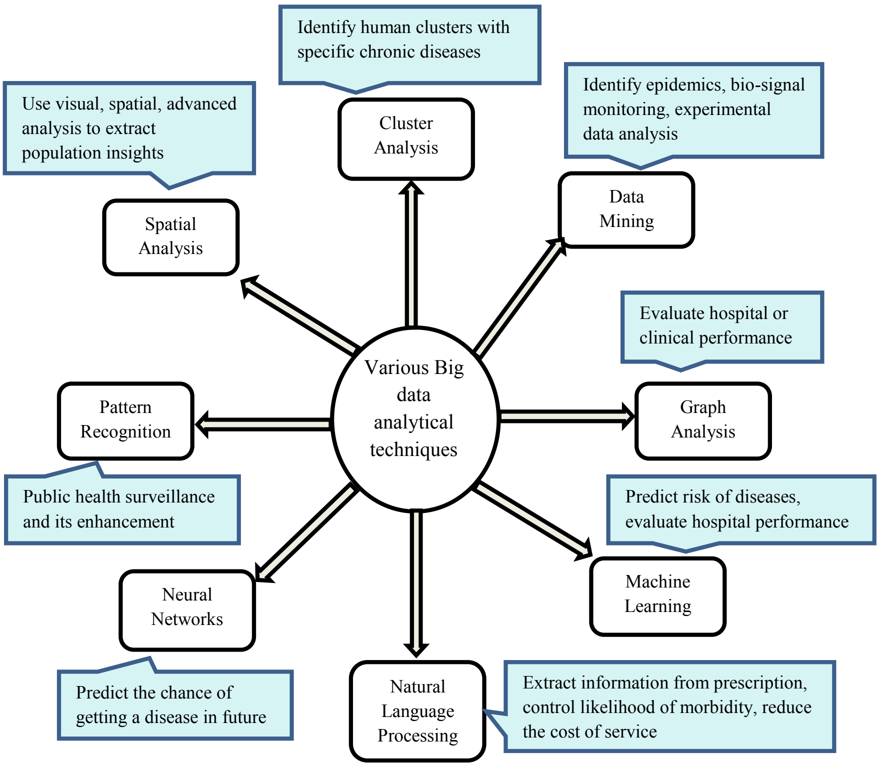

Fig. 3 Analytical techniques and examples of big data in healthcare

analytical techniques such as neural networks, data mining, pattern analysis, and so on, help analyse big data in healthcare applications.

2.3 Big Data and IoT in Healthcare

The big data analytics along with IoT (Cravero 2018) in the healthcare services has become much faster and accurate to diagnose and treat chronic diseases like arthritis, cancer, tumour, dementia, Alzheimer's, and so on. As per the prognosis, this combination in the field of medical applications benefits in terms of cost, especially during long-term monitoring (Hosseini et al. 2017). For example, the diagnosis and treatment of arthritis need long-term monitoring. Hence, if big data and IoT are manoeuvred, the arthritis patients can get treatment with these technologies and can get cured of the disease with minimum expenditure. It can be seen that both are complementary technologies, where IoT can directly modify various events depending on the analysed data, but big data needs some human involvement.

3 Existing Techniques for Alzheimer's Disease Evaluation

3.1 About Alzheimer's Disease

The changes in cerebral metabolism in the brains are a notification of AD, which makes the neurons within the brain to stop its normal functions and loses its connectivity with other neurons in the brain. The loss of brain function is termed as dementia and the patient finds if difficult to think, express and behave in a normal way, including recognizing their family members. The most common symptoms of AD are memory loss, mood changes, inability to communicate, confused state to find places and time, vision problem and poor judgment. Usually, the symptoms are seen after the age of 60, but persons with genetic mutations may show these earlier. Currently, there is no specific medicine that can cure this disease, but its speed of progression can be slowed down if it is detected.

Table 4 explores various stages of AD, from mild cognitive impairment to severe AD (https://wiki.mcmaster.ca/LIFESCI_4M03/doku.php?id=group_4_presentation_3__alzheimer_s_disease&rev=1516911539 (Last visited April 20, 2020)). AD affected people around the world are above 44 million. This indicates the need for an effective tool or technique to detect and prevent these types of neurodegenerative diseases.

Mild cognitive impairment (MCI) is normal in almost all humans beyond a certain age and it causes forgetfulness. People suffering from MCI could be affected by AD. Detection of this disease in early stages is very tedious, even though memory complaints are reported to their family doctors. It is because of the following:

- Family members' unwillingness to accept the disease as the symptoms are underestimated.
- Symptoms are attributed to ageing.
- Sometimes, some symptoms are ignored and, hence, not analysed.

Table 4 Various stages of AD

Various stages of AD	Duration (week)	Portions of the brain affected	Symptoms
Mild cognitive impairment	7	Medial temporal lobe	Short-term memory loss
Mild AD	2	Lateral temporal and parietal lobes	Reading, object identification and direction sense problems
Moderate AD	2	Frontal lobe	Faulty awareness, impetuous, short attention
Severe AD	3	Occipital lobe	Ocular problems

It is known from the literature that the gene which acts as the prime cause for AD is Apolipoprotein E or, APOE. With or without a gene one could be affected by AD; the severity would be high of the number of genes is more.

3.2 Disease Evaluation

Although the exact cause of this disease is not known, researchers believe that it is due to the development of beta-amyloidal plaques and neurofibrillary tangles in the brain. Reading the medical history, mental status testing, a physical and neurological exam, blood tests and brain imaging examinations of the patients help identify this disease. Alzheimer's is evaluated by performing a complete medical examination including CT, MRI or PET/CT of the head and also EEG.

- *CT imaging of the head*: Computed tomography (CT) scanning takes cross-sectional images of the body with the help of computers and rotating X-ray machines. Doctors used this to evaluate AD by avoiding brain tumour, subdural hematoma or stroke which leads to dementia.
- *MRI of the head*: Magnetic resonance imaging (MRI) uses a powerful magnetic field, radio frequency pulses and a computer to give a detailed picture of internal organs of the body, soft tissues and bones. MRI is mainly used to find the abnormality related with ageing, that is, MCI. MRI images will not show any variation in the early stages of AD. In the later stages, MRI images of the Alzheimer's patient will have a size reduction in the temporal and parietal lobes of the brain. In the early stages of AD, an MRI scan of the brain may indicate it to be normal.
- *PET and PET/CT of the head*: A positron emission tomography (PET) scan is a powerful tool to diagnose and determine the severity of a variety of diseases using the radioactive material called a radiotracer. A PET/CT scan can differentiate this Alzheimer's from other types of dementia.
- *Electroencephalography (EEG)*: It is used to monitor and record the electrical activity of the brain through an electrophysiological monitoring method. The recorded waveforms are used to predict cortical electrical activity. It is typically non-invasive, with the electrodes placed along the scalp.

3.3 Existing Frameworks

Several studies have been undertaken in this field to detect/predict AD using various models, platforms and tools. In Maudsley et al. (2018), a comprehensive survey of recent methods, semantic analysis and deep learning technique are reviewed for the development of diagnostic applications for AD. In Hampel et al. (2017), a framework for Alzheimer Precision Medicine Initiative (APMI) based on integrative disease modelling (IDM) is detailed. The functional diagram of the framework is shown in Fig. 4. Initially, big data is generated from clinical records, research theories and

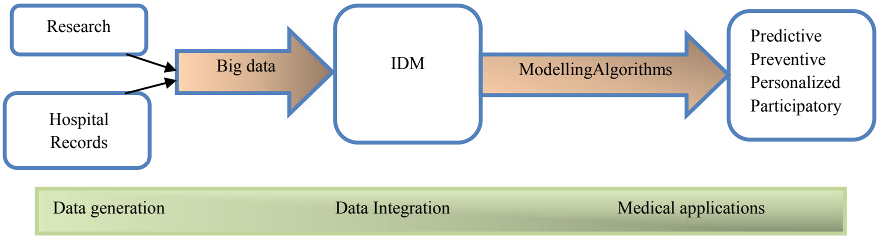

Fig. 4 Functional diagram of APMI

scientific publications along with Omic and imaging tools. In the IDM, the data are converted into a standard format and integrated using modelling algorithms for taking decision on predictive, preventive, personalized and participatory medicines.

A multi-modal fusion technique was proposed in Alvarez et al. (2018) to analyse data and extract significant features to improve the care of Alzheimer's patients. A three-level architecture is introduced which consists of a service subsystem, a high-level and a low-level subsystems. The low-level subsystem tracks health-related records as activity-related data and medical-related data. The activity-related data are analysed for abnormal behaviour detection (ABD) within the low-level subsystem itself. The ABD analysed data and the medical-related data are sent to the high-level subsystem for further analysis and decisions using fusion techniques and decision support tools. The decisions are given to the service subsystem for various services, and actions to be taken in support of the patient treatments by himself or a medical practitioner.

4 Proposed Model

4.1 Alzheimer's Health Management and Analysis (AHMA) Model

The proposed architectural framework for predicting the early stage of AD based on EEG data and IoT is shown in Fig. 5. It is called Alzheimer's Health Management and Analysis (AHMA) model. The AHMA model is divided into four sections like the EEG sensor data, data acquisition and transformation, data analytics and decision and information support section.

Patient: The data about the patient such as personal information, predicted disease, symptoms and treatment history are collected during the visit of the medical consultant or doctor. It is stored and maintained in the cloud server, and this information is used for finding the likelihood of the disease to be affected in the future.

The EEG sensor data: The wearable EEG biosensors are used to collect vital changes in electrical activities of the brain. The collected information is forwarded

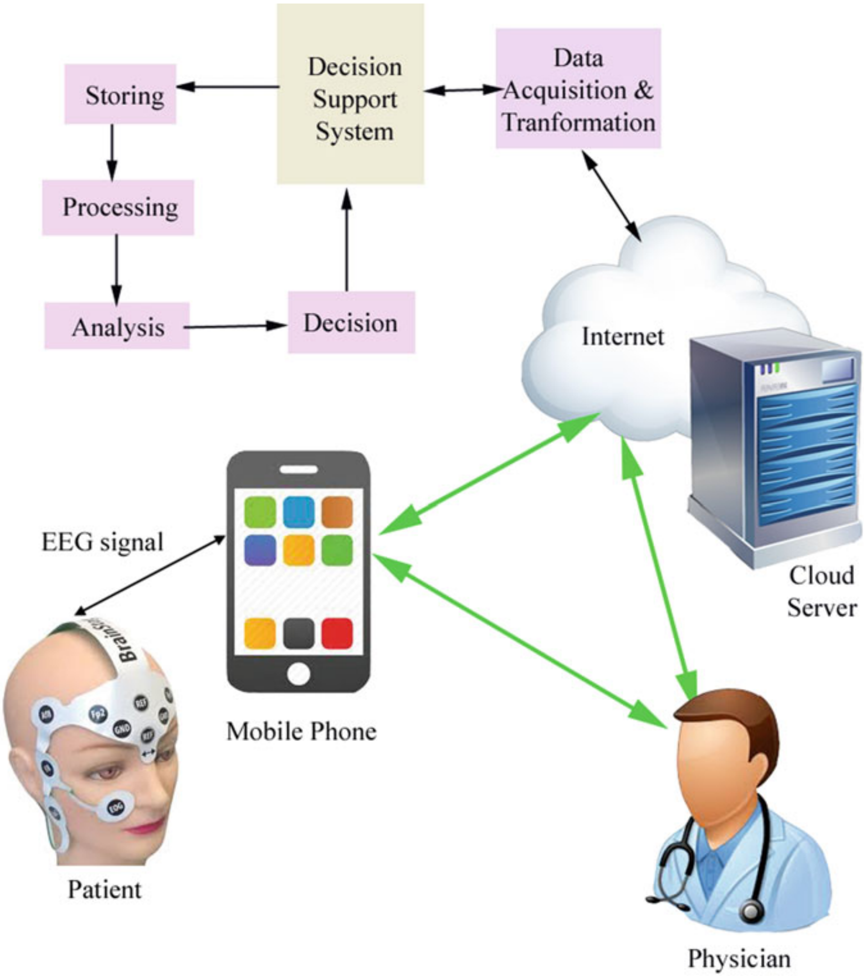

Fig. 5 AHMA architecture showing an overview of communication between the components

to the cloud server through a smartphone or portable devices for diagnosing the disease. Then the predicted results and treatment suggestions are forwarded to the medical practitioner or user's mobile phone through internet.

Cloud server: The utilization of cloud server can reduce processing time and expenses involved in disease prediction. It provides massive storage, computational resources and data management in an on-demand manner. Also, it continuously maintains all medical data (disease type, causes, symptoms, diagnostic method, treatment, etc.) and patient's information (personal ID, symptoms, treatment history, etc.). This information is given as input parameters of the automated decision system in the cloud server which can be used to diagnose the disease and to interpret the chances of disease occurrence based on the similarity measurement and prediction score.

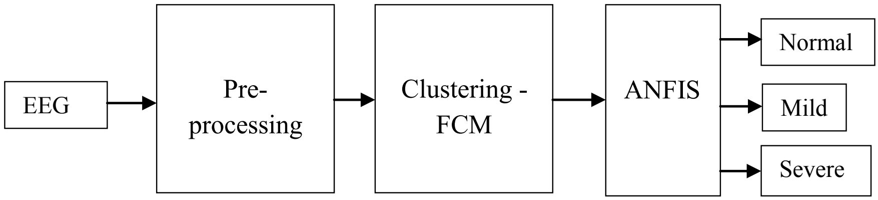

Fig. 6 Decision and information support system

Data acquisition and transformation: In this unit data is processed by acquisition and transformation. The data obtained from the sources are heterogeneous and, hence, should be converted into standard formats. For data interoperability and integration, a common data model needs to be used. Some of the standards that can be used are Health Level-7 (HL7) which is an international standard for transferring clinical or administrative data from one format to the other. The Fast Healthcare Interoperability Resources (FHIR) is the latest standard, extracted from HL7, which is better than its original standard. It is widely used for cloud communications and server communications in large healthcare institutions.

Decision support system: The decision support system for AD prediction using EEG has been diagrammatically represented in Fig. 6. The main components of the automated decision-making system include input data, pre-processing, clustering, fuzzy modelling and diagnosis output.

Pre-processing: At this stage, the raw input data are sampled and given to the low-pass filter which is used to remove the noise and artefact in the input signal by removing the outliers from the data set and also to produce the statistical value to normalize the data set.

Feature selection and extraction: After getting the pre-processed EEG signals, selection of features and extraction are important tasks, in which fast Fourier transform, wavelet transform, autoregressive model, and so on are used to identify the vital content of EEG signals such as its power spectrum and frequency bands.

Clustering: By using the unsupervised learning approach clustering classifies and produces patterns of clinical data applied to the decision support system. The fuzzy c-means (FCM) clustering is most commonly used for performing data classification and clustering. It is also used to evaluate big data applications and validate the healthcare system. The analysed data are given to ANFIS for decision making. According to the output of the classifier, the severity of AD is identified as normal, mild, moderate or severe stage concerning some reference dataset. Based on the decision, this unit also can advise regarding the dosage of medication that should be prescribed to the patient. The outcome of this decision unit helps the medical practitioner to easily conclude the status of the suspected AD patient. From this model, the decisions can be communicated to medical practitioners through IoT cloud using gateways. The decisions are available at any time for the timely advice of the doctor.

Table 5 EEG band's ranges

Frequency band	Frequency range in Hz	Characterization
Delta	1–4	Deep sleep
Theta	4–8	Vital role in childhood, associated with brain disorder of adults
Alpha	8–12	Appear in occipital location during eyes closed, that is, mental inactive under relaxation
Beta	12–25	Appear in central and frontal locations during tension
Gamma	25–30	Cognitive and motor function

Source Aghajani et al. 2013

4.2 *Major Findings in the Existing Research Papers Related to the AD Based on EEG*

EEG is used to record the electrical activity of the brain by measuring the voltage fluctuation in the neurons. The recent advancement in sensor technology, embedded system and wireless communication makes it possible in designing a lightweight wearable EEG cap. The placement of the EEG electrode is based on the 10–20 international standard system, which usually records the electrical activity by 20–40 min. There are 19 channels that include Fp1, Fp2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2, Cz, Fz and Pz and seven bipolar channels that include F3-F4, F7-F8, C3-C4, T3-T4, P3-P4, T5-T6 and O1-O2 which are used to record 650 features per AD patient. Changes in the rhythms of theta and gamma are directly related to the brain degenerative pathology which affect the synaptic function and electrical activity of the brain. The EEG band's ranges are presented in Table 5 (Aghajani et al. 2013).

Several studies have investigated the correlation test such as Mini-Mental State Examination (MMSE) (Folstein et al. 1975), Cambridge Cognitive Examination (CAMCOG) (Roth et al. 1986), and Global Deterioration Scale (GDS) (Reisberg et al. 1982) for achieving global cognition for the EEG spectral parameters. The compound test of MMSE (Folstein et al. 1975) was found to be the most widely used EEG test of global cognition. Based on the MMSE score, AD is classified into (i) mild AD patient (MMSE $\geq$ 18) and (ii) moderate to severe AD patient (MMSE $<$18).

In quantitative analysis, AD patients show low beta power, increase in theta power and less peak frequency. This is used to predict the cognitive decline on the global cognition CAMCOG, that is, it is one of the earliest symptoms in mildly demented AD patients. During the AD, the alpha activity goes down (Jiang 2005). The different level of cognitive impairment was investigated by correlating the EEG spectral parameters which were measured through (1) alpha reactivity and its coherence during memory activation; (2) theta relative power and (3) alpha coherence during eyes closed. For the AD patient with memory complaints, the MMSE and GDS score is reduced because of increasing theta activity during rest and lowering alpha activity during eyes closed. The review related to band consideration in EEG signal for AD prediction is shown in Table 6.

Table 6 Band consideration in EEG signal for AD prediction—a review

References	Classification methods	Major findings in band consideration in EEG signal
Aghajani et al. (2013)	SVM (supervised classification)	Reduced the alpha band obtained in the central, parietal and limbic regions and also an increased theta band in the frontal and occipital temporal regions in the left brain hemisphere In the right brain hemisphere, a reduced alpha and beta band in the entire brain region. A unique sense in the right temporal region which has a considerable difference in the two groups of all frequency bands
Blinowska et al. (2017)	PCA and ROC	A reduced coherence estimates, especially in posterior and temporal regions at theta band
Kulkarni and Bairagi (2014)	LDA and SVM	The increased power of low frequency in the delta and theta band reduced the power of high frequency in the alpha and beta band
Vecchio et al. (2012)	ROI	An abnormal increase of delta power in the cortical sources as well as a power decrease of posterior alpha sources (Eyes closed state)
Kang et al. (2015)	Principal Dynamic Modes (PDM)	Slower neural connectivity between the occipital and the frontal cortical regions, i.e., increased power in the theta and reduced power in the alpha band
Melissant et al. (2005)	ICA, k-nearest neighbour classifier, Feed-forward neural network, Linear discriminant	Relative power in theta band
Moretti et al. (2009)	ANOVA statistical tool	Increase in theta/gamma ratio (relative power at peak frequency) was associated with impairment in memory tests

(continued)

Table 6 (continued)

References	Classification methods	Major findings in band consideration in EEG signal
Hiele et al. (2007)	SPSS for Windows (release 12.0.1)	Theta relative power during eyes closed, alpha reactivity during memory activation (i.e. the perceptual decrease in alpha power as compared to eyes closed) and alpha coherence during eyes closed and memory activation
Baker et al. (2008)	k-means clustering algorithm	Beta power profiles

5 Benefits of the Technology Integration

As far as a WBAN is considered, the challenges that have been addressed are energy, reliability, low cost, quality of service (QoS) metrics, scalability, network coexistence and security/privacy. These challenges could be mitigated to an extent using various algorithms and protocols in the layered network architecture. Most of the protocols concerning the network layer are discussed in Bhanumathi and Sangeetha (2017). The network co-existence issues are addressed using various interference mitigation techniques and avoidance algorithms. Using certain encryption/decryption techniques and key management algorithms, the network can be rendered safer and more secure. As discussed in this chapter, by introducing big data and IoT, some of the challenges of WBAN could be reduced. The reasons for choosing big data are:

- It has a minimal structure, unlike the traditional table and column-like structure. Hence, the data need not be stored like in conventional nodes with a high degree of compression.
- It deals with the raw data and, hence, it will not transform any data.
- It costs less since it is more unstructured compared to the traditional databases.
- It can be used for predictive analytics.

Apart from these advantages, it has certain challenges like expert programmers can only handle data analytics. But shortly, all users can easily use these analytics with user-friendly tools. Hence, the design and development of such tools will make the healthcare industry accessible to more number of users. Another challenge for big data is security. The most important thing in the healthcare sector is the security and privacy of patient data records. Since big data is an open technology, the organizations should take enough steps to ensure data security and privacy. Healthcare without big data makes us depend always on physicians who may or may not be experienced and also may not be available during an emergency. This situation is going to change in the coming future through big data and predictive analytics that has the potential to revolutionize the healthcare industry in terms of quality and costs.

6 Conclusion

The WBAN along with the latest trend-setters—the big data and IoT—can do wonders in the healthcare industry by carefully utilizing the benefits for disease prediction and its diagnosis. The significant application of big data healthcare is to forecast chronic diseases like dementia, cancer, Alzheimer's, Parkinson's disease, etc. In this chapter, an overview of big data analytics and IoT connectivity in healthcare is presented. The architecture for making decisions and predictions of AD called AHMA is modelled and explained. The model uses big data like EHRs, sensor data and images like MRI, which can predict the chance of occurrence of AD well in advance by two years. The system implementation consists of various stages starting from the data collected from all the sensors and devices, data aggregation, classification, computing and finally decision-making to detect the disease. Along with the stage of severity, the type of treatment or dosage of medication preferred will be available as the outcome on which basis physicians can take immediate action to save the life of patients. If a robust big data analytic technique is applied to our proposed decision model the usual painful, invasive, high cost, radiation-exposed methods can be avoided to diagnose neurodegenerative diseases. The future work for this proposal is the design of an error-free data analytical algorithm and the development of an extended framework using fog computing for fast and accurate medical diagnosis of multiple chronic diseases.

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Chapter 5
Impact of IoT in Healthcare: Improvements and Challenges

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1 Introduction

In the modern era of communication technology, the internet is one of the most powerful tools throughout the world. As the internet and the World Wide Web have grown to link all signs of intelligence, the idea and practice of connecting everything fructified as the Internet of Things (IoT). In 1999, the term IoT was coined by Kevin Ashton during his work on supply chain management domain (Ashton 2009). At present, there are many definitions of IoT, which may vary based on the context and perspectives of those defined it. IoT may be defined as the "integration of sensors and actuators embedded in physical objects that are capable of establishing communication between devices without human interference" (Ambrosin et al. 2016). The basic foundation of IoT is machine-to-machine communication where two or more devices communicate with each other through radio-frequency identification (RFID) and sensor networks (Da Xu et al. 2014; Bi et al. 2014; Zhong et al. 2011). Even though IoT has survived for more than a decade, the rapid development of electronic devices such as wireless connectivity and mobile devices is the basic reason for the rise of this technology. Further, the growth of the digital economy and knowledge-based capital has also played a key role in the rapid development of this technology. The objective of IoT is to provide a global network-assisting universal computing and context awareness among devices, which are primary requisites of ambient intelligence. The enormous usage of IoT offers benefits such as technical optimization,

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_5

enhanced data collection, increased efficiency, etc. among various businesses. With more than 12 billion devices connected to the internet and researchers of CISCO had estimated that there would be 26 times more connected things than people on the earth by 2020 (Evans 2011). IoT also provides solutions to a variety of applications in different sectors such as industrial automation, traffic congestion, smart cities, waste management, healthcare, agriculture, smart grids, emergency services and so on. Moreover, it is predicted that more than 25 billion things or objects will be attached to the internet to build intelligent decision systems (Ray 2018). Hence, IoT will be emerging as an advanced area of research soon.

Healthcare has always been an important area of research with vast scope. Healthcare is defined as the process of diagnosis, avoidance and medication of disease, illness and other physical and psychological deteriorations for sustainment or enhancement of health. Healthcare is provided by physicians associated with health fields. To meet demands of needy people, healthcare systems are established. As per the World Health Organization (WHO), the efficient performance of healthcare system needs strong finance mechanism, highly trained and sufficiently paid workforce, accurate information and well-maintained health facilities to deliver standard medicines and technologies to the health needs of the targeted population (WHO 2018). Since the last few decades, it has been experienced that there is a stable rise in life prediction in many regions of the world leading to a sharp rise in the number of elderly people. In a recent report of the United Nations (UN 2013: 8–10), it has been forecast that there would be 2 billion (20 per cent of the world population) older people by 2050. It also specifies that more than 89 per cent of aged people live independently. The survey indicates that about 80 per cent of aged people older than 65 suffer from at least one chronic disease (Weinstein 2005). The WHO and UNICEF reports state that each year 585,000 women die from reasons related to pregnancy and childbirth (WHO-UNICEF 1990). It is also found from the WHO survey that out of 57 million global deaths, 63 per cent die from chronic diseases, heart attacks, cancer, blood pressure and glucose. Currently, there has been significant pressure on the healthcare system due to the growing rate of the ageing population and chronic diseases. To overcome the pressure of chronic patients and elderly people, many clinical applications have been proposed (Bau et al. 2014; Lanata et al. 2014; Lobelo et al. 2016; Shemeikka et al. 2015). There are many problems in the current healthcare system such as time-lapse in the diagnosis of diseases, providing same health history when every time patient visits the physician, unavailability of critical information of the patient and so on. Moreover, most of the cancer-related deaths are caused due to the late diagnosis of abnormal cellular growth at the final stage. In the modern era, improving the quality of the healthcare system by providing quality service to the patient with reduced healthcare cost and time-lapse is considered as one of the important goals of the healthcare industry.

Due to the rapid development of inexpensive devices and storage and minimized energy consumption rates, smart devices are bringing a radical change in the development of IoT in healthcare. It provides an extensive study of the current technologies that are used within the proposed framework. The growth of IoT is based on the identification and perception technology. To address short-range communication, radio frequency identification technology is used. For receiving and transmitting signals, RFID uses a tag and a reader. Nowadays, RFID technology with highlighted features such as low cost and reliable tags and continuous monitoring capabilities provide a better solution for IoT (Buettner et al. 2008). Bluetooth, which is used for short-distance communication between two or more devices, is a wireless communication network. It implements security methods based on authentication and encryption (Cvitić and Vujić 2015). On 2.4 GHz band, it utilizes 79 radio frequency channels with a bandwidth of 1 MHz. The connectivity is provided up to 100 m at a speed of 3 Mbps. As IoT applications are used in telemonitoring, all devices used in this scenario are based on low energy consumption solutions such as Bluetooth (Tadoju and Mahesh 2015; Gentili et al. 2016). In the implementation of IoT, ZigBee technology often plays a major role because of its significant features such as security and network resilience, interoperability and low power consumption (Gao and Redfern 2011). As this technology uses a mesh network, even when an object fails, the other objects continue to communicate with one other without disruption (Ndih and Cherkaoui 2016).

Wireless technologies are considered as one of the main components of IoT. Wi-Fi has been extensively used in applications such as home automation, wearable sensor devices, smart devices and smart grids (Lee and Kim 2016). At present, most of the hospitals support Wi-Fi-based LANs. IEEE 802.16a standard is the basic version of WiMAX. It can be operated in licensed and unlicensed frequency bands that have frequency band spectrum ranging from 2 to 11 GHz. WiMAX-standard IEEE 802.16b that operates in a frequency band range of 5–6 GHz provides quality real-time voice service to customers. Besides, WiMAX IEEE 802.16c provides interoperability among various vendor devices and gadgets and operates in a frequency band range of 10–66 GHz (Gupta and Kaur 2018). Rapid development has occurred in mobile communication networks. The first generation uses an analogue system for carrying of voice over the network. The second-generation (2G) network provides text messaging with digital network infrastructure. The third generation (3G) came into existence due to the increasing demand for online information exchange (Gonzalez et al. 2008). The fourth generation (4G) has been developed to overcome the drawbacks of 3G such as quality of services, bandwidth and to provide resources for a reduced cost. Further, the fifth generation (5G) provides high system capacity and improved energy efficiency when compared with 4G. Finally, the sixth-generation (6G) network was initiated to unify satellites and to provide effective coverage in a wider area (Parikh et al. 2010; Li et al. 2009).

Wireless sensor networks (WSN) consist of divergent sensors for observing physical world conditions. Features such as coverage of a larger area, less installation cost and real-time data gathering are benefits provided by WSNs. Because of the benefits, WSNs have been applied in various fields of healthcare such as observing of physiological parameters, drug and device management in hospitals and handling of an emergency (Pandian et al. 2008; Tseng et al. 2006). Sensing technologies play the main role in acquiring physiological parameters from the patient (Woznowski et al. 2015; Ciuti et al. 2015). Different types of sensors such as accelerometers and pressure sensor, electrocardiography (ECG) monitoring and heart rate sensor, fitness band and smartphone (Lo et al. 2005) are used in monitoring healthcare system. These sensors are categorized as inertial, biosensor and wearable sensors, accordingly.

Some brief and detailed studies on applications of IoT in healthcare have been analyzed by several pieces of research. Ahmadi et al. (2018) examined and evaluated 60 different papers on IoT during the period 2000–2016 in the healthcare domain to find out the important application areas, usage of various architectures and technologies and the concerned challenges, compatibility and security issues in the deployment of IoT architecture in healthcare. This paper aims at providing a complete report that reveals the importance of the IoT architecture in the healthcare system. Further, this study also would help officials in the healthcare sector to formulate plans for improving the quality of life and defeating health inequities by implementing IoT in the healthcare sector. The authors have comprehensively reviewed different applications such as home, hospital, etc. drawing upon theoretical considerations. Also, they have presented a tabular comparison of various technologies such as Bluetooth, RFID, ZigBee, Wi-Fi, WiMAX, LR-WPAN, WSN to solve the challenges of the latest trends in IoT. AbdElnapi et al. (2018) have proposed an analysis of medical sensors, technologies and projects used by IoT in the healthcare domain. They have presented a brief description of different technologies used in IoT-based healthcare system such as radio frequency identification, cloud computing and Big data. They have represented different wearable devices and sensors available along with their usage in tabular form. Furthermore, a brief description of IoT projects such as Smart-Mirror, Technology-Enhanced Emergency Management, E-care@Home, CAMI project, etc. has been presented. The study also focuses on the key challenges such as cost of the system, standardization, synchronization, quality of service, balancing and so on.

Yuehong et al. (2016) discussed the implementation in dealing with new situations by examining emerging technologies such as smart devices in the healthcare industry. As rapid development occurred in controlling healthcare, this paper aimed at describing the history, development of futuristic studies and standard assessment of emerging technologies in IoT healthcare systems. Further, the authors discussed some special IoT methods applied for various healthcare systems with their future utilities. They mainly focused on identification, location and communication technologies with its detailed applications. Moreover, some case studies along with various implementation strategies of IoT and Big data have been elaborated. Whitmore et al. (2015) have presented the current state of IoT by reviewing the literature (of 127 papers) in areas such as enabling technologies, applications, challenges, business models and so on. To assist researchers, they have presented future directions and overview/survey of IoT. The results of the literature review based on category, subcategory, section category have been represented in tabular form. Atzori et al. (2010) have done a systematic review of enabling technologies, IoT paradigm, application areas in IoT such as transportation, healthcare domain, smart environment, personal and social domain and issues in the implementation of IoT such as addressing, networking, security, privacy and standardization efforts. They have also represented differences between RFID system, WSN and RFID sensor network in tabular form.

Table 1 depicts the analysis of various reviews on IoT in the healthcare system.

Table 1 Analysis of previous literature reviews on IoT in healthcare

Author/Year	Focused area	Not covered
Ahmadi et al. (2018)	Application areas in healthcare, IoT technologies, IoT Protocols, IoT communication models	Latest technologies such as fog computing, Big data and current challenges in IoT have not been addressed in detail
AbdElnapi et al. (2018)	Medical sensors, IoT project, IoT technologies	Only few IoT technologies in IoT have been addressed
Yuehong et al. (2016)	Enabling technologies, smart healthcare devices and systems, strategies and methodologies	IoT Protocols, challenges and applications of IoT in the healthcare system have not been addressed
Whitmore et al. (2015)	Challenges, business models, technology, applications, overview, future decisions	Not detailed description of technologies and business models has been represented
Atzori et al. (2010)	Different visions of IoT paradigm, technologies such as RFID systems, wireless networks, RFID sensor networks, principal applications and open issues in IoT	Only a few emerging technologies have been addressed

Despite all these studies, some specific areas such as related issues in architecture, challenges, applications, etc. remain to be covered. Drawing upon this fact, a novel attempt has been made in this chapter to discuss various applications and implementation issues in an analytical manner. This chapter makes a systematic review of various papers in different areas of IoT such as applications, architecture, enabling the deployment of IoT in the healthcare sector for technologies and challenges to provide a complete survey that serves as a basis for the deployment of IoT in the healthcare sector for stakeholders such as technocrats, researchers and common people.

2 Application Areas of IoT in the Healthcare Sector

This section describes different areas of the healthcare sector implementing IoT.

2.1 e-Health, m-Health and k-Health

The usage of IoT in healthcare has been highlighted due to rapid development in communication technologies such as smartphones and sensor devices. Various wearable sensor devices have been developed to collect physiological signals from the human body. These signals are then securely forwarded to healthcare organizations that assist in handling a medical emergency.

e-health (Ball and Lillis 2001) is one of the emerging fields in the healthcare sector. In e-health, information related to medical and public health is delivered through the internet and related technologies. It not only connects technical development but also connects communication and information technology to enhance healthcare services locally, regionally and globally.

m-health (Almotiri et al. 2016) is a component of e-health. m-health or mobile health is defined by Global Observatory for e-health (GOe) as medical and public health practice supported through smart devices such as smartphones, sensor devices, personal digital assistants (PDAs) and other wireless devices. To enhance healthcare services globally, m-health also makes use of smartphone facilities such as voice messages, short messaging services, GPRS, GPS, Bluetooth, 3G and 4G telecommunications, etc.

A systematic analysis of the security challenges that have been raised due to the increased implementation of IoT for e-health on the cloud was done by Ida et al. (2016). They have proposed latest solutions to provide security to the medical information against the malicious attacks. They have discussed the possible opportunities, security challenges, network susceptibilities such as data interchange, unauthorized access and multifarious vulnerability and application susceptibility such as native application, cloud and cryptographic vulnerability to secure the e-health information in IoT and cloud without decreasing the quality of service. Furthermore, they proposed an architecture that aims at providing security at different layers of the architecture, namely, hardware, network and software.

Chen et al. (2018) have presented three approaches, namely, power level decision (PLD) algorithm, power level and packet size decision algorithm (PPD) and Global Link Decision (GLD) scheme for deploying fast, accurate and energy-efficient IoT system in e-health care. They have reviewed previous studies and proposed a synthetic optimization approach for improving the performance of the network. The GLD scheme increases reliability and minimizes overall delay by increasing battery energy. The optimal solution is provided by considering two algorithms namely preceptual liver prediction (PLP) algorithm that reduces energy consumption while transmitting data by choosing optimal power level for links and PLD algorithm selects best packet size either by reducing delay or by reducing energy consumption. Further, they have evaluated the performance of GLD scheme by conducting experiments with parameters such as delay, reliability and lifetime of the network and comparing results with lower power level decision system (LPLD).

The concept of fog computing and smart e-health gateways is implemented in IoT-based healthcare system for providing various end-user services such as real-time data processing, embedded data mining, etc. Rahmani et al. (2018) have presented the architecture of fog-assisted IoT-based smart e-health gateways to meet the challenges such as energy efficiency, scalability, reliability, etc. They have also elaborated the features and services of fog computing-based IoT healthcare system. Further, they explained the functionality of architecture by implementing a prototype of smart e-health gateway namely UT-GATE. The functionality of fog-assisted system illustrated with case study called early warning scores that aim in monitoring severe illness of patients.

Focused on providing collaboration between components of hardware and software for incorporating new facilities and challenges in e-health services, Firouzi et al. (2018) have addressed challenges such as scalability, compatibility, safety, device–network–human interfaces that have emerged with the advent of wearable biosensors and Big data analytics through different case studies. They have explained with examples that maximization methods can be used to solve major problems in e-health. Further, they have elaborated the benefits of IoT, the functionality of the three-layer system architecture and have provided a case study of integrative multi-omic investigation of breast cancer for incorporating IoT solutions in the e-health.

Saha et al. (2018) have proposed a new solution, namely, alarm activation that serves the prescribed medicine in time by displaying it on LCD after making a thorough review of the existing health monitoring system. They have also proposed a scheme that sends alert to the patient through email and SMS if any one of the parameters related to healthcare exceeds the threshold value. It aims at providing optimum surroundings that make the environment comfortable for the patient. They have also explained the functionality of basic modules or block diagrams such as health monitoring and data collection, medication and precaution according to needs of the patient, database preparation from acquired data, sending alerts to patients and medical reports to concerned doctors for handling emergencies.

Ullah et al. (2016) presented their work in two components. First, they have thoroughly reviewed the existing literature for the proper set-up of IoT in the areas of e-health and m-health. Second, they have developed a new model called 'k-Health care' consisting of four layers, namely, sensor layer, network layer, internet layer and services layer that serves as a platform for monitoring patients health data using built-in smartphone sensors and body sensors. They have represented the comparative analysis of different IoT healthcare models and applications by considering parameters such as the provision of emergency aid, technology used, standards followed, support for heterogeneous device and implementation of artificial intelligence in tabular form. They have elaborated the working of k-Health care model with a case study. Furthermore, the challenges in the k-Health care model such as security and privacy are considered as limitations of this paper.

2.2 Hospital Management System

Even though hospital attains a certain degree of informatization through Hospital Information System, it has some deficiencies such as manual input of medical information, fixed networking mode, single function, relatively independent between each department, etc. The rapid rise of the IoT has provided a way for a smart hospital where it is possible to connect any items with the internet. Smart hospital support features such as information exchange, intelligent identification, positioning, tracking, monitoring and management of medical data could be accessed by using technologies such as RFID, infrared sensors, GPS, laser scanners and other information sensing equipment.

Thangaraj et al. (2015) have explored the real-time implementation of smart autonomous hospital management system using IoT. The concept of data modelling of medical devices, critical data validation, the workflow of remote device coordination, network architecture middleware, application services have been explained in detail. They have represented smart data objects along with their significant data processing in IoT-enabled healthcare system through algorithmic implementation. Further, they have explained the functionality of framework as architecture.

Muhammed et al. (2018) discussed the implementation of the ubiquitous framework to ensure the quality of service in healthcare through the concepts of edge computing, deep learning, IoT and high performance computing (HPC). They have considered the challenges affecting healthcare domains such as network dormancy, bandwidth, energy consumption, etc. They have explained the working of the ubiquitous framework of three-component and four layers by implementing the algorithm and by applying technologies such as Cloudlets, Deep Neural Network. This paper illustrates advances related to IoT and Big data and advanced applications of mobile healthcare in UbeHealth system. They have assessed the UbeHealth system by considering a nationwide case study and three extensively used dataset to improve the rate of data transmission, routing decisions and to reduce the network traffic.

Rajeswari et al. (2018) have proposed a system that tracks the patient's location and reduces the risk of chronic diseases by continuous examining of patients by physicians with a decision support system. It aims to reduce the risk of ischemic heart disease with IoT devices. They have discussed the trends and opportunities available with IoT in the healthcare domain. They have explained the functionality of IoT in healthcare by considering the use case 'Care at Home'. The proposed work consists of a mobile application that collects all parameters that are relevant to analyzed the risk of the patient using the decision support system. Further, they have addressed key challenges in the implementation of IoT in rural areas such as security, cost of equipment, use of analytical tools, ability to operate IoT devices in rural healthcare, etc.

An approach named HM-oriented Sensing Service scenario (HM-SS) was designed by Neagu et al. (2017) to provide quality service and approachability in health monitoring system by combining cloud computing with IoT technologies. They have explained the opportunities provided by correlating cloud and IoT technologies such as data management, provision for sharing of data, etc. Furthermore, the architecture of the healthcare system based on three layers and the architecture for a smart hospital system that is based on six layers have been elaborated. They have explained the applications of IoT in HM by considering examples of diabetes, heart rate monitoring, body temperature monitoring, etc.

2.3 Home Healthcare

As per the WHO report, the life expectancy has risen beyond 60 years (Navarro 2000). By 2030, it is estimated that healthcare services will be transformed into home care services (Epstein and Street 2011; Koren 2010; Branger and Pang 2015). Rapid development in technology can address various aspects of ageing people such as regular body temperature monitoring, emergency and medication management, rehabilitation methods at the time of strokes and telemedicine (Plaza et al. 2011; Klasnja and Pratt 2012; and Ludwig et al. 2012). Different architectures have been developed for home healthcare monitoring. Care of ageing or disabled people is supported by an IoT-based service called ambient-assisted living (Costa et al. 2015). Ambient assisted living (AAL) can provide better solutions for ageing people suffering from chronic diseases and disabilities (Singh et al. 2017; Kleinberger et al. 2007).

Blackman et al. (2016) have explained three generations of AAL. Wearable devices and alarms have been used in the first generation. Sensors that respond to hazard detection have been presented in the second generation. The third generation combines first- and second-generation devices for monitoring patient health condition and to assist in emergency medical situations.

Woznowski et al. (2015) presented an AAL architecture based on sensor technology, namely, SPHERE. This architecture consists of three components such as body-worn sensors, video sensors and environmental sensors. This architecture provides a better graphical user interface for care donors as well as the patient's family members. Sensing data are collected and then analyzed to send messages to the user periodically. The 3D simulation environment is also provided by this architecture.

Dimitrov (2016) has explained the emergence of new models due to the transformation of healthcare from the traditional system to the digital system. It focuses on the analysis of medical IoT and Big data to avoid chronic diseases and to improve the overall lifestyle of people. It has illustrated that the results of IoT in pharma offer the latest technologies and services in the treatment of disease by reducing the amount of cost incurred on wearable devices and sensors such as Myo, Ziopatch, MyDario, Sleepbot, etc.

Thakar and Pandya (2017) have discussed the impact of the IoT in healthcare for monitoring the health of the aged and children in remote areas regularly. They have explained the functionality of various monitoring systems such as body temperature monitoring, oxygen saturation monitoring, electrocardiogram monitoring, elderly monitoring, etc. Further, they explained applications and services provided by IoT devices in the healthcare system. This paper also addresses various security issues and challenges raised in the implementation of IoT devices in healthcare.

A systematic study of techniques based on the latest publications and productions used for healthcare and assisted living known as the Internet of Health Things (IoHT) has been done by Rodrigues et al. (2018). This work presents analysis and review of advances made in the technologies, challenges to be met and techniques to be used in IoHT; it would serve a platform for beginners as well as experienced researchers. They have reviewed publications on IoHT in the areas such as remote healthcare, monitoring healthcare solutions based on the smartphone, assisted living and wearable devices. They have discussed services provided, companies, product availability and a brief description of characteristics of each of the identified IoHT solutions has been presented. A comparison analysis of technologies used in selected publications by considering criteria such as security, communication technologies and hardware/OS platform.

3 Communication Models in IoT

To establish communication between these heterogeneous objects, the Internet Architecture Board (IAB) has published a list of guidelines in March 2015, based on which, four communication models have been deployed in IoT, as explained in Rose et al. (2015).

i. *Device to Device Communications*: In this model, two or more devices communicate with each other through an intermediate application server mainly using. IP networks or the internet. Protocols such as Bluetooth, Zigbee and Z-wave are used in communication. It is normally used in small applications such as home automation system IoT devices such as bulbs, thermostats, switches, door locks and so on. In this model, messages can be exchanged between devices by using a specific type of protocol.
ii. *Device-to-Cloud Communications*: In this model, the application service provider acts as an interface between the IoT device and internet cloud for exchanging data and controlling message traffic. To establish communication between device and IoT cloud, it makes use of mechanisms such as wired Ethernet or Wi-Fi connections. IoT devices such as the Nest Labs Learning thermostat and the Samsung smart TV make use of Device-to-Cloud communication model.
iii. *Device to Gateway Model*: In this Gateway model, application layer gateway serves as an interface between IoT device and cloud service. This model is also called a device-to-application-layer gateway (AGL) model. AGL provides services such as security, protocol translation and so on. This model is used in consumer devices like a fitness tracker. These devices cannot connect directly to IoT cloud service. These devices make use of smartphone app software that acts as an intermediate gateway to connect fitness tracker to IoT cloud. Rise of 'hub' devices in the home automation application is an example of a device-to-gateway model.
iv. *Back-End Data-Sharing Model*: This model is an extension of the single device-to-cloud communication model where users can collect and export data from a heterogeneous environment and can transmit securely to another user. Only authorized users can access the sensed data from IoT devices. This model suggests an integrated cloud service approach that facilitates the interoperability of smart devices in a cloud environment. Table 2 lists protocols used in different communication models.

Table 2 Communication models and protocols used

Communication model	Protocol stack
Device-to-device communication model	Bluetooth, Z-Wave, ZigBee
Device-to-Cloud communication model	HyperText Transfer Protocol, TTP, TLS, Transmission Control Protocol, Internet Protocol, CoAP, DTLS, User Datagram Protocol
Device-to-gateway model	HyperText Transfer Protocol, TLS, Transmission Control Protocol, IPV6, CoAP, DTLS, User Data gram Protocol
Back-end data-sharing model	HTTP, CoAP, Oauth 2.0, JSON

4 Technologies Used in IoT

The major enabling technologies that have been used in connecting IoT devices for establishing communication are summarized below.

i. *ZigBee*: ZigBee Alliance proposed a new wireless networking technology namely ZigBee (Kinney 2003; Zillner and Strobl 2015). It is an IEEE 802.15.4 standard designed for monitoring and controlling a limited range network because of its short transmission range and low data rate. It belongs to the wireless personal area network (WPAN) because of its low range and high-level communication protocol. Applications such as home automation, smart energy devices, lighting, HVAC are considered as major areas of ZigBee technology. The unique features of this technology are self-organizing, multi-hop, mesh networking and long battery lifetime.

ii. *RFID*: Radio frequency identification (Juels 2006; Jia et al. 2012) aims addresses short-range communication between 100 m and 1 km. It is ISO/IEC 15,693 standard designed for identifying and tracking objects by using small electronic chips called tags. The data rate is up to 1–24 Mbps and to access devices, it needs internet-enabled gateway. The unique features of this technology are low cost, large mobility and efficiency in identifying devices and objects. The implementation of the TCP/IP protocol has not been provided in RFID communication modules. The main areas of applications are agriculture, healthcare and medicine management, defence, environment monitoring, disaster warning management, transportation and so on.

iii. *Bluetooth*: Bluetooth (Bisdikian 2001; Harris et al. 2016) is a wireless communication IEEE 802.15.1 standard. It has been designed for short-range and low-cost devices of wireless radio technology. It is a wireless communication protocol designed for replacing short-range wired communication with lower power consumption. It has a unique feature of providing personal area network during communication and communicates to its neighbour who is not in visual line of sight. It is also known as WPAN. As many devices in the IoT have limited energy resources, it plays a vital role in IoT.

iv. *Bluetooth 4.0 LE*: Bluetooth low energy (BLE) (Gomez et al. 2012; Nair et al. 2015) is a subset to Bluetooth v 4.0 and has been used since June 2010. Previously it was known as WiBree. It consists of a new protocol stack and profile architecture. The unique features of Bluetooth low energy are new adverting mechanism and it uses asynchronous connectionless MAC. Because of this unique feature it offers low latency rate and fast communication.

v. *6LoWPAN*: The 6LoWPAN (Ma and Luo 2008; Kasinathan et al. 2013) is a wireless connection-oriented protocol that consumes less power and utilizes the IPV6 network. In this, the router transmits the data through 6LoWPAN gateway to its next neighbour who in turn is connected to an IPv6 domain. IPv6 then transmits data to the corresponding destination device. In 6LoWPAN, sensor nodes make use of network protocols like HTTP and TCP/IP.

vi. *Z-Wave*: This was developed by Zensys and further aided by Z-wave Alliance (Badenhop et al. 2017; Unwala and Lu 2017). It is designed as open communication and low-energy-consuming protocol. It is mainly used in automation and light commercial environment. It can pass messages from the control unit to one or more nodes in a reliable way. It consists of two types of devices such as a poll controller that sends commands to slaves and the second device sends a reply to the controller for carrying out commands.

vii. *Wi-Fi*: Wi-Fi (Aneja and Sodhi 2016; Dhawan 2007) is an acronym of wireless fidelity. It is an IEEE 802.11 standard protocol that connects devices to the internet without wires. The Wi-Fi standard family uses the wireless network for short-distance communications. Various series of Wi-Fi networks are IEEE 802.11, IEEE 802.11a, IEEE 802.11b, IEEE 802.11 g, IEEE 802.11n, IEEE 802.11e: QoS extension, IEEE 802.11f: extension for managing handover and IEEE 802.11i security extension. It works on an unlicensed spectrum of 2.4 GHz band.

viii. *WiMAX*: WiMAX (Abichar et al. 2006; Wang et al. 2008)) is broadband wireless technology. WiMax is a wireless version of ethernet. It is primarily designed to provide broadband access to customer premises. The unique features of WiMAX are high speed, large range distances and access to a large number of users. WiMAX overcomes the physical limitation of wired infrastructure by providing services to areas that are difficult for wired infrastructure to reach.

The comparison analysis of communication technologies is presented in Table 3 and its advantages and disadvantages are listed in Table 4.

Table 3 Communication technologies: a comparison

Parameters	Wi-Fi	WiMAX	6LoWPAN	Mobile communication	Bluetooth	Bluetooth 4.0 LE	ZigBee	RFID	Z-wave	WSN
Standard	IEEE 802.11 a, 802.11c, 802.11b, 802.11d, 802.11 g,802.11n	IEEE 802.16	IEEE 802.15.4	GSM, CDMA in 2G UMTS, CDMA 200 in 3G, LTE in 4G	IEEE 802.15.1	IEEE 802.15.4	IEEE 802.15.4	ISO/IEC 15,693	Z-wave alliance	IEEE 802.15.4
Topology	Star	Mesh	Mesh, star	Radio access network topology	Star	Star	Mesh	–	Mesh	Star or mesh or tree
Energy Consumption	High	Medium	Low	Medium	Very low	Very low	Very low	Very low	Very low	High
Max Data rate	1 Mbps–6.75 Gbps	Fixed: 1 Mbps–1 Gbps mobile 50–100 Mbps	40–250 Kbps	50–100 Kbps in 2G 200 Kbps in 3G 0.1–1 Gbps in 4G	1–24 Mbps	5–10 Mbps	20 kbps–250 kbps	106 K–424 Kbps	9600 bits or 40 kbits	20–250 Kbps
Range	20–100 m	<50 km	10–20 m	Entire cellular area	<30 m	5–10 m	10–100 m	Up to 100 m	30 m	20–100 m
Spectrum	2.4–5 GHz	2G–11 GHz	2.4 GHz	1.8 GHz in 2G 1.6–2.0 GHz in 3G 2–8 GHz in 4G	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4–5 MHz
Channel Bandwidth	22 MHz	1.25 M–20 MHz	868–EU: 868.6 MHz NA: 902–928 MHz WW: 2400–2483.5 MHz	900 MHz in 2G 100 MHz in 3G 100 MHz in 4G	1 MHz	2400–2480 MHz	0.3/0.6 MHz, 2 MHz	860–960 MHz	868 MHz	902–928 MHz
Cost	High	High	Low	Medium	Low	Low	Low	Low	Medium	High

Table 4 Advantages and disadvantages of different IoT technologies

Technology	Advantages	Disadvantages
ZigBee	• Cost is low • Consumes less power • Provides longer battery life • Easy to install and implement • More number of devices can be connected • Supports controlling and monitoring of remote devices • Supports scalable and reliable networks • Supports wireless synchronization with other technologies	• Does not support a larger range of communication • Rate of data transmission is low • Vulnerable to security attacks
RFID	• It provides efficiency by scanning multiple items at once • It provides durability as it can handle exposure to sun and rain • It is less vulnerable to security attacks	• Cost is high • It cannot transmit through materials like metal and liquid • Less reliable and accurate when compared with barcode scanners • Difficult to implement and takes more time
Bluetooth	• Cost is low • Easy to install • Easy to connect heterogeneous devices • It is a wireless communication network	• Vulnerable to security attacks • Does not support a large-range communication between devices • Only two devices can be connected at a time
Wi-Fi	• Easy to install • It can be accessed anywhere within the Wi-Fi AP (Access point) coverage area • Wi-Fi-enabled USB dongles are available at low rates • 802.11n, 802.11a, 802.11c supports a data transmission rate of 300 Mbps and higher	• Data transmission rate decreases when more number of computers are connected to the Wi-Fi access point • Vulnerable to security attacks • It can connect up to 30–100 m
Mobile communications	• It offers more efficiency and productivity • It provides flexible and quality service • Provides more access to modern apps and services • It provides efficient communication in and out of the workplace • It consists of enhanced networking capabilities	• Cost is high • More vulnerable to security attacks • It requires additional training

(continued)

Table 4 (continued)

Technology	Advantages	Disadvantages
Z-Wave	• Easy to install network configuration • It consumes less energy • It provides longer battery life • It provides interoperability with different devices available in IoT • The devices that make use of Z-wave technology are available at low cost	• Does not support a larger range of communication • Cost increases if the range of communication increases • More vulnerable to security attacks • It can connect a few number of nodes (232 nodes) when compared with ZigBee (65,000) • It supports the data transmission rate of only 100 kbps
Wireless sensor networks	• Easy to establish network setup • It can transmit data through sea, mountains, rural areas or deep forests • It provides more flexibility in establishing new workstation • Cost of implementation is less • New devices can be easily accommodated	• Less secure • Speed is less when compared to a wired network • Difficult to configure • Due to signal attenuation cannot transmit through walls and large distances • More vulnerable to security attacks • Data transfer rate is low • It may be affected by Bluetooth • Cost is high

5 IoT Protocols

The internet applications make use of HTTP protocol, which is not suitable in a constrained environment. Therefore, protocols such as Constrained Application Protocol (CoAP), Message Queuing Telemetry Transport (MQTT), MQTT-SN, Advanced Message Queuing Protocol (AMQP), Extensible Messaging and Presence Protocol (XMPP) and Data Distribution Service (DDS) have been developed for implementing the IoT architecture (Al-Fuqaha et al. 2015; Luzuriaga et al. 2015).

i. *Constrained Application Protocol (CoAP)*: IETF proposed CoAP protocol for accessing and managing information from sensor devices. The goal of CoAP is to satisfy the requirements of resource-constrained devices. It consists of two layers. It makes use of UDP protocol that made it more suitable for IoT applications (Al-Fuqaha et al. 2015). It supports messages such as confirmable, no confirmable, acknowledge and reset with transaction codes 00, 01, 10, 11.
ii. *Message Queuing Telemetry Transport (MQTT)*: MQTT is a lightweight protocol that is used for device-to-device communication on low-bandwidth environment. It consumes less power. It is a reliable protocol as it uses TCP. MQTT consists

of three components such as connection definitions, routing and endpoints (Al-Fuqaha et al. 2015). The components of this protocol are publisher, broker and subscriber.

Publishers → Broker → Subscribers

While the responsibility of publisher and subscriber is to send messages to the client the broker's responsibility is to dispatch messages between the sender and appropriate receiver. MQTT packet length consists of fields such as control header, protocol, flags, length of message and payload. The difference between MQTT and MQTT-SN is that MQTT makes use of TCP/IP protocol, whereas MQTT-SN makes use of UDP and ZigBee protocol.

iii. *Advanced Message Queuing Protocol (AMQP)*: AMQP is an open-source and asynchronous protocol that aims at providing interoperability among a large range of heterogeneous systems (Al-Fuqaha et al. 2015). Its functionality is similar to that of MQTT. Also, it makes use of a message-exchange mechanism that provides separate queues for the corresponding subscriber.
iv. *Extensible Messaging and Presence Protocol (XMPP)*: IETF proposed a message-oriented protocol, namely, XMPP (Karagiannis et al. 2015). Initially, it was used for chatting and exchange of messages. As it uses XML, it is reused in IoT applications. It makes use of both publish/subscribe and request/response architectures. As it does not provide quality service, it is not used in the machine to machine communication. It consumes more power because of the additional overheads of a large number of headers.
v. *Data Distribution Service (DDS)*: Object Management Group (OMG) designed DDS protocol (Pardo-Castellote 2003). As it depends on the brokerless architecture, it provides a reliable and better quality service in IoT. It makes use of data-centric publish-subscribe and data local reconstruction sub-layers. Data-centric publish-subscribe sub layer is responsible for message delivery and data-local reconstruction sub-layer is responsible for the integration of DDS into the application layer. Among all the protocols, Advanced Message Queuing Protocol and Message Queuing Telemetry Transport are the most widely used protocols. Differences between AMQP and MQTT are presented in Table 5.

6 IoT Challenges

Many challenges have arisen in the deployment of IoT in the healthcare sector. In the following section, we briefly address these challenges.

As IoT devices move around different locations, their IP and network address have to be changed accordingly. This can be done by using the RPL protocol, which in turn creates additional overhead. Another issue that comes up in *mobility* is the address of service provider has to be changed due to interruption in the service.

Table 5 Differences between MQTT and AMQP

	MQTT	AMPQ
Protocol	TCP/IP	TCP/IP
Use of protocol	It is designed for small devices and works on low-bandwidth environment	It works on any device with any bandwidth
Architectures	Publisher/subscriber	Publisher/subscriber
Frame utilization	Uses a stream-oriented approach and does not support fragmentation	Uses the buffered-oriented approach and supports fragmentation
Response	Uses basic acknowledgement	Uses different acknowledgement schemes
Header size	2 bytes	8 bytes

As IoT in healthcare is concerned with emergency management, *reliability* plays an important role. In IoT applications, the system must be reliable and fast, otherwise it may lead to erroneous results. As millions of devices are connected to the same network, another issue that raises is *scalability*. As new services and devices are frequently connected to the same network, IoT applications must be designed in such a way to provide extensible services and functionality. As large number of devices is interconnected, another issue that rises is continuous *monitoring* of devices to enhance the overall performance of the system. Providers should continuously monitor fault, performance, accounting, security and configuration problems raised in the implementation of IoT. It can be considered as software and hardware *availability*. *Software* availability means services should be available to all authorized users at any time. Hardware availability means devices can be accessed and operated easily with protocols of IoT. To embed with IoT devices, protocols should be designed compactly. As different heterogeneous devices are connected, another important issue is *interoperability*. Both application developers and service providers should handle interoperability to provide services regardless of the platform. As large volumes of patient data are shared, privacy and confidentiality play an important role in the implementation of IoT in the healthcare sector. These *security* vulnerabilities are classified as hardware, network and application vulnerabilities (Ida et al. 2016). To provide privacy and confidentiality of patients' data, the system should be protected from these vulnerabilities.

Based on the above studies, Table 6 presents the distribution of papers based on the type of disease/condition, IoT application, technology, services, protocols, architecture and publication type.

Table 6 Distribution of papers based on type of disease/condition, IoT application, technology, services, protocols, architecture and publication type

Author(s)	Type of disease/condition	Home health care/ehealth/mhealth/hospital management system	Type of services	Type of technology	Type of protocol	Journal/conference	Type of architecture
Williams et al. (2016)	Patient monitoring	e-Health	Challenges			Journal	
Sreekanth and Nitha (2016)	Patient monitoring	e-Health		Wireless sensor networks		Journal	IoT Gateway
Ida et al. (2016)		e-Health	Challenges			International Design & Test Symposium (IDT)	IoT Cloud
Ullah et al. (2016)		e-Health and m-health		RFID, WSN		Conference	
Sallabi and Shuaib (2016)		e-Health			SNMP	Conference	
Dimitrov (2016)	Chronic diseases	m-Health				Journal	
Sivagami et al. (2016)	Hospital and patient monitoring	Hospital management system		RFID with enhanced WSN (HSN)	6LoWPAN	Journal	IoT Gateway
Natarajan et al. (2016)	AAL	m-health		RFID	MAC Protocol	Journal	
Laplante et al. (2016)		Hospital management system		RFID		Journal	

(continued)

Table 6 (continued)

Author(s)	Type of disease/condition	Home health care/ehealth/mhealth/hospital management system	Type of services	Type of technology	Type of protocol	Journal/conference	Type of architecture
Yeole and Kalbande (2016)	Children monitoring and critical patients					Conference	IoT Cloud
Neagu et al. (2017)	AAL	Hospital management system				Conference	IoT Cloud
Manogaran et al. (2018)	Patient monitoring	Hospital management system		Wireless mobile sensor network		Journal	MF-R (meta fog redirection) and GC (grouping and choosing)
Kumar and Gandhi (2018)	Heart diseases	Hospital management system		5G mobile networks		Journal	IoT Cloud
Prasad et al. (2017)	Patient monitoring	Hospital management system		Wireless body sensor networks, Zigbee	6LoWPAN	Journal	IoT Cloud
Wu et al. (2017)	computer-assisted rehabilitation	e-health		Bluetooth		Journal	IoT Gateway
Laplante et al. (2017)	Acute care, community-based care and long-term care	Home healthcare and Hospital management system	Quality requirements			Journal	

(continued)

Table 6 (continued)

Author(s)	Type of disease/condition	Home health care/ehealth/mhealth/hospital management system	Type of services	Type of technology	Type of protocol	Journal/conference	Type of architecture
Chen et al. (2018)	Patient monitoring	e-Health		Wireless sensor networks		Journal	
Rahmani et al. (2018)	AAL	e-Health, m-health		Wi-fi, Bluetooth	6LoWPAN	Journal	Smart e-health gateways
Farahani et al. (2018)	Chronic diseases	e-Health	Challenges			Journal	IoT Fog
Jabbar et al. (2017)	Heart disease	e-Health				Journal	
Thakar and Pandya (2017)	Chronic diseases	Home healthcare				Conference	
Ali et al. (2018)	Chronic diseases	Hospital management system				Journal	Type-2 Fuzzy logic
Sanjay et al. (2018)	Patient monitoring	e-Health		Bluetooth		Journal	
Rizwan et al. (2018)		e-Health		Nano communication		Journal	
Abatal et al. (2018)		Hospital management system				Conference	IoT Cloud
Rajeswari et al. (2018)	Heart disease	m-Health				Conference	

(continued)

Table 6 (continued)

Author(s)	Type of disease/condition	Home health care/ehealth/mhealth/hospital management system	Type of services	Type of technology	Type of protocol	Journal/conference	Type of architecture
AbdElnapi et al. (2018)	Patient monitoring	e-Health		RFID, Bigdata and Cloud computing		Conference	
Saha et al. (2018)	Patient monitoring	Home healthcare and e-health		Raspberry pi		Conference	
Tse et al. (2018)			Challenges	Bigdata		Journal	
Mahmoud et al. (2018)		e-Health	Challenges	Cloud computing		Journal	CoT
Belesioti et al. (2018)		Home healthcare and m-health				Conference	VICINITY project
Mutlag et al. (2019)				Fog computing		Journal	
Rodrigues et al. (2018)	AAL	m-Health				Journal	

7 Interpretation of Collected Data

As the deployment of IoT in healthcare has been increasing, many research papers on IoT in healthcare have been published in various databases. For this reason, we have selected some standard databases such as IEEE, Springer, InderScience, Science Direct, etc. to create a complete bibliography of review papers on IoT in healthcare. The papers that are published up to 2018 on IoT in healthcare are selected to search for review papers. We used keywords such as IoT in healthcare, e-health, m-health, hospital management system and home healthcare to extract research papers from the concerned standard databases. In our study, related research papers are reviewed through their abstracts, introduction, basic preliminaries, methods and conclusion. To identify appropriate research papers that apply to our research inclusion and exclusion criteria were considered. Therefore, to choose appropriate publications, inclusion measures have been described as follows:

1. Concentrating on technologies that have been used in IoT in healthcare, without considering whether they have been used in a remote or short distance.
2. Concentrating IoT architectures in healthcare and their main components and organization.
3. Concentrating latest trends, their usage and deployment of IoT along with the challenges in the healthcare environment.

However, we have considered the following exclusion measures.

1. Papers or abstracts those were not accessible.
2. Papers that are irrelevant to IoT in healthcare.
3. Papers of IoT in healthcare those were disseminated in the encyclopaedia, data articles, mini-reviews, thesis reports, patent reports and other literature reviews.
4. Papers that were focused on other domains such as agriculture, home automation, industrial automation, transportation, defence, etc.

Later, all the essential data are gathered from the concerned papers. The data that have been considered from each paper are as follows: communication models, enabling technologies, important application areas of IoT in healthcare, the impact of IoT technology in healthcare, latest trends in IoT healthcare and challenges raised in the deployment of IoT in healthcare.

In our analysis, several papers have been found based on the inclusion and exclusion measures that we have considered. From those papers, a total of 5614 papers were extracted that were related to the study. Among those 5614 papers, 4364 papers were found as duplicates and 1000 papers were excluded during the review of abstracts and 150 papers were filtered during the full-paper study. Finally, the full text of the remaining 100 papers was considered for the entire study. A schematic process for searching, by considering inclusion and exclusion criteria, is illustrated in Fig. 1.

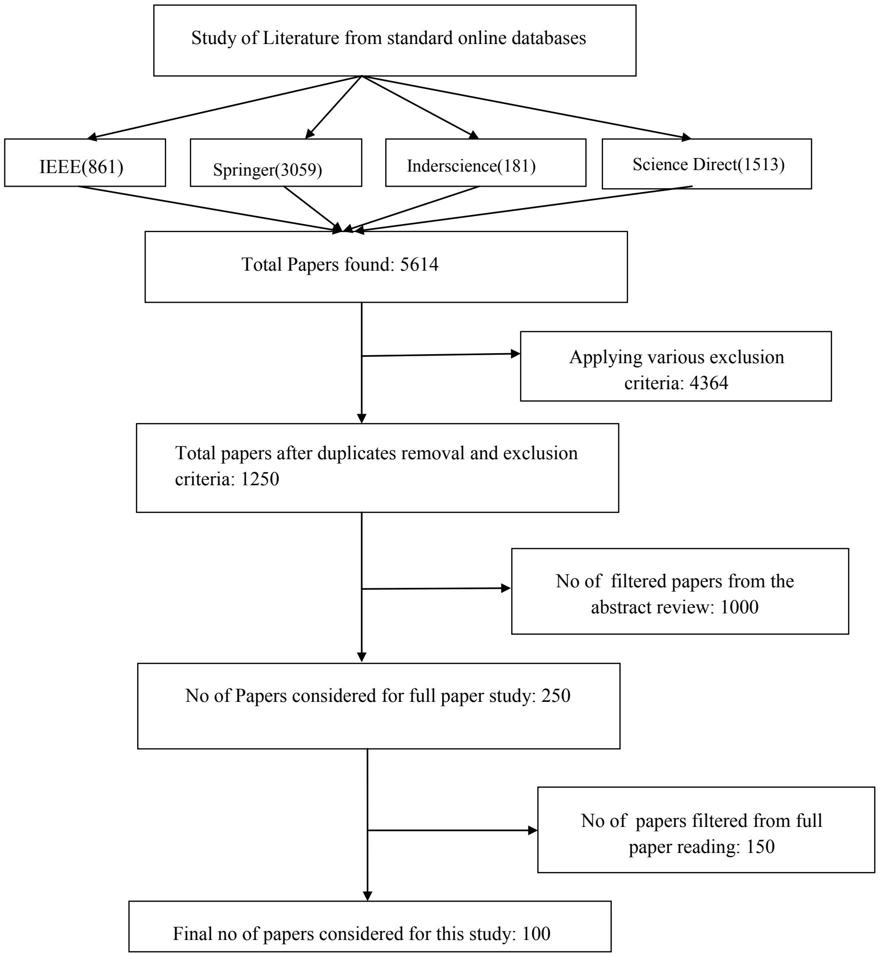


Fig. 1 Flow diagram of the systematic review of research work by considering inclusion and exclusion measures

8 Critical Investigation

The quality of patient life, monitoring of elderly people with chronic disease from remote locations and handling of emergencies can be improved by deploying IoT in the healthcare domain. In our systematic review, a total of 100 papers related to IoT in healthcare have been identified. In our study, a systematic review of application areas in healthcare, enabling technologies used in IoT architecture, advantages and disadvantages of enabling technologies, challenges and issues in the deployment of IoT in healthcare has been carried out. Some of the important inferences drawn are presented in the following.

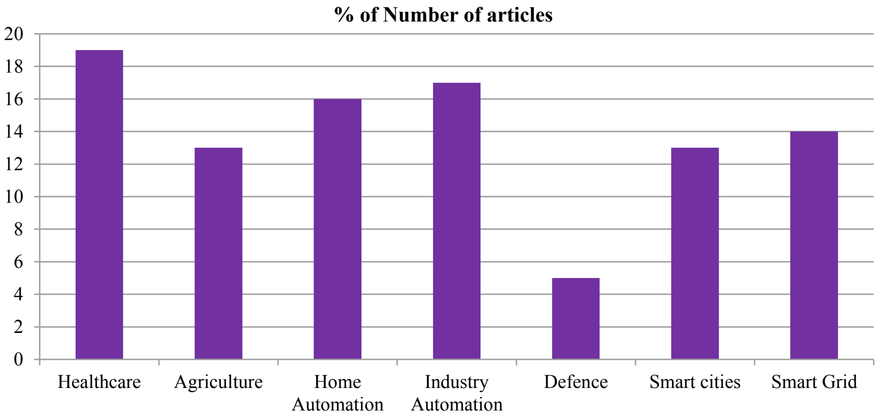


Fig. 2 IoT in healthcare against other domains

8.1 Distribution of Published Articles by IoT in Healthcare Against Other Domains

Figure 2 depicts the distribution of articles by IoT in healthcare sector against other domains. From this chart, it can be observed that healthcare sector is one of the prominent areas among other domain areas of IoT such as agriculture, home automation, industrial automation, defence, smart cities and smart grids. More number of articles have been published in the healthcare sector when compared with other areas of IoT (19%).

8.2 Distribution of Published Articles by Publication Year

From Fig. 2, it is observed that IoT in the healthcare sector has been the most significant among other sectors. More research articles were published in IoT in healthcare. Figure 3 represents the number of papers published in IoT in healthcare from 2014 to 2018. From the chart, it may be concluded that there is a drastic increase in the number of publications from 2016 onwards.

8.3 Distribution of Published Articles by Technologies

The distribution of papers based on enabling technologies in healthcare is depicted in Fig. 4. From the chart, it can be concluded that most of the researchers are making use of RFID technology (29%). As illustrated in the chart, Bluetooth is the next enabling technology that researchers have used (22%). Also, technologies such as Wi-Fi, Wimax, Zigbee have an equal frequency in paper contribution.

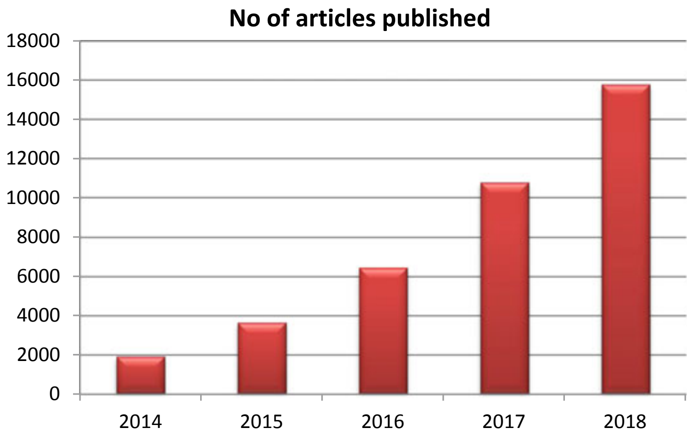
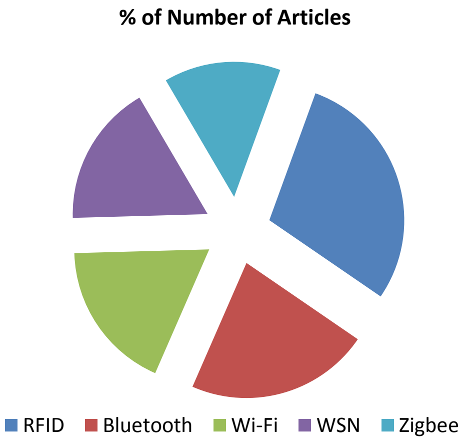


Fig. 3 Statistics of paper publications on IoT in healthcare in the last 5 years

Fig. 4 Distribution of papers based on enabling technologies



8.4 Distribution of Published Articles by Application Areas in Healthcare

In our study, it is established that IoT has been deployed in several application areas in healthcare sector such as e-health, m-health, hospital management system and home care. It has been observed that higher number of research works has been carried out in home care and hospital management system. Distribution of articles by application areas in healthcare is depicted in Fig. 5.

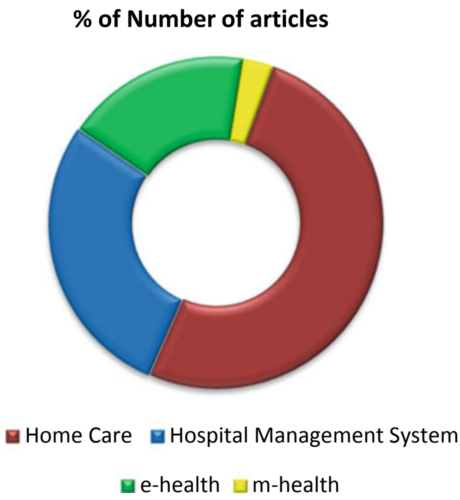


Fig. 5 Distribution of papers in IoT application areas

8.5 Distribution of Articles by Journal and Conference

The papers were selected from various standard journals based on the keyword search. Table 7 depicts the distribution of articles by journal as well as conference. IEEE journals have the top contribution regarding IoT in healthcare (21.7%). *Future Generation Computer Systems* has the second highest contribution (16%). *International Journal of Scientific Research in Computer Science, Engineering and Information Technology* has the third highest contribution of articles (4.3%). The strategies for classifying the articles are described in Table 7.

9 Challenges and Discussions

Due to the increasing use of IoT in a real-time environment, extensive research on IoT has been carried out and many articles have been published by researchers since the last few years. As managing health issues is becoming a serious concern, IoT in the healthcare sector is the eye-catching domain for many researchers. Despite several articles on IoT in healthcare, it is found that there remain several concerns in which extensive research work has to be carried out.

In the deployment of IoT in the healthcare domain, various vendors exist to provide different devices with different protocols. Therefore, standardization becomes a complex issue. From this perspective, detailed studies have to be carried out in providing integrated services using a standard protocol. As medical data are sensitive and it is related to the privacy of the patient, data can be easily misused if it is not properly managed. Big data governance in the health domain is less developed when compared with other domains. In our study, there was no evidence of a framework that provides a complete view of how Big data analysis has been done. Furthermore, due to the dynamic nature of healthcare resources, patients need to share these resources with the lowest cost. From a clinical aspect, implementation of the governance framework and topology- and ontology-based heuristic algorithms are necessary for effective handling of huge volumes of data and for finding optimal solutions for large-scale systems. It has also been observed in the healthcare system

Table 7 Distribution of articles published by journal and conference

Conference/journal	Article type	Frequency	Weightage (%)
International Conference and Exposition on Electrical and Power Engineering	Conference	2	4.3
International Conference on Consumer Electronics	Conference	1	2.1
IEEE Sensors Journal	Journal	1	2.1
IEEE International Conference on Computational Intelligence and Computing Research	Conference	1	2.1
IEEE International Circuits and Systems Symposium	Conference	1	2.1
Procedia Computer Science	Conference	1	2.1
International Journal Of Advance Scientific Research And Engineering Trends	Journal	1	2.1
IEEE	Journal	10	21.7
healthcare Systems Management: Methodologies and Applications	Journal	1	2.1
Research J. Pharm. and Tech	Journal	1	2.1
International Journal of Innovations &Advancement in Computer Science	Journal	1	2.1
International Journal of Scientific Research in Computer Science, Engineering and Information Technology	Journal	2	4.3
Future Generation Computer Systems	Journal	6	13
International Conference On Big Data Science And Engineering	Conference	1	2.1
International Federation for Information Processing	Journal	1	2.17
Int. J. Enterprise Network Management	Journal	1	2.1
International Research Journal of Engineering and Technology	Journal	1	2.17
International Conference on Inventive Communication and Computational Technologies	Conference	1	2.1
International Journal on Future Revolution in Computer Science & Communication Engineering	Journal	1	2.17

(continued)

Table 7 (continued)

Conference/journal	Article type	Frequency	Weightage (%)
Systems, Applications and Technology Conference	Conference	1	2.1
Euromicro Conference on Digital System Design	Conference	1	2.1
Internet of Things Journal	Journal	1	2.1
Journal for Research	Journal	1	2.1
Digital Communications and Networks	Journal	1	2.1
International Conference on E-Health and Bioengineering	Conference	1	2.1
Computers and Electrical Engineering	Journal	2	4.3
International Journal of Mobile Computing and Multimedia Communications	Journal	1	2.1
Wireless Communications and Mobile Computing	Journal	1	2.1
Computer Communications	Journal	1	2.1

that large volumes of patient data from several sources raise security challenges. Therefore, extensive research work has to be carried out in areas of trust and privacy to prevent the unauthorized use of the patient's personal information.

In recent years, the concept of Socail Internet of Thing (SIoT) has been introduced and that provides an environment for intelligently networking the objects. Most of the articles use cloud-based architecture. The issues raised in the implementation of cloud-based architecture such as latency problem and limited storage capacity can be overcome by using fog computing paradigm but none of the articles has demonstrated the functionality of SIoT and challenges raised in deploying the architecture. Very few articles were published on fog computing paradigm. So, intense research needs to be conducted on this aspect. Another advancement in IoT is the IoT of Nano-Things. It describes the interconnection of nanodevices with the internet. Therefore, there is a need to propose an architecture for implementing the internet of nano-things. The problem with sensor devices is power consumption. Most of the articles have presented rechargeable batteries as a solution. Much efforts have to be made to develop sensor devices with low power consumption and renewable energy such as solar power. In our study, it is also observed that most of the systematic reviews have been carried out on enabling technologies, protocols, communication models, applications of healthcare and different devices for implementing the services. None of the studies has provided a review of the cost analysis of different devices. All these limitations are needed to be addressed, so that they serve as the basis of information for most of the technocrats and researchers to carry out further research.

10 Conclusion

Since the past few decades the usage and applications of internet have been growing fast. Rapid development in the technology of information and communications has made the wider usage of the IoT in various applications of real-time environment. Among various domains of IoT, the healthcare sector is gaining more importance. Providing quality service to the patient with low cost and without time-lapse is the main objective of the healthcare domain. Several research studies have been carried out in various fields of IoT in healthcare.

In this study, the relevant research is divided into eight different sections. Some preliminary concepts about IoT, healthcare and technologies relevant to the healthcare sector were explained earlier. It also addressed the areas that have not been covered in previous survey papers. Accordingly, we have addressed different application areas, communication models, enabling technologies with its advantages, disadvantages and challenges raised in the deployment of IoT in the healthcare domain along with a literature survey. In a further section, the strategy for extracting papers based on inclusion and exclusion measures was also specified in detail. Critical investigation and challenges that have been observed were described in the previous section.

Based on our analysis, researchers and practitioners are strongly recommend to focus on Big data governance and security issues for providing an optimal solution in large-scale system and to protect from unauthorized access by deploying fog computing, SIoT architectures.

This survey would help researchers, planners and policymakers to develop strategies for effective implementation of IoT in the healthcare sector. As per our analysis, home care and hospital management system have extended use of IoT when compared with e-health, m-health areas in the healthcare sector. Several research studies have been carried out in latest enabling technologies, communication models and issues raised in the deployment of IoT in the healthcare sector. Further, this survey underscores that the patient should engage on the self-management of their health to live a healthier longer life. Therefore, the deployment of IoT in healthcare sector enhances the patient's life by providing quality service to remote areas at low cost, reduced risk of chronic diseases of elderly people and overcoming inequities existing in the present healthcare system.

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Chapter 6
Paving the Way for Smart Agriculture in India

Debasish Kumar Mallick, Ratula Ray, and Satya Ranjan Dash

1 Introduction

In the last decade, India has shown promising growth in the field of digital technology and it is growing exponentially with passing years. With over 460 million internet users India is slowly approaching a technological revolution that can cater to various sectors like healthcare, agriculture, banking, etc. The Internet of Things (IoT) has been described as being highly beneficial in such a scenario. IoT, as the 'global neural network', connects different systems and devices for establishing a smarter communication (Sharma and Tiwari 2016). Sensor technology merged with the ability to store huge data can contribute effectively to the working of IoT.

With the population of India reaching over 1.32 billion, the country offers an excellent global market potential and thus, the need for introducing digitalization becomes extremely important. Managing needs of such a huge population requires the support of digital technologies. Newer and better opportunities in the market are also created, as a result of which more efficient outcomes are produced. It also allows saving of valuable resources and time.

But in a country like India, where the literacy rate is relatively low, the introduction of digitalization does not come without its challenges. Empowering citizens and providing them with digital infrastructure are essential. Improvement of digital literacy, especially, in rural areas is vital and should be taken up seriously to bring about inclusive growth.

India is an agriculture-based country and the sector provides employment for about 70 per cent of the population and accounts for about 18 per cent of the gross domestic product. Artificial Intelligence (AI) has brought about a revolutionary

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_6

change in almost all fields of science, including agricultural biotechnology, which can be immensely useful in case of disease diagnosis in crops for producers in developing countries who lack proper research infrastructure, smart greenhouse options and efficient usage of energy and resources on the field. To solve these issues, it is necessary to come up with integrated systems which will track the procedures at each stage. Key components of the system comprise interfacing sensors, actuators, microcontrollers, Wi-Fi connectivity and single-board computers such as Raspberry pi (Gondchawar and Kawitkar 2016). AI allows the farmer to utilize every acre of the land to the fullest of capabilities and use resources available at hand judiciously. Broadly classifying, AI in agriculture can be distributed in three major categories: agricultural robotics, agricultural parameters monitoring and predictive analysis. Integration of these three fields requires the power of IoT which in turn increases the efficiency of the products.

1.1 Computational Intelligence and Its Importance

Computational intelligence refers to the power given to the machine to take decisions independently from a pattern in the dataset or from observations made from carrying out an experimental study. It allows the computer to think like a human and take decisions based on algorithms of certain statistical models.

Computational intelligence is a subset of AI that can be broken down into different sections that mimic the biological system of a human being. Concepts such as Natural Language Processing, Fuzzy logic, Artificial Neural Networking (ANN), etc., are all parts of it. ANN has been used extensively in tasks involving predictive analysis for classification where the framework mimics the complex biological neural network of the human brain to reach to the desired accuracy in prediction. Optimization techniques involve the concepts of evolutionary computation which are inspired by Darwin's theory of natural selection, probabilistic approach to computing the performance of the machine learning models, etc. to name a few.

Broadly speaking, the idea of computational intelligence merges the concepts of various disciplines such as mathematics, computer science, statistics and domain-specific requirements. The fact that the models which we build can learn from the changes made in the dataset and give the outcomes accordingly, just like humans learn from changes in the surroundings, is the pillar behind the concept of AI. The ability to reason, learn from experiences, solve problems, recognize images and understand natural languages, are the reasons why we strongly feel that AI has the power to bring about a huge transformation in the lifestyle of people.

Organizations all over the world realize the level of efficiency that comes with automation which leaves very little space for human errors to occur. Time is saved and productivity is exponentially increased if the algorithm is backed up with proper statistical model and the program has been carried out properly. Data privacy and cybersecurity is a concern when it comes to dealing with AI but steps have to be taken to enhance the security of personal information. Digital assistants like Apple's Siri, Amazon's Alexa and Google assistant have already found their places in people's lives, which show that people have started to accept the changes brought by AI in various walks of life.

With the increase in population, food security concerns have also increased. Change in climatic conditions has also contributed to this problem and thus, the need for AI in agriculture has become increasingly important. With the advancement in sensor technology, crop and soil monitoring has become relatively easy. Soil management has become an important criterion in understanding the dynamics of the ecosystem and assessment of soil health gives us a better opportunity to analyze the problems at hand. Human labour in agriculture is being replaced by autonomous robots which can complete the task in a relatively shorter period with greater productivity and volume. Predictive analysis, which is a subcategory of machine learning, also allows the farmers to make informed decisions regarding sowing time of the seeds by predicting changes in the weather pattern. The crop quality can also be studied by analyzing the features and deciding the price in the market and reduce wastage. Precision agriculture also allows for yield prediction. This allows farmers for the optimization of economic growth and plan out agricultural work accordingly (Liakos et al. 2018). Making the technology available in remote agricultural locations is the key to the success of precision agriculture. Awareness among farmers regarding the latest technological advancements in the field of agriculture is very crucial to gain the necessary support and insights.

2 Digital Agriculture in India

Precision agriculture utilizes resources available at hand to the maximum extent possible by maximizing productivity and sustainability. But the future of agriculture requires more efficient management solutions to meet the growing need for food and the requirement to survive with limited available natural resources.

The power of sensor technology, coupled with devices such as rate controllers, yield monitors, GPS navigation system and variable rate technology (VRT) farming options allows farmers to make the vision of precision agriculture a reality. In a developing country like India, the requirement is to use minimum resource input to gain maximum output and this is what precision farming aims at (Hakkim et al. 2016).

Field-based experimental studies have also been conducted to test the utility of sensor-based valve-controlled systems to bring about the concept of automation to achieve judicious utilization of natural resources like water in farming. The concept of an efficient irrigation system is being brought into the limelight through the advent of digitalization in agriculture. Optimization of operational parameters such as flow rate of water, controlling the pressure of pumps, etc., is essential in the building of energy-efficient models. Remote controlling of these parameters is the vision natural forests implementing in the farms. Precision agriculture utilizes two main technologies for fulfilling this purpose: yield technology and information and communication technology (ICT). Yield technology is concerned with the time frame between pre-plantation and post-plantation periods. ICT is solely focused on the building of software-based tools that aid the precision farming process (Abdullahi and Sheriff 2017).

Putting up of security surveillance system is another important aspect of smart farming. Providing remote access control to farmers for surveillance of valuable equipment in the farm is important and ICT can assist effectively in meeting these purposes. Alert systems and CCTV cameras can send in messages and footages to the owner in their mobile phones in case someone trespasses into the farm (Patil et al. 2016).

India has also come up with different android-based mobile applications that can aid the farmers to take informed decisions. Some of the apps and their functions are listed in Table 1.

The need of the hour is to assess the strengths and weaknesses that India holds as an agriculture-based country and put the practice of precision farming into use accordingly. Identifying the problems underlying the Indian agriculture system is the key to progress as a more advanced nation in terms of agricultural produce. Figure 1 shows advantages and disadvantages of Indian agriculture.

Table 1 Depicting the android-based platforms for smart farming in India

Apps	Functions
mKisan	Allows the farmers to access information in the form of text or voice messages and receive advises even in the absence of internet connectivity. It also allows access to a huge database that can be utilized by the farmers (Brief Overview of the mKisan Portal https://mkisan.gov.in/)
Farm-o-pedia	Specifically designed for farmers in Gujrat, it offers the support of multiple languages for communication. It allows the farmers for remote monitoring of the crops for their growth and tracking of weather conditions (eGovernance in Agriculture: https://farmer.gov.in/mApp/)
Markets near me	Keeps the farmer updated regarding the market price of the products within the area of 50 kms. It utilizes the location feature in the mobile of the farmer and traces the information of the commodities available within 50 km of the user
Digital Mandi India	Allows the user to remain updated with the prices of goods at the Mandi and keep a track of the market price from any place (digitalmandi.iitk.ac.In/new/?l=en&p=mobile_apps)

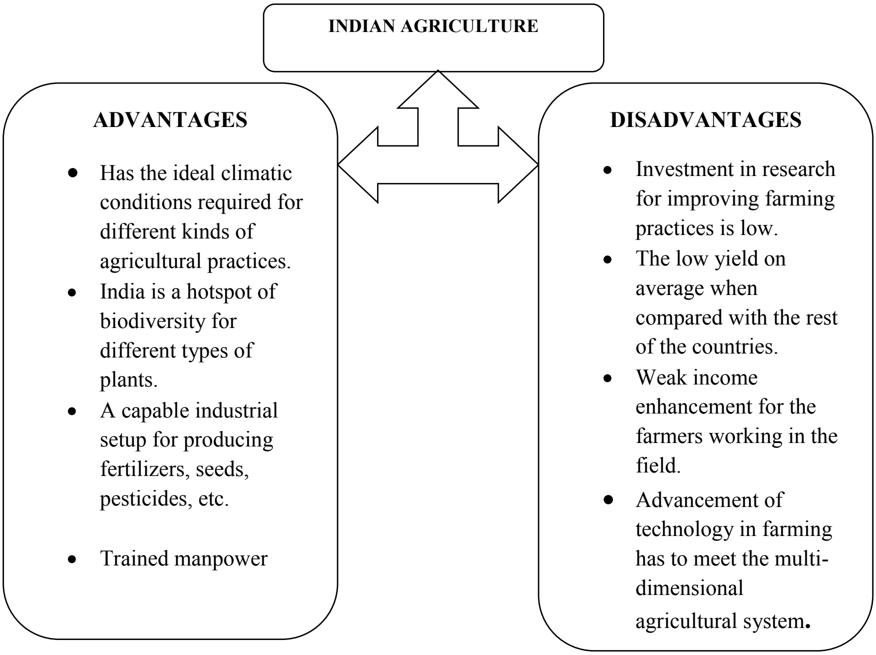

Fig. 1 Strengths and weaknesses of Indian agriculture

3 Case Studies

This section highlights three case studies concerning the introduction of Smart Farming in India. It discusses the planning required for creating such models and how the proposed works in a real-life scenario be put to combat the problems.

3.1 Pollution Control During Harvesting and Efficient Energy Control System

When leaves of the rice crop start turning yellow, it suggests that the rice crop has entered its ripening period. Harvesting can release harmful dust in the atmosphere, giving rise to air pollution. In northern Asia, the rice plant is cut before it enters its ripening stage, whereas in countries like India, the cutting occurs after the yellow colour has arrived. Once the cutting is done, the produce goes for harvesting by machine or by hand.

During paddy harvesting, the harmful dust mixes with air which may lead to the incidence of skin and lung diseases amongst farmers. Some dust mixes with the rice rendering it impure and consuming it might lead to diseases affecting the stomach.

Also, the loss of energy might occur if the harvesting machine is kept running when not in use during the absence of farmers.

Proposed Model: A microprocessor is a unit in IoT which is responsible for processing a set of instructions designed specifically for carrying out logical and computational tasks. It is also responsible for interposing the communication and management of input and output data. It has n-number of transistors, which will help to execute instructions systematically. In this case study, we will use Raspberry-pi as the microprocessor, a single-board computer relatively small in size.

Our motion detector, designed to meet our purpose, will have a PIR (Passive Infrared Sensor) which will sense the body for higher temperature and some lower level of radiation. It will consist of circuits, resistors and capacitors. The sensor will have facilities for delay time adjustment and sensitivity adjustment so that it can sense the area for coverage for the detection.

A camera will also be present for video streaming when the air purifier is in use. The air pollution detector, which we discuss here, is planned for detecting the pollution while harvesting the rice crop. It will start working as soon as it senses the imbalance of certain components in the air such as ozone, carbon monoxide, carbon dioxide and nitrous oxide.

Methodology: A manual machine is not generally energy efficient and one of our main agenda in this case study is to construct our model in such a way that it saves as much energy as possible. A microprocessor will be used for processing the instructions as per the data given by sensors. Here, we will use Raspberry-pi microprocessor for decision-making purposes. A motion detector will also be connected to Raspberry pi's GPIO (General Purpose Input Output) pin and will require 3.5 V for running and the output will be given as the signal to the microprocessor for instructions. But to sense the presence of the personnel handling the machine a motion detector is not enough and a camera will also be required to be connected to the microprocessor. If the motion sensor senses any activity nearby, then only the camera will get activated. The camera will perceive images frame wise and send them to the microprocessor. In the microprocessor's memory, a set of algorithmic instructions will be present which will process the image of the person and, through face recognition, will come to the conclusion whether it is that particular person or not. Upon recognition by the microprocessor, it will establish an electrical connection with the harvesting machine and thus, can take attendance of workers who have worked or used the machine on that particular day.

Another problem that we are looking at in this case is that during harvesting the polluted dust particles might mix up with the air. People who are working there are at a much higher risk of getting exposed to diseases such as asthma. Our plan suggests that when such cases occur, the dust particles will be detected by sensors which will give the signal to the microprocessor. The microprocessor will be connected to an air purifier which will be activated by Raspberry pi and send out shock waves to throw out the dust particles and purify the air. Figure 2 depicts the workflow diagram of the proposed model.

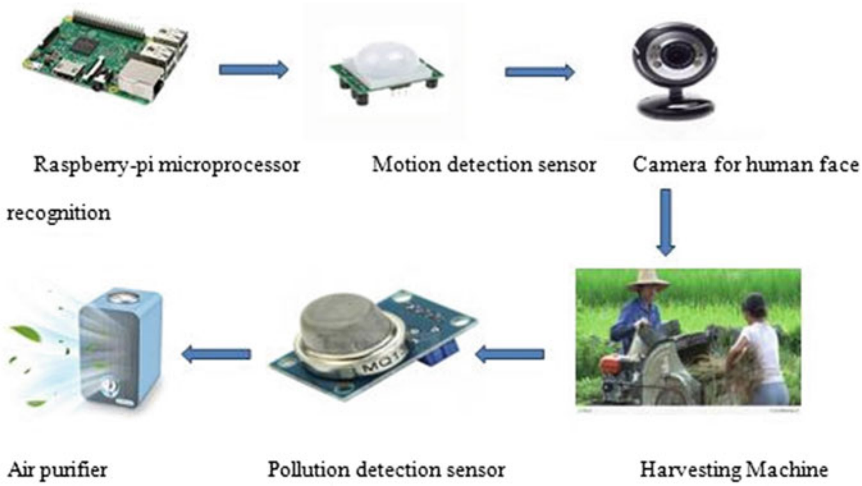

Fig. 2 The workflow of the proposed design for energy–efficient pollution control system data flow diagram

3.2 Smart Greenhouse

Manual farming poses certain disadvantages in comparison with farming at the greenhouse in an optimal set-up. Human error can lead to unequal distribution of the essential elements for plants in the field such as water, manure, etc., in case of manual farming. Many plants may die due to an excess amount of water and also because an equal amount of attention is not provided to all the plants in the field. As it is not possible to perceive the suitability of soil for a particular plant it might again result in a loss in the farming business.

Multiple plantings in a field can lead to an increase in the capability of soil for farming. For cold areas, greenhouse with automation for temperature is one of the best options for agriculture production. In other areas, the introduction of automation will give higher yield and provide better results as compared to traditional farming methods. Greenhouses are equipped automation systems in meeting separate requirements for water, temperature and pesticides for the respective varieties of plants.

Proposed Model: A greenhouse is an artificially created closed area with optimal conditions that allow for the plants to grow. Different kinds of plants require different conditions for growth and a greenhouse can help in meeting the desired requirements for each of them. The different conditions might include temperature requirements, moisture content requirement and desired content for organic fertilizers to be provided for every plant.

A moisture sensor is a tool used for sensing the moisture present in the soil. It works by inserting the sensor tip inside the soil and readings can be taken simultaneously. The moisture sensor consists of two probes through which the current is passed inside

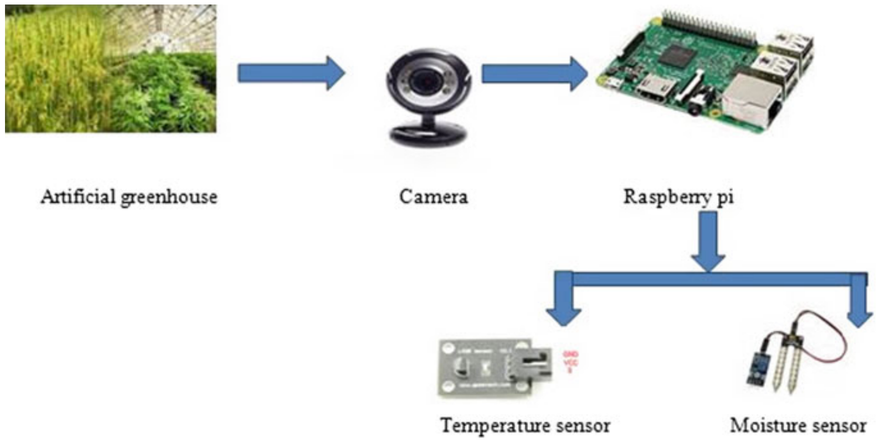

Fig. 3 Workflow diagram of the automated Smart Greenhouse Data flow diagram

the soil. More water in the soil allows for a good flow of electricity to occur, whereas when the moisture content is low, greater fluctuations in the results are observed. It requires a potential difference of 3.3 or 5V for it to function and the output voltage signal is 0 ~ 4.2V. The value ranges from 0 ~ 300 for the dry soil, 300 ~ 700 for humid soil and 700 ~ 950 denotes high amount of water present in the soil. The advanced moisture sensors can detect the type of soil depending upon the moisture-retaining capability. Figure 3 depicts the workflow layout for the smart greenhouse model with automation.

The LM35 linear temperature sensor is based on the semiconductor that offers high linearity and sensitivity. It can be used for sensing ambient air temperature. Its functional range is between 40 and 150 °C. A better sensor can provide with better results than this. Its sensitivity is 10 mV per degree Celsius. It is made up of platinum resistance, thermal resistance, temperature semiconductor chips and thermocouples.

Methodology: Artificial greenhouse with automatic farming option will enable more productivity than the manual greenhouse and traditional methods for multiple farming. As in the case study 1, a microprocessor will be present for controlling the environment. This microprocessor, along with a camera, will be trained using explicit machine learning algorithms for the detection of a variety of plant species by image processing. It will also be trained for meeting the requirement of water and temperature to be provided for a particular plant. This moisture sensor connected to it will give the signal to predict the amount of water present in the soil and which type of soil is it by detecting the flow of electricity. The signal will then go to the microprocessor, and by analyzing the pre-trained dataset, the machine will be able to decide the type of soil and its suitability for the plant and send the feedback to the farmer. The job of providing perfect amount of water cannot be determined precisely by manual farming, and thus automated greenhouse can offer perfect solutions in such scenarios. Similarly, temperature sensors are used for meeting the requirements of different plants. Like in case of moisture sensors, the pre-trained microprocessor attached with the temperature sensor will also allow the machine to make decisions regarding which plant requires what amount of water. According to the information gained from the pre-trained dataset, the signal is sent to the microprocessor which, in turn, controls the temperature to be provided to different plant species.

3.3 IoT-Based Detection of Diseased Coffee Plants and Its Eradication in Real Time

As part of the natural wood decomposition procedure, the wood-boring pests invade inside the bark of trees and thin out the stressed plants. A characteristic noise is being produced as the insect makes its way inside the wood and a shrill chewing sound is being heard. *Xylotrechus quadripes,* also known as the white stem borer, is one of the most serious threats to the species of Arabica coffee plants (Venkatesha and Dinesh 2012). They have a typical black and white striped pattern on their forewings and the males are relatively shorter in size than the females. These pests are most active during the summer season. As the pest progresses inside of the stem, the noise is produced. Distinct visible features are observed as ridges on the barks of the coffee plants as shown in Fig. 4. Other characteristic symptoms might include yellowing and wilting of the tree which ultimately results in the death of the plant.

Proposed Model: Traditional management techniques of such problems include the use of chemicals like pesticides, which are to be given at specific times of the year and the dosage and the time are hard to keep track of. Scrubbing is also another technique that is being used to get rid of the affected parts of the stem where the insect lays eggs, thus putting a stop to the progression of the infestation. These traditional methods are not precise and labour intensive. Automation can eradicate such problems and prevent losses caused by the pest to such plants.

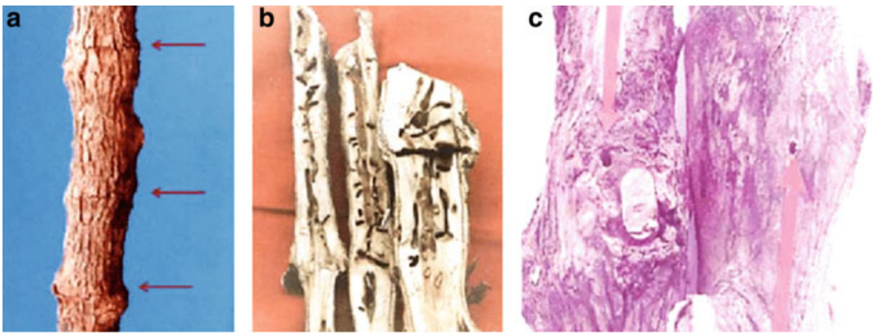

Fig. 4 Coffee stems depicting the symptoms of infestation by Xylotrechus quadripes (White Stem Borer): **a** borer ridges, **b** borer tunnels and **c** borer exit holes. Venkatesha & Dinesh (2012)

In the case study, we are aiming to solve this issue using the concepts of IoT equipped with drone technology and robotics. Our design aims for detection of the infested plant in real time using a noise detection sensor placed on a drone, which will sense the signal of the characteristic noise of the white stem borer, making its way through the bark of the coffee plant. Once the noise has been detected, it will guide the drone to the location from where the noise is coming using the GPS facility. Once the drone reaches its target, it will send a signal to the chainsaw-wielding robot to cut down the tree.

Methodology: In our model we make use of the sound detection microphone sensor KY-038 attached to the drone. It can send both digital and analogue signals to the microprocessor like Raspberry pi. We can test with a potentiometer to configure the value for the sonic. If the extreme value exceeds, the sensor can send signals as a digital output. If it sends the signal directly as a voltage value, then it will give analogue results as output. LED1 will detect the voltage and LED2 will show the detection of a magnetic field. The model is divided into three parts. In the first part, a sensor unit is attached at the front and it measures the physical area and sends an analogue signal to the amplifier which is placed in the second unit. In the second unit, the amplifier amplifies the signal as per the resistance value of the potentiometer and sends a signal to the output module which is analogue in form. The third part of the component is a comparator that switches between the digital output and the LED as per the falling of the signal. We can control the sensitivity by adjusting the potentiometer accordingly. The noise produced by the white stem borer making its way through the stem of the coffee plants is the signal that is taken up by the sound detecting microphone sensor and processed. The microprocessor is trained with explicit machine learning algorithms to be able to recognize that particular noise and also to be able to differentiate between different types of noises.

On receiving the signal from the drone, the chainsaw-wielding robot will follow the directions assisted by GPS facility and reach the location of the infested plant. Once it reaches the spot, the robot starts chopping off the tree. This allows the infested trees to be removed completely and stops the infestation by the pest from spreading out to the healthy plants. The workflow has been presented through the pictorial workflow in Fig. 5. In taking up such smart initiatives for pest management in the agricultural fields lies the future of Indian agriculture and farmers need be encouraged to constantly look at newer options to resolve such issues in real time.

4 Discussion

The awareness regarding technological advancements in case of agriculture is essential to be created among Indian farmers so that they are well informed and can compete at par with the world agriculture economy. Training farmers in the latest technology and creating an environment so that they can adapt to it faster are crucial. The main problem lies in the fact that they are unable to draw long term solutions which would be sustainable. Different strategies have to be applied to meet the

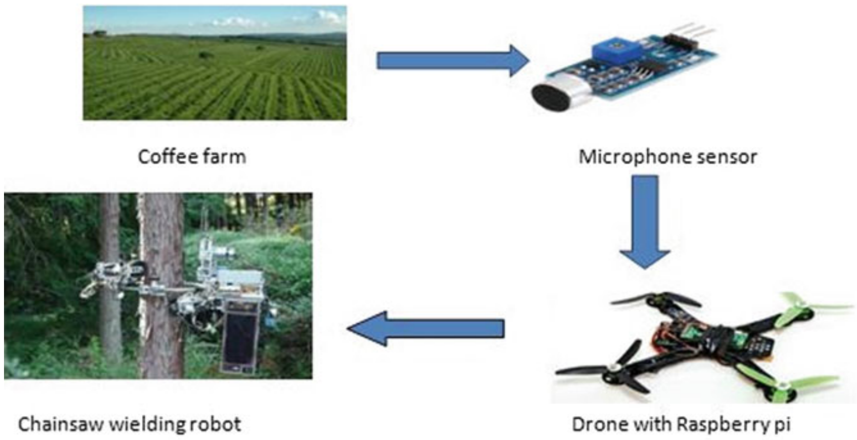

Fig. 5 Depicts the workflow for IoT-based detection of infested coffee plants data flow diagram

growing requirements and bring about a technological revolution in the agricultural sector in India.

Working towards ensuring that farmers get the fair share of the profit is important. Inability to assess consumers' needs is due to the lack of effective communication between different strata of this business. In 2017, a report in *The Times of India* suggested that over 12,000 farmers had committed suicides in India each year since 2013. The rise in the cost of inputs required for agricultural practices like fertilizers, seeds, etc., is one of the leading causes of depression among farmers. Another major factor that contributes to the issue is the huge literacy gap that exists among the rural population in the country. Awareness among the farmers regarding the advancements in the agricultural sector is almost non-existent, and the farmers are not updated with the latest technologies. Distresses due to loans taken from moneylenders and absence of proper schemes available to meet the financial burden are also responsible for the increased suicide rates among farmers.

Another aspect to focus on regarding the improvement of agriculture practices in India is the investment that goes into research and development for agricultural sciences. Building of proper infrastructure aids in creating a group of better and well-informed farmers who will be able to accelerate the growth of productivity annually. Drawing comparison with countries like China, which invests an almost triple the amount in research and development for agriculture, India is lagging by a huge margin. Integration of technology with farming options is the key to assisting the vision of sustainable agriculture in India.

Ensuring the power of technology in the hands of the farmers is of vital importance. With the availability of cell phones and internet connectivity, farmers are directly able to connect with the market and negotiate prices of their produce. Countries abroad are investing in machines that assist in smart harvesting options. The concept of autonomous vehicles assisted with the power of AI—which enables them to make

Table 2 Discusses the different startups in India who are embracing the option of precision agriculture

Startups	Agenda
Barrix Ago Sciences, Bangalore	Offers environment-friendly crop protection techniques
Anulek AgroTech, Mumbai	Using BIOSAT (Biochar-based soil amendment technology) to increase the fertility of the soil, thereby bringing about a great change in the productivity of the crops
MITRA, Nashik	Aims at developing newer machines using the latest technology in agriculture like air blast sprayers
Cropin Technology Solutions, Bangalore	A cloud-based platform that allows the farmers to track the development in the growth of their crops from any remote location and stay updated regarding the stats of various agribusinesses across the country
Skymet, Noida	Aims at accurate weather prediction using concepts of machine learning and assessment of climatic risks so that the farmers can be prepared beforehand

decisions on their own—is emerging to be useful. Along with the emergence of agricultural robotics, airborne surveillance is also coming up as another trend in precision farming. The data gathered from sensors attached with drones are being taken up and analyzed and better production models are created.

Various start-ups in India have already come up with solutions for bringing about changes in the agricultural frontier of this country. Table 2 highlights some of the recent start-up companies that are becoming major game changers and driving force for changing the outlook of the Indian agricultural system.

India holds immense potential to become one of the major countries in agricultural production if it uses its resources properly and strategically. Initiatives have to be taken towards strengthening the R&D infrastructure of agriculture in India. Figure 6 highlights five major strategies for addressing the issues and suggests ways to bridge the gaps in the context of Indian agriculture.

5 Conclusion

The growing population of India is hugely dependent upon agriculture for food security. The Green Revolution, Blue Revolution and White Revolution are some of the major milestones in the development of agricultural technology in India. The most recent development has been ICT that has hugely impacted agribusiness. Communication established via IoT is rapidly making its way towards improving the lives

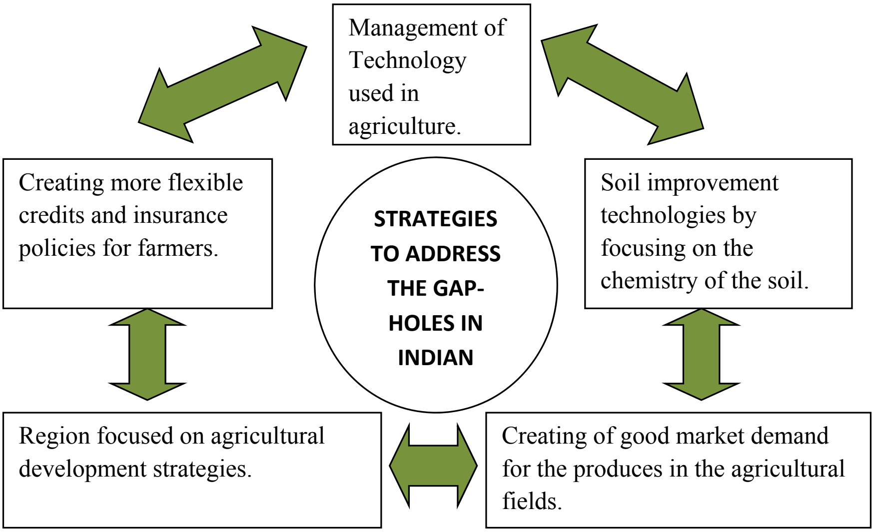

Fig. 6 Depicts the five important strategies to combat the problems faced by the Indian farmers

of farmers and also allowing them to make informed decisions and stay on par with the latest technologies of global agriculture.

The Indian government constituted the National Commission of Farmers in 2004 under the chairmanship of M.S. Swaminathan, based on the recommendations of which in 2007 the National Policy for Farmers was announced. It emphasized introduction of latest technologies in agribusiness in India. In 2012, the National Telecom Policy stressed upon broadband connectivity and the need for empowering farmers with cell phone communication so that they could stay connected with the market directly. Also, developers have been coming up with various software-based applications that are available online and powered by the machine learning algorithms that can assist in predicting weather conditions, image recognition of the diseases of plants, etc. Access to all these is possible when farmers are informed regarding the possibilities of technology and how its application can improve the quality of work in the field.

Other than the advantages that the introduction of technology in agriculture brings in, there are certain downsides to it as well. Imparting computer literacy to the population in the rural areas of India is a challenge in itself and to overcome it would require both time and financial support. Distortion of information regarding technology given to farmers is also one of the reasons that cause scepticism in them regarding adoption of newer technologies in farming. Establishing internet connectivity in remote locations is another problem that needs to be sorted out.

The main goal of ICT is to create a common platform for the exchange of newer ideas and to bridge the gap of information available between the richer and poorer formers. In India where diverse languages are spoken ICT can offer an effective solution for communication. With concepts like Natural Language Processing (NLP) coming to the forefront, effective communications can be established by farmers who do not speak or understand English. This makes the exchange of information much easier and the farmers are also more comfortable in expressing their views. The potential that Indian agriculture holds is endless and only upon effective merging different aspects of science and technology and having an opening mind towards receiving newer ideas will allow us to bring up relevant solutions to address issue of food security for the growing population of the country.

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Chapter 7
Agricultural IoT as a Disruptive Technology: Comparing Cases from the USA and India

M. Umme Salma and Srinivas Narasegouda

1 Introduction

With the advancement in science and technology, a gradual yet powerful transformation has occurred in the field of agriculture. From the era of traditional toil and moil way to that of smart farming, agriculture has witnessed many landmarks—mechanical farming that made use of vehicles and machines for farming and harvesting instead of labour alone, the green revolution that led to large production of crops due to better seeds, organic and inorganic fertilizers, pesticides and storage systems. M-agriculture brought a new wave of transformation where required information related to agriculture was provided to the farmers on time through mobiles. This has been possible with the help of the Internet of Things (IoT). IoT is a disruptive technology where various technologies are bound together via the internet serving the needs of people with myriad applications. According to Waher (2015), IoT is 'a collective system of living and non-living things which include animals, people, machines, hardware and software with unique identifiers (UIDs) and possessing ability of data transfer over the internet with a minimal or no human-to-computer or human-to-human interaction'.

Among the various applications of IoT, agriculture is the major area where tremendous scope exists. Agricultural IoT is used to cater to the needs of farmers and farming industries like soil analysis, weather forecasting, smart farming, livestock monitoring, precision agriculture, etc. The usage of IoT in agriculture can lead to automation of agriculture and thus improve the yield and production of crops. The main aim of this chapter is to provide a comparative study on the role and impact of IoT in Indian and American agriculture. Section 2 details the significance of IoT

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_7

in agriculture and its various applications. Section 3 presents a brief note on the agricultural scenario in India and the USA. Issues in application of IoT in USA and India are discussed in Sect. 4. Section 5 provides the summary and conclusion of the study.

2 Role and Significance of IoT in Agriculture

According to a United Nations Organization's report released on June 14 2013, the global population would be around 9.6 billion by 2050 and catering to their requirement of food would be a major issue. To fulfil the demand of the food agriculture must make use of the latest scientific and technological advancements including IoT.

With the fast growth of IoT, the smart agriculture market is estimated to reach the profit of around 18.45 billion $ approximately in 2022, at a CAGR of 13.8 per cent. As the IoT devices possess the strength of improving the agriculture 'Business Insider', a major American business platform, expects export of over 75 million IoT devices for agricultural purpose in 2020, at a CAGR of 20%.[1] Keeping these statistics in mind many countries have invested in agricultural IoT. The major focus area of agricultural IoT concerns soil analysis, seed analysis, crop growth analysis, field monitoring, smart irrigation, precision agriculture, weather forecasting, smart greenhouse, telematics, livestock management, food preservation and many more. The next subsection covers the research and applications of agricultural IoT carried out during the last decade.

2.1 Research and Applications of Agricultural IoT

Agricultural IoT has myriad applications and extensive research is being carried out in this arena. Some of the prominent research areas of agricultural IoT are as follows:

1. **Field analysis**: Field analysis is one of the major applications of agricultural IoT that includes soil analysis, seed analysis and crop growth analysis. Cloud computing along with IoT can be used to record field information which includes growth of crops, fertilization, plant diseases, environmental factors, etc. This recorded information is used for analyzing the hidden patterns that can be of great potential. The recorded data can also be used to predict future outcome (TongKe 2013). IoT has been used at different levels in the agro-industrial market benefiting different stakeholders from small farmers to big industrialists. IoT is used to assess the soil state, biomass of animals and plants and the climatic conditions. The IoT systems reduce human interference and build a strong network of powerful devices that provide a valuable feedback mechanism and analytic

[1] https://blog.beaconstac.com/2016/03/iot-ecosystem-iot-business-opportunities-and-forecasts-for-the-iot-market/ (2018). Accessed on 20.12.2018.

support (Talavera et al. 2017). A large number of countries invest their time and money in the research related to soil analysis where different types of soil are tested for their bio-content (humus), pH level, moisture humidity and chemical content. Various physical and electrochemical sensors are deployed to obtain readings (data) and communication technologies such as Zigbee, LoRaWAN, GPRS and Bluetooth technology are used depending upon the size of the sample and application (Chen et al. 2014; Mafuta et al. 2013).

2. **Precision agriculture**: Precision agriculture (PA) is different from traditional agriculture and involves the usage of technology to collect the agriculture data, perform diagnosis, analyze the data, perform field operations, and evaluation. PA facilitates smart farming that includes smart water management, pest and weed control, and efficient usage of fertilizers and the other nutritional requirements for the strong growth of plants. PA is a management strategy that incorporates IoT to enhance the quality and the quantity of the crops (Jawad et al. 2017). A cyber-physical system-based integrated PA management system was developed by Rad et al. (2015), where a smart system was designed to increase the yield of the potato crop in Romania. The system evaluated the physical parameters such as topological and soil related. The analysis helped in decision-making, which resulted in increased productivity of the potato crop. Nanotechnology, one of the advanced technologies, is also being used in agricultural IoT. For instance, it is being used in precision agriculture where nanofertilizers can be used to overcome the problem of soil nutrient depletion. Similarly, nanopesticides and insecticides can be used to prevent various diseases in plants. The data collected using IoT are analyzed and based upon the analysis suitable nanoproducts are used to facilitate proper growth of crops (Kumar and Ilango 2018).
3. **Weather forecasting**: Weather forecasting includes predicting the future climatic changes and providing necessary information related to the safety and security of the crops. Over 90 per cent of the farming starting from crop selection to planting and harvesting all depends on the rainfall timings. IoT can be used for weather forecasting that can help to plan the cultivation well in advance. Weather forecasting also reduces agricultural risks. A large amount of climate data are collected using sensors at weather stations and rainfall and other natural events are predicted through this information which is broadcasted so that safety and security of the crops can be ensured (Tzounis et al. 2017). As the agricultural IoT relies on the internet it is very important to get uninterrupted power and internet supply. But due to bad weather, the internet connection gets disturbed. To overcome this problem, Microsoft and the Massachusetts Institute of Technology have come up with a new solution called FarmBeats discussed in Vasisht et al. (2017). FarmBeats proposed a novel weather-aware IoT base station design that maximizes and minimizes the energy and bandwidth as required.
4. **Smart greenhouse**: Smart greenhouse is a new approach to monitoring fields by creating a controlled environment with the help of technology that facilitates proper growth of plants. An advanced comprehensive system called as Intelligent Greenhouse Management System (IGMS) was proposed to produce a good yield in an optimized environment. A greenhouse environment was created using

wireless sensor networks, which continuously monitored the moisture level of the soil. Based upon the moisture content, the required amount of water was supplied to the field. This system provides plants to get only the required amount of water and conserves water (Kassim et al. 2014). An IoT-enabled system was integrated into a greenhouse to monitor the growth of cucumber crop. The data collected from the soil sensors were stored in the cloud and Zigbee technology was used for communication. At the server side, the software runs continuously to estimate the environmental variables (temperature, pressure, humidity, light, etc.) and soil parameters (pH, moisture level, humus content). Over drain measurements and substrate, conditions were transferred through the internet and suitable decisions were made by the systems. The smart decisions resulted in the increased yield of cucumber (Carrasquilla-Batista et al. 2016).

5. **Telematics**: Agricultural telemetry is used to establish communication between the client and server devices to facilitate monitoring of the crops. One of the significant researches carried out in the field of telematics was proposed by Oksanen et al. (2016). In this research, the authors developed a client-side combine harvester system and client-side remote monitoring system to send agriculture-related information. The proposed system was found to be working fine with a latency over the internet of fewer than 250 ms. Recent advancement in telematics is Mobile to Mobile (M2M) communication where M2M platforms are integrated with cloud and IoT to render sensing and actuating services. Suciu et al. (2015) presents a literature survey that contains applications of M2M telemetry in all fields including agriculture.
6. **Intruder identification**: An intruder detection system in agriculture is used for identification of intruders. Intruders may be the unauthorized persons or the animals that enter to destroy the crops. A system called AID—Agricultural Intrusion Detection was proposed by Roy et al. (2015) to identify the intruder entering the field. This system rings an alarm at the farmer's residence and also sends the message to his mobile alerting him to take necessary action. The system was designed and deployed using Advanced Virtual RISC (AVR) microcontroller-based wireless sensor boards and Zigbee communication technology. M2M-based intrusion detection system and deep learning-based multiple intrusion attack identifications were proposed by Arshad et al. (2018) and Diro and Chilamkurti (2018), respectively.
7. **Livestock management**: Livestock management is a mechanism of managing the livestock used by the farmers and it includes usage of Radio Frequency Identification (RFID) and other technologies to identify the cattle. The animals are tied with the sensors (e.g., RFID) and left free to gaze. Using the identification sensors, the location of the animals can be known. Various biomechanical sensors are also used to monitor pulse rate and body temperature and the variation is reported to the user so that immediate treatment could be started. Some of the interesting works on livestock management have been reported (Havstad et al. 2018; Lopez-Ridaura et al. 2018; Qu et al. 2018).
8. **Disease identification**: Based upon the country conserved, agricultural requirement research is carried out to identify diseases in crops. In India, Ramesh and

Rajaram (2018) came up with a hybrid system for identifying disease in paddy crop (rice). The authors developed a hybrid IoT-based framework that included the modules for data acquisition, quantification, classification, analysis and visualization. The image data was sent to MS-Azure cloud server where various image processing algorithms were executed and the result was sent to the farmers. The main drawbacks of this proposed system are that it is time consuming and costly. Export of apples and berries from the USA being an important business, there is the need for developing a system that identifies the disease in fruit crops in the early stages. To address this issue, Ampatzidis et al. (2017) proposed an IoT-based framework to identify disease in various fruit crops. Many other works of similar type on various crops have also been available (for instance, Dang et al. 2013; Luvisi et al. 2016; Rad et al. 2015).

3 Usage of Digital Technology in Agriculture

3.1 Indian Experience

When it comes to digital technology use in agriculture India is far behind many countries. The only full-fledged such technology usage in India is **mKrishi** scheme which is a landmark initiative developed by the Tata Consultancy Services in 2009. In **mKrishi**, the mobile technology is used to answer the queries of farmers who post queries and the experts answer those by obtaining data from the GPS based analytical systems. It also provides reports and feedback mechanism. The **mKrishi** technology comes in three versions, namely, **mKrishi Lite, mKrishi regular** and **mKrishi Plus** and all the three are paid versions.

In 2015, the Government of India came up with a new proposal for digitalization of farms using IoT. In this regards, a draft policy was released that focused on the following projects:

1. Projects for precision farming monitoring the agricultural data that include climate data, soil data, crop data, etc. to analyze patterns that can contribute to increased agricultural growth.
2. Online projects to update farmers with current agricultural information.
3. Alert system projects to warn farmers against natural disasters and pest menace.
4. IoT-based solutions like unmanned vehicles for sowing seeds, spraying of pesticides and harvesting.

3.2 USA Experience

Modern agriculture in the USA focuses not only on commercial farming but also on small-scale land and hobby farms. Genetic engineering has increased the production of high yield crop varities; however, it has also led to many controversies related to the safety and nature of the crops. People research has been carried out to find new solutions related to the improvement of seed and soil quality. The US agriculture sector has come up with several alternatives like bio-plastics, bio-fertilizers, bio-pesticides that serve a boon to farmers. The bio-farming way of agriculture has reduced the problem of soil nutrient depletion. Nowadays, the shift is towards IoT where hardware and software devices are integrated to cater to the needs of farmers. The hardware and software may be as simple as a mobile device and a basic operating system and a simple database to complex system consisting of Artificial Intelligence (AI), Embedded Systems (ES), Robotics and many more. The applications of modern technologies by the US government in the field of agriculture are illustrated briefly through five cases.

Case 1: Analyzing satellite images—The crops are under satellite vigilance to monitor the fields for intruder detection and crop health monitoring. Here, the images of the crops are taken and are subjected to image analysis where the image processing-based software identifies the infection and/or diseases in the plants in its early stage. It also identifies the intruders in the field. The intruder may be the pests or any unauthorized person.

Case 2: Infield monitoring With the help of aerial unmanned vehicles fields are monitored not only by capturing images of crops but also by identifying infected plants so that pesticides are sprayed only to those infected crops instead of the whole field. The sensors in drones also help in data collection which can be used later for analysis.

Case 3: Predictive analytics—The data collected from the sensors can be used in predictive analytics where future outcomes are forecasted. The predictive analytics in agriculture is mainly used for rainfall prediction, weather forecasting, natural disaster alarming, predicting the yield, etc.

Case 4: Assessing crop/soil health-using IoT sensors—These are used for periodic monitoring of crop and soil health so that the yield obtained is both qualitatively and quantitatively strong.

Case 5: Agricultural robots—These are smart enough to take decisions concerning the agriculturist in different phases of farming, from toiling to harvesting. It not only reduces the labour charge but also improves the efficiency of the task and saves time.

To boost the development of technology and increase productivity, the USA government has made many data public for the data scientist.[2] Using these free and publicly available data many researchers, developers, and industry personnel have developed many prototypes and tested their models and later many of the models, tools were made available to the farmers freely. Examples of software developed thus include Farmplenty and Flockplenty.

Farmplenty is a software that helps farmers to get a better analysis of open data on crops grown within a 5-mile radius from their location. This application is free and is maintained by the US Department of Agriculture (USDA).

[2]US Government open data. https://www.data.gov/ (Accessed November 21, 2018).

Table 1 Agriculture value added per worker in USD (World Bank 2018)

Year	Annual income per person in agriculture in India amount in $	Annual income per person in agriculture in the USA amount in $
2008	1108.86	65,764.11
2009	1128.20	76,627.66
2010	1240.94	74,064.04
2011	1366.53	68,423.12
2012	1431.89	64,826.64
2013	1491.82	79,271.74
2014	1497.07	76,396.30
2015	1519.35	76,344.99
2016	1620.50	83,735.80

Flockplenty is another mobile app that helps farmers to keep track of the diet of their flocks so that quality eggs are laid. This app provides information related to feed quantity to be given to animals. It also helps to know the quality of the egg by uploading the images of the egg. Apart from financial handling facility, the app provides periodic feedback and reports related to the health of the flocks.

11 km Apart from the free software, some company has come up with paid software to help different stakeholders.

Onfarm is a farm management tool developed by Fresno that collects data from different sources and turns it into valuable information benefiting different stakeholders from farmers to the industrialists.

Farmobile is a digital platform developed by Leawood that redefines the accumulation, sharing, standardization and visualization of farm data. It is the first platform that connects farmers with buyers and industries to generate revenue and it is a one-stop platform to get an answer for various farm queries.

4 Concluding Observations

In this chapter, we observed various roles and significance of IoT in the agriculture sector. IoT is being used by researchers in many ways to help farmers in increasing the productivity of their agricultural goods; these include, field analysis, precision agriculture, weather forecasting, smart greenhouse, telematics, intruder identification, livestock management and disease identification.

As would be clear from Table 1 average per capita income from agriculture is often over 50 times higher in the USA compared to that in India. One major reason for this difference is the use of advanced digital technology by the USA.

A common pattern observed in both the countries is that most of the revenue from the agriculture sector emanates from livestock. However, while the US government focuses on research and development towards livestock management (as for example, **FlockPlenty**), little attention is paid to digital convertor technology in India.

In India, the **mKrishi** scheme is the only predominant scheme that helps farmers to receive answers to their queries related to agriculture. But, the major drawback of **mKrishi** is that it is a paid software. Another scheme called **Soil card scheme** is successfully running in many parts of India where the farmers can get the health report of soil samples through IoT-based system. The major drawback of this system is that it is an offline system where soil samples are collected from the officials and tested. The report is given to the farmers after a few days. The centres are available only in district headquarters of few states and not many farmers are aware of this scheme. Whereas the USA supports farmers with many free and paid softwares. The free apps called **Farmplenty** and **Flockplenty** are readily available all over the country and answer all basic queries of farmers.

Another main reason for agricultural advancements in USA is its research and application of advanced digital technologies like robotics, artificial intelligence and IoT both at individual and industrial levels. According to the World Bank, USA invests 2.79 per cent of its GDP in research, whereas India invests only 0.63 per cent of its GDP towards research and innovation (World Bank 2018). When it comes to the application of technology in India these technologies are either at the proposal level or yet to be initiated properly on a full scale.

By analyzing all the aspects of notwithstanding diverse approaches to digital technology in agriculture in both USA and India, one may still hope that there is always a scope for improvement in Indian agriculture. As India is rich in resources and climatic variations support different types of crops, and most importantly as India ranks number one in having the largest cultivated land area, there was a great opportunity to improve Indian agriculture through digital technology inputs. If the Government of India invests more in research and development and supports farmers with new projects involving advanced technologies as IoT and also assists financially progress in agriculture is possible.

Acknowledgements The authors would like to thank the World Bank, Ministry of Agriculture, Government of India, and US Department of Agriculture for providing valuable data.

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Chapter 8
A Survey of Digitized Handwritten Signature Verification System

Anjali Rohilla and Rajesh Kumar Bawa

1 Introduction

Biometrics is the key concept in today's security requirement. It is defined as the process to confirm and verify the identity of an individual by using various unique traits that are referred to as biometric traits. There are usually two types of biometric systems: verification and identification. In verification systems, a person's identity is authenticated based on his/her claimed identity while in identification systems, a person's identity is compared against all templates that are stored in the database. In both types of systems, different kinds of biometric traits such as physiological or behavioural are used. Physiological traits are the biological features of a human being such as a face, iris, fingerprint and hand geometry while voice, gait and handwritten signatures are usually considered as behavioural traits. Figure 1 shows the different traits used to build various biometric systems and in this chapter, signature biometric problem is analysed in two modes: online and offline.

In present times, biometric systems are accepted worldwide as an important tool for personal identification. Biometric is a way to replace traditional identification practices using password-based authentication, a token such as identity cards, magnetic cards, etc., which are less authentic as they can be lost, forgotten or stolen. There are different applications where biometric systems such as fingerprint, facial recognition, and iris recognition are being used by the government for the benefit of the citizens. Some of the applications where biometric systems are successfully implemented by different countries are financial organizations, law enforcement agencies, healthcare departments, travel and immigration, etc. In India, one of the major applications that are based on biometric identification is the Aadhaar card that has been accepted worldwide as a means of personal identification. Fingerprints, face recognition and iris recognition are some of the biometric traits that are used in

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_8

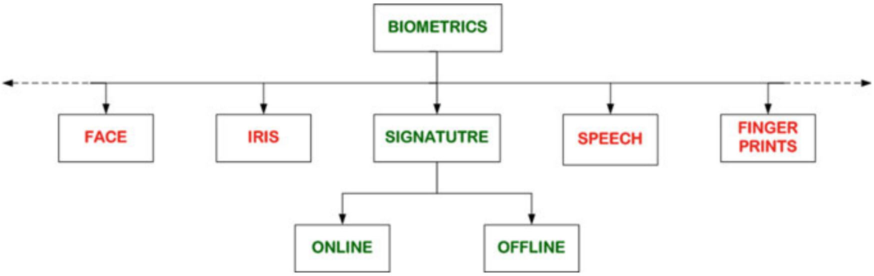

Fig. 1 Signature as a biometric problem

Aadhaar card-based verification. Fingerprints are also used for biometric attendance in many government organizations. Among all other biometric traits, handwritten signatures also occupy an important place in the field of biometrics, this is because they have long been established as a method of personal verification.

1.1 Importance of Signature as a Biometric Trait

Signature is a handwritten depiction of someone's name that acts as a method of authentication. Signatures are used for signing a document we want to authorize. Signatures are being used in most of the administrative and financial institutions as a means of personal verification because people are aware of their use in daily life. Signature verification in banks is done physically where a person verifies the signature from the cheque with specimen signature stored in the database. The work has been done to automate the signature verification system in banking applications (Kumar and Dhandapani 2015; Dongare and Ghongade 2016; Jayadevan et al. 2007). Sometimes there may be a situation of biometric data got leaked out, then that data cannot be used in future. To handle this issue, cancellable biometric methods have been used. Among different biometric traits, signatures are considered cancellable from the perspective of spoofing that makes signature verification an important field to be focused on (Nakanishi et al. 2011). Different kinds of techniques are being used in the development of signature verification systems. Based on the acquisition method of signatures, there are two categories of signature verification systems: online and offline. In case of online mode, data are, usually, collected at the time while the signatures are being done. The basic features that are used in online signature verification are x–y coordinate points, time-based features, pressure-based features, angular features, etc. The devices such as mobiles, personal digital assistant, pen tablets and tablet PCs, etc. help in the collection of online signatures. The dynamic features obtained from online signatures are difficult to duplicate as compared with the static features of the offline signatures. Offline signatures are acquired after the signing process is over. Offline systems are not easy to develop due to unavailability of active information like velocity, stroke ordering, etc. The verification process depends on the features that are captured from the signature image such as pixels, image segments, edge detection, thinning of signatures, grid-based features, texture-based features, etc. Moreover, an image analysis work is always involved in offline mode of signature verification, which is a very time-consuming process.

1.2 *Phases of the Signature Verification Model*

As shown in Fig. 2, a general signature verification system has the following stages.

Signature collection: In any biometric system, data collection is usually implemented with the help of a sensor module that captures the biometric data of an individual. Here, in the case of signature collection, signatures are acquired using different data acquisition methods for both offline and online modes of signature verification. In the offline mode, a signature image is captured or scanned as data while in the online mode, signatures are collected using a web camera, digitized tablet or through the stylus.

Pre-processing: This step is performed to ready the image for feature extraction process. Here, the acquired signature is enhanced by applying various pre-processing techniques. Different researchers have used different techniques according to their need but some of the commonly used pre-processing techniques in case of offline signatures are signature extraction, noise removal, signature size normalization, binarization, thinning and smearing, while in case of online signatures, commonly used pre-processing techniques are filtering, noise reduction and smoothing (Impedovo and Pirl 2008).

Feature extraction: At this stage, the feature extraction is implemented that processes the collected data to capture various feature values. In the case of signature verification, feature values for both offline and online signatures will be captured independently. For example, offline features are the grey-level position of image, signature image area, height and width of the signature and online features are velocity, pen inclination, pressure, position, time of each data point captured, etc.

Verification: At this stage, a matching module is used for comparing the generated feature values with the templates that are stored in the database by producing a matching score. In the verification process, many critical aspects are involved like the

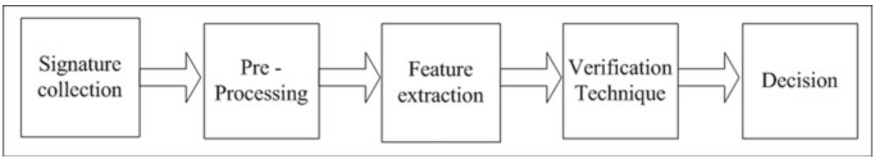

Fig. 2 Phases of the signature verification model

matching technique used and the strategy used for developing a database. Different types of matching techniques such as support vector machine (SVM), deep learning, dynamic time warping (DTW), fuzzy logic, hidden Markov model (HMM), etc. are used for signature verification.

Decision: At this level, a decision module is implemented through various kinds of thresholds that decide whether an identity claimed by the user is accepted or discarded based on resemblance score produced through a matching module, and the score can also declare a signature either as genuine or forged.

1.3 Performance Evaluation of the Signature Verification System

Various techniques for verification have been developed to address the online and offline signature verification problems and researchers have studied different approaches. There are two classes of signature that are studied while evaluating the performance of the signature biometric problem. One class is of original signatures of the writer himself/herself and another is of imitated signatures done by others. For analysing the performance of this biometric verification system, two classes of error are considered: Type 1 and Type 2 errors. Type 1 error describes the number of original signatures that are considered as imitated signatures that are usually quantified as False Rejection Rate (FRR), while Type 2 error gives the number of imitated signatures that are considered as genuine signatures but are measured as False Acceptance Rate (FAR). These two error rates are used to derive two more error rates: Average Error Rate (AER) and Equal Error Rate (EER). AER is the arithmetic mean of FAR and FRR while EER is another metric where FAR and FRR intersect in the performance evaluation graph, which is known as receiving the operator characteristics curve.

The rest of the chapter includes summaries of work done in the field of online and offline signature verification during the last five years. After that, various challenges and issues faced in signature verification are mentioned. The chapter concludes by summarizing various benchmark databases used in both online and offline signature verification systems.

2 Related Work in the Literature

Since the past 40 years many pieces of research have dealt with the automation of signature verification problem. There is always a need for developing fast, effective and more reliable systems due to which it is still an ongoing area of research in biometrics. Some of the already developed systems in this area are summarized below.

2.1 Work Done in Online Signature Verification

In Table 1, previous work in the field of online signature verification from the recent five years is summarized. The results are presented in the form of standard error rates using different techniques, features and databases used in this field.

Guru et al. (2017) focused on the writer-dependent parameters such as decision threshold and the dimension of features for online signature verification. A set of real features for each of the writer was opted by using feature selection criteria that use the filter-based technique. Selective features were depicted as an interval-based symbolic vector.

Xia et al. (2017) collected online signatures as real-time signals that were captured from users with different devices. They mentioned that there could be variations due to different parameters such as the size of signature, location and angle of rotation and the changing environment. They proposed a method for alignment of signatures using Gaussian mixture model. Experimental results achieved through the system indicated the effectiveness and robustness of the proposed method.

Rohilla and Sharma (2017) identified 80 features to specify the online signatures that were presented in the form of a vector with the help of a representation technique that is symbol based. In this procedure, two types of feature vectors were used for original and duplicate signatures. The SVM classifier was used for verification. The SVC 2004 database was used for experimental analysis.

Sharma and Sundaram (2016) proposed a system based on an updated Dynamic Time Warping (DTW) with the help of code-vectors obtained through Vector-Quantization (VQ) strategy for online signature verification. Warping path was made after putting constraints on sample points of signatures in which they proposed a technique of voting for aligned pairs. The results of the system were analysed on SVC 2004 and MCYT 100 databases. This work implemented the features of warping path in signature verification.

Porwik et al. (2016) proposed a pattern recognition technique in biometrics. As compared with classical techniques, they used composed features instead of comparing the features of raw objects. The most favourable results were acquired through Hotelling's method. The results of the study were carried out on SVC 2004 and MCYT databases.

Doroz et al. (2016) presented a verification method that used dynamic properties of signature in which the feature space was connected through similarity measures that can be applied in signature verification. As compared with other methods, the proposed method selects the biased features and resemblance measures.

Cpalka et al. (2016) proposed an approach that used hybrid partitions to increase the accuracy of the signature survey. Hybrid partitions were made of vertical–horizontal portions in the signature. Vertical sections represented different timings of the signing duration, rather the horizontal sections include the area of signature related to velocity and pressure on the tablet. Their previous work in signatures motivated them to design the algorithm used (Cpalka et al. 2014; Cpalka and Zalasiński 2014).

Table 1 Work done in online signature verification

Authors	Features	Techniques	Dataset	Results
Guru et al. (2017)	The interval-valued symbolic feature vector of 100 online derived features	Symbolic matching	MCYT-100	EER 2.2
Xia et al. (2017)	Centripetal acceleration, velocity, position coordinates, pressure	DTW with SCC (signature curve constraint)	MCYT-100	EER 2.15
Rohilla and Sharma (2017)	The reference feature vector of 80 features	Two class SVM with symbolic matching	SVC 2004	Mean FAR 7.0092, Mean FRR 2.2633
Sharma and Sundaram (2016)	Position coordinate, pressure, angle-based features	Dynamic time warping with vector quantization	SVC 2004	EER 2.73
Porwik et al. (2016)	Signature time, acceleration, velocity, position coordinate, pen up time, pen downtime	Probabilistic Neural Network (PNN) with Particle Swam Optimization (PSM)	SVC 2004, MCYT-100	EER 0.71, 0.71
Doroz et al. (2016)	Signature time, acceleration, velocity, position coordinate, pen up time, pen downtime	Signature time functions (*x*, *y*), trajectories, similarity coefficients and hoteling statistics	SVC 2004, MCYT-100	FAR 3.50, 0
Cpalka et al. (2016)	velocity, pressure on the tablet surface in different moments of the signing process	Neuro-fuzzy classifier	MCYT-100, Bio-Secure	AER 3.33, 4.88
Manjunatha et al. (2016)	Online global features	NB, SVM, NN, LDA, PCA, PNN classifiers	MCYT-100, visual sub-corpus of SUSIG dataset	EER 19.4, 1 0.92
Antal and Szabo (2016)	Global feature duration and local feature maximum velocity, sign change and histogram-based features	Euclidean, K-means, Knn-Manhattan, Manhattan-scaled detector	DooDB	EER 22.9, 22.4

(continued)

Table 1 (continued)

Authors	Features	Techniques	Dataset	Results
Faruki et al. (2015)	Eight dynamic features	Fuzzy inference system	FIS and reference database with 20 signatures from 15 users	FAR 10.67, FRR 8.0
Pirlo et al. (2015)	Displacement, velocity, acceleration, pressure	DTW with local stability analysis and stability model	SUSIG database	FAR 2.15, FRR 2.10
Kahindo et al. (2015)	Position coordinates	Dynamic Time Warping (DTW)	MCYT-100	HTER (Half total error rate) 6.517
Fischer et al. (2015)	Position coordinates, velocity, pressure, pressure derivative, acceleration	Dynamic Time Warping (DTW) with score normalization	MCYT-330, SUSIG	EER 3.94, 3.04
Liu et al. (2015)	Energy features and sparsity features	Discrete Cosine Transform (DCT) and sparse representation	SUSIG 40, SVC2004	AER 2.98 (CT), 0.51 (UT), 5.61 (CT), 3.98 (UT)
Cpalka et al. (2014)	X trajectory and Y trajectory combined with pressure and velocity signals and Signature partitioning	The neuro-fuzzy classifier of the Mamdani type	SVC2004 and BioSecure (BMDB)	AER 11.58, 3.7
Martinez-Diaz et al. (2014)	Global and local features	HMM-based local and global system	BioSecure and signature database captured using a device (Samsung Galaxy Note)	Global EER and Local EER 10.9 and 9.3, 4.2 and 6.2
Lopez-Garcia et al. (2014)	Global online features	Gaussian mixture model (GMM)	MCYT-100 database	EER 2.74
Parodi and Gomez (2014)	Velocity, acceleration, log curvature radius along with other global features	SVM and random forest (RF)	SigComp2011 Chinese dataset, Dutch dataset	EER (SVM and RF) 10.54, 8.93, 5.5, 10.68

Manjunatha et al. (2016) presented a method of online signature verification that used writer-specific features and classifier. As compared with already existing writer-independent models, this approach used the features and classifier that is writer dependent. The error rate achieved was less in comparison with different existing works in online signatures, particularly when the training samples were adequate.

Antal and Szabo (2016) studied the execution of signature verification systems on touch-sensitive mobile devices. Results were evaluated on DooDB database that contained doodles and pseudo-signatures. Some detectors comprised the feature-based anomaly that were also used for database evaluation. The results were depicted in the form of EER, which showed variations in the EER values.

Faruki et al. (2015) used an FIS method in signature verification because biometric features are difficult to lose, forget or duplicate. FIS was suitable for this work as there is a resemblance between individual signatures despite having differences. Signatures were captured with the help of a tablet PC. Eight real-time features were gathered from this data that were then fuzzified to train the fuzzy inference system that decides whether a particular signature is real or fake.

Pirlo et al. (2015) discussed a method for online signature verification that used the stability information. This method used a multi-domain technique to classify the signatures. A signature was partitioned into different parts based on stability model of a signer. The favourable area of the presentation was detected for each part. The originality of signatures was decided using local verification decisions. The results were analysed on SUSIG database.

Kahindo et al. (2015) presented a technique for selection of instances of signature of an individual. To collect the signature instance, they proposed a new complexity measure. They selected the reference signatures by implementing a method that used the distribution of complexity values for all real signature samples from MCYT-100 database were considered in this approach.

Fischer et al. (2015) analysed various approaches to scoring normalization and then suggested a multi-stage normalization that detected different types of forgeries in different stages. MCYT online signature corpus and the SUSIG visual sub-corpus datasets were used in this system. The results demonstrated that the score normalization procedure was the main module in signature verification. The performance was evaluated using random as well as skilled forgeries.

Liu et al. (2015) implemented a method using Discrete Cosine Transform (DCT) and sparse representation for online signature verification. They found a characteristic of DCT that is used to develop a compact representation of an online signature. An attempt was made to apply sparse representation for online signatures.

Cpalka et al. (2014) advised a way of verification for analysing the dynamic signature. They used a technique that used horizontal partitioning to consider the characteristics of the signatures. Partitions represented time moments of the signing of the user. Some of the most important features include using fuzzy set theory, the flexible neuro-fuzzy systems and explainable classification system for the categorization of final signatures.

Martinez-Diaz et al. (2014) analysed the impact of those devices on signature verification that can be held in hand. The authors compared the capacity of different features of signatures among mobiles and pen tablets.

Lopez-Garcia et al. (2014) discussed the use of Field Programmable Gate Arrays (FPGAs) on a system of online signature verification. Vector Floating-Point Unit (VFPU) was used in a system that accelerated the computations performed in the biometric entity. The designed system took less than 68 ms to complete the verification process by using a clock rated at 40 MHz.

Parodi et al. (2014) analysed feature combinations related to time functions of signing. Legendre polynomial-based series expansions were also used to propose a consistency factor. Two different styles of signatures of a public signature database were used to analyse the nature of the system. The results of the experiment showed a nice correlation between consistency factor and errors, which suggested that consistency figures could be implemented to identify the optimal features.

2.2 Work Done in Offline Signature Verification

In Table 2, work done in the area of offline signature verification in the recent five years is summarized. The results are summarized in the form of standard error rates using different techniques, features and databases used in this field.

Bouamra et al. (2018) investigated run-length distribution to design this signature verification system for addressing the inter-personal variability in signatures. The motive of this research was to increase the capacity of signature verification systems, so that they could work in a real form after trained in using genuine signatures without any access to duplicate samples. The classification was performed using Support Vector Machine (OC-SVM) and the results were analysed on GPDS960 dataset.

Sharif et al. (2018) advised a method in an offline verification system. There were four stages in the proposed system that includes pre-processing of signature images, extraction of features, selection of features and verification. Different types of global features and local features were used like aspect ratio, signature area, pure width–height, signature height and signature centroid, slope, angle, distance, respectively. A suitable feature set was obtained using a generic algorithm that was input to the SVM for verification. CEDAR, MCYT and GPDS synthetic databases were used for analysing the results.

Okawa (2018) proposed a method for feature extraction that used the Fisher Vector (FV) with KAZE features obtained from signature images by applying the strategy of fusion. Both KAZE features and fused KAZE features showed good results. The proposed method yielded low error rates than the other signature verification approaches available at that time.

Serdouk et al. (2017) proposed a method of offline handwritten signature verification. A descriptor based on Histogram of Templates (HOT) was found. They proposed the reliable implementation of Artificial Immune Recognition System (AIRS). The classifier was based on the natural immune system that produced antibodies for

Table 2 Work done in offline signature verification

Authors	Features	Techniques	Dataset	Results
Bouamra et al. (2018)	Black and white run-length distributions	One-class support vector machine	GPDS-960 corpus	FAR 6.65, FRR 4.13
Sharif et al. (2018)	Aspect ratio, signature area, width, height	Genetic algorithm and ANN	MCYT-75, GDPS synthetic, CEDAR	AER 4.67, 5.42, 5.96
Okawa (2018)	Fisher vector (FV) with KAZE features	SVM	MCYT-75	EER 5.47
Serdouk et al. (2017)	Quad-Tree Histogram of Templates	AIRSV	MCYT-75, GPDS-300, GPDS-4000	EER 10.60, 9.3, 18.15
Bhunia et al. (2019)	Wavelet and local quantized patterns (LQP) features	2 One-class SVM for both features and 1 one-class SVM for combined	MCYT-75, GPDS-300, BHSig 260 and CEDAR	EER 12.06, 11.46, 24.8, 7.59
Hafemann et al. (2017)	Feature learning	Convolutional neural networks and deep learning	GPDS-160, GPDS-300, MCYT-75, CEDAR	EER 3.23, 3.92, 3.58, 5.87
Hadjadji et al. (2017)	Curvelet transform	OC-PCA	GDPS-300, CEDAR	EER 5.04, 2.01
Boudamous et al. (2017)	Histogram of templates	Support vector machine(SVM)	CEDAR	AER 5
Hamadene and Chibani (2016)	Contourlet transform-based feature generation method	One-class SVM	CEDAR, GPDS-300	AER 18.42, 2.1
Yilmaz and Yanikoglu (2016)	HOG and LBP features	Two different (GSVM and USVM) classifiers	GPDS-160	EER 6.97
Pan and Chen (2016)	Grid features and global features	SVM	SigComp (contains 3395 signature images from three different countries)	Minimum EER 14.9, 4.7, 7.7

(continued)

Table 2 (continued)

Authors	Features	Techniques	Dataset	Results
Zois et al. (2016)	Posset-oriented grid features	SVM classifier	CEDAR, GPDS-300, MCYT-75,	EER 4.12, 6.02, 9.87
Soleimani et al. (2016)	HOG and DRT features	DMML	UTSig, MCYT-75, GPDSsynthetic, GPDS960 GraySignatures	EER 17.45, 20.28, 9.86, 10.06, 12.8, 22.76
Pal et al. (2016)	Texture features LBP and ULBP	Nearest neighbour (NN)	GPDS-100, BHSig260	EER 32.31, 32.72
Guerbai et al. (2015)	Curvelet transform-based features	One-class SVM	CEDAR, GPDS-300	AER 8.70, 16.92

protecting the human body from antigens. Experiments were conducted on various datasets like MCYT-75, GPDS-300 and GPDS-4000.

Bhunia et al. (2019) discussed a mechanism for signature verification that depends on the writer. Two texture-based features such as wavelet and local quantized patterns were used to obtain transform and statistical data from the images of signature. Two different one-class SVM's were trained to obtain two different originality scores. It was also mentioned that a score-based fusion method was employed to combine the two scores to achieve the verification score.

Hafemann et al. (2017) proposed memorizing the presentations from signature images with the help of Convolutional Neural Networks. They proposed a new formulation method knowing skilled forgeries in the process of learning about features. GPDS, MCYT, CEDAR and Brazilian PUC-PR datasets were used for experimental analysis.

Hadjadji et al. (2017) proposed an identification system based using the one-class classifier. They introduced two ways for generating the features that used the curvelet transform. A method based on Fuzzy Integral (FI) was also introduced to combine the individual systems. The design framework and density estimation were also introduced. Experimental results were analysed on CEDAR and GPDS handwritten signature datasets.

Boudamous et al. (2017) discussed various challenges that were faced in offline signature identification and verification such as a limited number of references and diversity in signatures. A writer-independent system for signature identification and verification was proposed. The authors proposed a feature extraction approach based on Histogram of Templates (HOT). They mentioned that they used SVM for identification and verification.

Hamadene and Chibani (2016) suggested a one-class system that used dissimilarity estimates and a few references. A contour-let transform-based feature generation technique was used in the proposed system. A WI threshold was used in verification. The design and verification stages were based on the WI concept.

Yilmaz and Yanikoglu (2016) suggested an approach that used score-level fusion for interdependent classifiers that were using various local features. They also mentioned that feature-level fusion was used by every classifier for representing local features. The EER reported was 6.97 per cent in the fusion of all the classifiers for skilled forgery tests at GPDS 160 database.

Pan and Chen (2016) proposed a signature verification method that used SVM for solving the limitations in manual identification such as technical accuracy and subjectivity of signatures. A powerful feature set of the grid and global feature of a signature pattern were collected. According to the author, this approach was used for the identification of various writing systems.

Zois et al. (2016) proposed a template-matching scheme in offline signature verification. Lattice-shaped probing structures were used for detecting the ordered transitions. The performance of the approach used was analysed on four signature datasets. Quality analyses of genuine signatures were also carried out. The probability to classify a claimed signature was improved if the real samples of signatures were of good quality.

Soleimani et al. (2016) suggested a metric learning method based on deep multi-cast learning approach. They introduced a suitable architecture for offline signature verification. It was also mentioned that good accuracy could be obtained through the knowledge of other signers. They claimed that the proposed method outperformed Discriminative Deep Metric Learning and SVM.

Pal et al. (2016) presented a contribution to the multi-script signature identification. The signatures of different languages like Bengali, Hindi and English were also considered for identification. The proposed system recognized whether a questioned signature belonged to Bengali, Hindi and English signature group. Two distinct feature extraction methods were used named as Zernike moment and histogram of the gradient. They used the SVM classifier. A database of 6300 signatures was used in which English, Hindi and Bengali were in equal proportion. They reported the accuracy of 92.14 per cent that was obtained using 4200 training samples and 2100 testing samples.

Guerbai et al. (2015) proposed a One-Class Support Vector Machine (OC-SVM) that used parameters of independent writers with genuine signatures. The performance of OC-SVM was good when there were large samples for precise classification. They proposed an updated decision function used for OC-SVM. They analysed results on CEDAR and GPDS signature datasets.

3 Challenges and Issues in Signature Verification System

- It is a fact that different signatures of the same person cannot be identical and there are a lot of variations even in the two original signatures of the same person. It usually happens with every two signatures as there are intra-class variations, which is one of the hurdles in building a reliable signature verification system.
- Signatures are usually recognized as two-dimensional handwritten patterns that can be easily copied by skilled forgers to a very high degree of resemblance that is known as inter-class similarity and is another challenge for this verification system.
- Signatures can be easily captured or collected. But it is habitual for people to sign their original signatures that are being used over the years and they are in the practice of the writer. Yet they build new signatures and give that signature for training the signature verification system. This leads to the incompetent database because the writer is not habitual with the new signature.
- A feature collection is one of the biggest challenges. Signature acquisition becomes so easy and accurate with the advancement in the technology, and in the same way, forgery of signatures is also getting closer to the genuine signature. In this era of digitization, new methods of feature collection must be established.
- In the enrolment phase, only a few samples of signatures were given by users due to the information available about them is very limited.

4 Benchmark Signature Databases

A significant amount of research has been conducted by various researchers in automatic signature verification by using their databases, which makes it difficult to compare and analyse the related work. But during the last decade, some benchmark databases are made publicly available that helped in the significant comparisons of related work. Some of the publicly available databases in signature verification are listed below.

4.1 Databases in Online Signature Verification

Some of the most commonly used publically available online signature databases include MCYT-330, MCYT-100, SVC2004, SuSig, SigSA and SigComp2011.

- MCYT-330 signature corpus was made of genuine and skilled forgeries with dynamic properties (Fischer et al. 2015; Ortega-Garcia et al. 2003). Signatures were acquired through a pen tablet, 435 model Intuos. Each signer gave 25 real signatures and 25 forged signatures. The total number of individuals who gave their signature in MCYT was 330. Hence, the total signatures of this database are 16,500.
- MCYT-100 database has 100 user signatures that were collected using a digitized tablet (Guru et al. 2017; Ortega-Garcia et al. 2003). Each set is having 25 original signatures of one signer and 25 skilled forgeries of five other signers.
- SVC2004 database was used by different members to adjust their systems for submitting in first international Signature Verification Competition in 2004. This dataset obtained data of 40 people who belonged to two different Asian and Western regions (Porwik et al. 2016; Doroz et al. 2016). Each person gave 10 real signatures in the first half and another 10 in the second half. 20 skilled forgeries were acquired from four other people. The signatures were acquired using a digitized tablet (WACOM Intuos tablet).
- SuSig database was made in two sessions that are obtained using two different pressure-sensitive tablets (Pirlo et al. 2015; Liu et al. 2015; Kholmatov and Yanikoglu 2008). The first kind of tablet enables real-time visual feedback, while in the other there is no visual feedback. The database consists of more than 3,000 original signatures and 2,000 skilled forgeries. For collecting skilled forgeries, forgers were given a chance to practice.
- MOBISIG is a pseudo-signature dataset that was made of finger-drawn signatures of 83 users by using a touchscreen-based mobile device (Margit et al. 2018). The dataset was obtained after three regular sessions. There were 45 real signatures and 20 skilled forgeries from every member.
- DooDB, as per the author's observation, is the only publicaly available mobile-based database till 2016 (Margit and Szabo 2016). It is a doodle database made up from the data of 100 users by using the touch-based mobile device under real-life

circumstances. The database has the finger-drawn handwritten signatures. This database contains genuine as well as forged signatures under worst-case scenarios.

- SCUT-MMSIG is a multi-modal database of signatures (SCUT-MMSIG) (Lu et al. 2017) that was acquired by using different devices such as phone, pen-based tablet and camera. There were 50 individuals in every sub-corpus, having 20 original samples and 20 skilled forgeries per user.

4.2 Databases in Offline Signature Verification

Some of the most commonly used publicaly available offline signature databases include MCYT 100, MCYT 330, MCYT 75, GPDS 100, GPDS 160, GPDS 960, GPDS 300, CEDAR, UTSig, SigComp, BHSig 260. These databases are used to evaluate offline signature verification systems.

- GPDS synthetic database consists of static signature images (Vargas et al. 2007). There were 24 original signatures and 30 forgeries from 4000 members. Signature images in the database are collected from a set of individuals. Hence, the dataset contains 96,000 genuine and 120,000 forged signatures.
- GPDS300 signature corpus was made from 24 original and 30 forged signatures from 300 members (Vargas et al. 2007; Ferrer et al. 2005). It has 7,200 genuine and 9,000 duplicate signatures. Original signatures of every member were collected within the same day.
- CEDAR dataset contains 55 sets of signatures with each set having one writer (Nguyen et al. 2010). Each one gave 24 samples that were considered as genuine. The forgeries of the dataset were acquired from arbitrary people. Hence, the database contains total 2,640 signatures with 1320 real signatures and 1,320 imitated signatures.
- The corpus MCYT dataset was collected at the Autonomous University of Madrid from 75 individuals (Ortega-Garcia et al. 2003). Each person gave 30 signatures (15 genuine samples and 15 forgeries). Hence, the database contains 2250 signature images. The signature images were collected to A4 size sheet of paper and were scanned by the resolution of 600 dpi.
- UTsig is a public signature dataset that contains 8280 signature images (Soleimani and Araabi 2017). There were a total of 115 classes where each class contains 27 real, 3 opposite-hand signatures and 42 skilled forgeries from 6 forgers. This database has more samples, classes and forgers in contrast to the already available database. They considered various parameters during the data acquisition procedure like signing period, a device used for signing.
- SigComp2011 is an offline dataset of Chinese and Dutch signatures. The training set was made of 235 original and 340 fake signatures from 10 Chinese members and 240 real and 123 duplicate signatures from 10 different Dutch members (Pan and Chen 2016).
- BHSig260 signature dataset contains signatures from 260 individuals. There were 100 Bengali and 160 Hindi signatures (Pal et al. 2016). For each signer, 24 genuine

and 30 forged signatures were available. Hence, in total 2,400 genuine and 3,000 forged signatures in Bengali and 3,840 genuine and 800 forged signatures in Hindi were available.

5 Conclusion and Future Scope

Handwritten signature plays a very important role in everyone's life. Signatures are mainly used as a method of identification and verification in different government and private sectors. Many financial and legal organizations still rely on handwritten signatures for authentication purposes. So, an automated signature verification system can change the manual system of verification. In various countries, signature verification has already been employed as a means of bank cheque verification. In India, Aadhaar card is a major application of biometric authentication. This Aadhaar-based identification can also be linked with handwritten signatures to improve the process of biometric identification and verification.

In this chapter, we have summarized a detailed study of automatic signature verification. Work done by different authors in the field of online and offline signature verification has been presented in a consolidated manner. Different kinds of benchmark databases available in the field of both online and offline signatures are also mentioned and we have observed that a very few numbers of mobile-based signature databases are reported till now, which motivates researchers to do more work in this direction. Many handwritten signature verification systems are developed that are based on multi-lingual scripts like Arabic, Chinese, Japanese, English, etc., which gives another dimension for the researchers to do work on different Indian scripts like Hindi, Bangla, Punjabi, Urdu, Tamil, Kannada etc., based handwritten signature verification systems. Signature databases of these Indian languages can also be generated to work in the field of signature verification. These research perspectives make handwritten signature verification an interesting field for further exploration in future.

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Part II
Access/Use, Aberrations and Obstacles

Chapter 9
Protection of Consumer Rights in E-Commerce in India

Richa Gupta

1 Introduction

E-commerce as a business platform has seen innovation as well as disputes, something inevitable with any new technology where conflict comes as an add-on of innovation. Conflicts are commonplace in the world of the Internet in areas such as health, education, social media and labour and even e-commerce. Data on the rising number of e-commerce-related disputes among consumers shows that complaints against e-commerce companies comprise the maximum number of grievances[1] at the National Consumer Helpline (NCH).[2] Moreover, these are only a fraction of complaints as there are other forums where consumers approach the companies directly. This trend can only rise in times to come as e-commerce has been expanding with double-digit growth rates in the country.[3] The government has flagged concern about a large number of consumer complaints against online platforms, directing the Consumer

[1] *Complaints against e-commerce companies top list at national consumer helpline.* https://economictimes.indiatimes.com/news/politics-and-nation/complaints-against-e-commerce-companies-top-list-at-national-consumer-helpline/articleshow/58786034.cms (Accessed 19 April 2020).

[2] NCH is a joint initiative of the Consumer Affairs Department and Indian Institute of Public Administration (IIPA), which receives about 3.5 lakh grievances annually. Since September 2016, the e-commerce sector tops in consumer complaints. https://economictimes.indiatimes.com/news/politics-and-nation/complaints-against-e-commerce-companies-top-list-at-national-consumer-helpline/articleshow/58786034.cms (Accessed 19 April 2020).

[3] *45% annual growth over the financial year 2017–2020 as per a report by domestic brokerage firm Kotak Institutional equities.* https://www.business-standard.com/article/economy-policy/indian-e-commerce-market-could-reach-28-bn-by-fy2020-report-116090900611_1.html (Accessed 13 July 2017).

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_9

Affairs Ministry to list complaints against each such e-commerce company.[4] Resolution of such conflicts is essential to realise the 'right to redressal', one of the consumer rights in the country which extends to e-commerce as well.

Like the dynamic nature of the sector, policy responses to better regulation and development of the sector have been evolving with time and the government has picked up the pace. For instance, an analysis of responses over the last 3 years reveals how the government has moved from seeing the sector like any other business or industry to one requiring special focus, with a different committee of secretaries, panels or task force being set up and a new Data Protection Bill already framed.

2 Architecture for Consumer Protection in E-Commerce in India

2.1 Laws

Different aspects of e-commerce entities come under different laws like Information Technology Act 2000, Indian Contract Act 1872, Company law, Labour Codes, Income Tax Law, Civil Procedure Code, Indian Penal Code and Sales Tax Law (now repealed), among others. The hands-off approach of the government a couple of years back, when it saw the e-commerce industry like any other business covered and regulated under existing laws, has changed drastically in recent times. The shift in the approach to e-commerce can be seen with the introduction of new law and regulations—the Consumer Protection Act (CPA), 2019 and rules under the Act such as the Consumer Protection (E-Commerce) Rules, 2020 and the Consumer Protection (Mediation) Rules, 2020—that address concerns specific to the sector. It is important to note that while there is no single law or regulation to govern e-commerce as a whole in India, as far as consumer protection is concerned, the Act[5] along with a slew of rules[6] under the Act forms the bulwark for consumer rights protection in e-commerce

[4] *Complaints against e-commerce companies top list at national consumer helpline*. https://economictimes.indiatimes.com/news/politics-and-nation/complaints-against-e-commerce-companies-top-list-at-national-consumer-helpline/articleshow/58786034.cms (Accessed 12 July 2017).

[5] Consumer Protection Act, 2019 (No. 35 of 2019). It came into force on 20 July 2020 and replaced the Consumer Protection Act, 1986 by way of repealment.

[6] The Consumer Protection (General) Rules, 2020; The Consumer Protection (Central Consumer Protection Council) Rules, 2020; The Consumer Protection (Consumer Disputes Redressal Commissions) Rules, 2020; The Consumer Protection (Mediation) Rules, 2020; The Consumer Protection (Salary, allowances and conditions of service of President and Members of the State Commission and District Commission) Model Rules, 2020; The Consumer Protection (Qualification for appointment, method of recruitment, procedure of appointment, term of office, resignation and removal of the President and members of the State Commission and District Commission) Rules, 2020; and lastly The Consumer Protection (E-Commerce) Rules, 2020. Most important are Consumer Protection (General) Rules, 2020 and Consumer Protection (E-Commerce) Rules, 2020. All except

in India. The older law, the CPA, 1986, has now been repealed and replaced by the new law.

To name a few laws and the provisions impacting e-commerce, online sale of hazardous and dangerous goods falls under the ambit of the Sales of Goods Act, 1930 (enforced by state governments); FDI in e-commerce is regulated by Foreign Exchange Management Act, 1999 (FEMA); online payments made for B2C e-commerce come under the Payments and Settlement Systems Act, 2007. Many other laws impinge upon the sector whose specifics have not been listed in detail here. For the purposes of consumer protection, the single most significant law which forms an overarching framework for the protection of consumer rights in e-commerce is the CPA, 2019. Further, provisions of the Indian Contract Act, 1872 and the Specific Relief Act, 1963 are important to ensure protection against unfair contracts.[7] Lastly, the Information Technology Act, 2000 and attached Rules[8] and the proposed Personal Data Protection Bill, 2019[9] are important towards ensuring data protection of consumers.

2.2 Policies

As far as a dedicated policy for the e-commerce sector is concerned, the government has been working on a draft national e-commerce policy for over 2 years,[10] but it has not been finalised till 30 December 2020. A national e-commerce policy along with a 'National Retail Trade Policy' is to come out soon.[11] As with laws, the policy response of the government regarding e-commerce has evolved with time. From having no composite policy nor feeling the need for one,[12] a paradigm shift in the government's approach can be seen with an extensive second draft of the national e-commerce policy on the works which aims to balance interests of consumers and

the last rule came into force on 20 July 2020 and the E-commerce Commerce Consumer Rules became enforced from 23 July 2020.

[7] *Protection against unfair contracts.* https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1657006 (Accessed 29 December 2020).

[8] The Information Technology (Reasonable Security Practices and Procedures and Sensitive Personal Data or Information) Rules, 2011.

[9] Bill No. 373 of 2019.

[10] The Department for Promotion of Industry and Internal Trade (DPIIT) under the Ministry of Commerce and Industry is working upon a second draft of the National e-commerce Policy. The first draft of the National e-Commerce Policy which came out on 23 February 2019 invited much attention domestically as well as globally due to 'data localisation' norms.

[11] *Govt: E-commerce policy in 'final stages' of drafting; retail trade policy to benefit 65 m small traders.* https://www.financialexpress.com/industry/sme/govt-e-commerce-policy-in-final-stages-of-drafting-retail-trade-policy-to-benefit-65m-small-traders/2115990/ (Accessed 29 December 2020).

[12] *Flipkart, Amazon off the hook: No e-commerce policy for now, govt plans a set of tightened rules.* https://factordaily.com/amazon-flipkart-off-the-hook-no-ecommerce-policy-for-now/ (Accessed 17 July 2018).

industry, create jobs, invite investments as well as protect data, i.e., reap benefits of the 'digital economy' to the fullest. Apart from defining the sector, it aims at legalising activities of e-commerce companies that had so far been operating without much legal hindrances. Details of the policy shall become clear as and when the policy comes out in the public domain.

As far as the FDI Policy on e-commerce is concerned, the policy has remained consistent—FDI is not allowed in inventory-based multi-brand retail trading through e-commerce.[13] The same has been reiterated from time to time through various policy circulars, viz., Press Note 2 of 2000, Press Note 3 (2016),[14] Press Note (2/2018)[15] and the latest consolidated FDI Policy circular 2020.[16] Cent per cent FDI is allowed in the 'Marketplace Model' in business-to-business (B2B) e-commerce in India while FDI in 'Inventory-based Model' is prohibited for business-to-consumer (B2C) e-commerce. This implies that e-retailers like Amazon or Flipkart, set up by foreign investors or are funded by them, cannot control inventory in warehouses or own stock of goods they sell as that would violate FDI norms, i.e., they need to run strictly as a 'marketplace' connecting buyers and sellers on their platform. Thus, the inventory of 'Amazon Fulfilment Centres' that stocks extensive goods sold on its site and open at major cities in India cannot be owned by Amazon directly, for instance.

Further, the FDI norms state that e-commerce companies cannot source more than 25% of products from a single seller or vendor on its site, i.e., more than 25% of overall sales should not be from a single vendor/seller. The policy, thus, aims to address a big loophole where big e-commerce companies directly or indirectly controlled firms that were also the biggest sellers on the platform due to which e-commerce companies were able to offer discounts offline sellers could not, raising competition concerns. Nevertheless, two of the largest sellers on Amazon India, 'Cloudtail' and 'Appario' are joint ventures with Amazon as minority partners (after restructuring to meet FDI norms),[17] which raises concern that norms are being met only superficially. Further, to prohibit e-commerce entities from operating on the inventory-based model, the FDI policy states "Inventory of a vendor will be deemed to be controlled by e-commerce marketplace entity if more than 25% of purchases

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[13] There are two business models of e-commerce: 'Market Place' model and 'Inventory-Based' model. Discussion Paper on E-commerce in India (2013–14) also discusses the same. https://dipp.gov.in/sites/default/files/Discussion_paper_ecommerce_07012014%20%20%2013.pdf (Accessed 17 July 2017).

[14] Foreign Direct Investment (FDI) on E-commerce. Press Note No 3 (2016), Department of Industrial Policy and Promotion. https://dipp.gov.in/sites/default/files/pn3_2016_0.pdf (Accessed 17 July 2017).

[15] *Draft e-Commerce Policy*. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1575760 (Accessed 29 December 2020), *E-Commerce Business Model* https://pib.gov.in/PressReleasePage.aspx?PRID=1595850 (Accessed 30 December 2020).

[16] Consolidated FDI Policy circular, pages 49–50. https://dipp.gov.in/sites/default/files/FDI-Policy Circular-2020-29October2020_0.pdf (Accessed 30 December 2020).

[17] *Who Owns Cloudtail India and Appario Retail, Amazon's Largest Sellers?* https://odishabytes.com/who-owns-cloudtail-india-appario-retail-amazons-largest-sellers/ (Accessed 27 December 2020).

of such vendor are from the marketplace entity or its group companies."[18] While the intent is fair in allowing e-commerce entities to provide storage and logistics facility to sellers in a "non-discriminatory" manner, the above-stated clause seems dubious and should instead be replaced with a clause checking and prohibiting e-commerce companies from owning goods stored in warehouses (such as 'Amazon Fulfilment Centres') and seeing that goods stocked are not overwhelmingly from one seller, especially retailers in which the e-commerce entity has a substantial stake (such as Cloudtail or Appario).

E-commerce companies have succeeded/indulged in establishing complex company structures where the predominant seller (the so-called 'third party' seller) and other smaller sellers as well are influenced by the parent marketplace e-commerce company. While the FDI policy may not directly impinge on consumer interests, the basic principle of not allowing inventory-based multi-brand retail trading in e-commerce should be enforced in letter and spirit as there may be a chance of undue influence on prices of goods and services otherwise, thereby impacting consumer rights.

2.3 Regulator(s)

Akin to the legal framework, there is no one regulator of e-commerce due to its cross-cutting nature. After repeated emphasis on the lack of a regulatory body or generally a regulatory framework dealing with the sector, a 12-member e-commerce committee[19] under the CEO, NITI Aayog was constituted in August 2016, to look into various aspects of regulation and development of the sector as well as FDI. The government accepted the need for a separate regulator for e-commerce in 2018.[20] Since then, the encouraging development has been the setting up of a new regulator to protect the rights of consumers in general and in the e-commerce sector with the establishment of the 'Central Consumer Protection Authority' (CCPA) or the Central Authority. The CCPA became operational from July 2020 after appointments were made in the body by the Ministry of Consumer Affairs. The Central Authority has been empowered with an 'Investigation Wing' of its own, headed by a Director General, to conduct suo motu inquiry or investigation (on receipt of a complaint). It can also intervene in any proceedings before the District Commission, State Commission

[18] *Review of policy on Foreign Direct Investment (FDI) in e-commerce.* https://pib.gov.in/PressReleasePage.aspx?PRID=1557380#:~:text=Such%20an%20ownership%20or%20control,entity%20or%20its%20group%20companies (Accessed 30 December 2020).

[19] Committee to Review *E*-Commerce Rules consisting of representatives from Department of Industrial Policy and Promotion, Department of Economic Affairs, Department of Electronics and Information Technology, Department of Consumer Affairs and certain State Governments, namely Assam, Karnataka, Madhya Pradesh, Maharashtra, Odisha and Punjab.

[20] *Govt Sets Up A Panel Of Secretaries To Look Into Draft Ecommerce Policy*. https://inc42.com/buzz/govt-sets-up-a-panel-of-secretaries-to-look-into-draft-ecommerce-policy/ (Accessed 17 July 2018).

or the National Commission with respect to allegations of violation of consumer rights and unfair trade practice and initiate prosecution. The powers and functions are listed in detail in Section 18 of the Act. It is also empowered to take action against misleading advertisements and can direct a District Collector to investigate into complaints regarding violation of rights of consumers, unfair trade practices and misleading advertisements.

Another body to be set up is the 'Central Consumer Protection Council' or 'Central Council', under Section 3 of the new CPA, 2019 (which came into force in July 2020). It is an advisory body mandated to meet at least once a year. Its objective is to offer advice on the promotion and protection of consumers' rights under the CPA, 2019. Similar to the Central Council, each state has to establish a 'State Consumer Protection Council' under Section 6 of the 2019 Act. It is also an advisory body to protect consumer rights at the state level. In each district, the state government is mandated by the Act to establish the 'District Consumer Protection Council' by notification. It is also an advisory body mandated to meet at least twice a year to protect consumer rights at the local level. Aside from the Central Council and Central Authority, the draft National e-Commerce Policy talks about setting up a 'data authority'[21] details of which would be clear when the final policy document is brought out.

Apart from the regulation of matters related to consumer protection, several other bodies regulate different aspects of e-commerce. The Ministry of Commerce is responsible for looking into the affairs of the sector relating to FDI. The fraud/cheating aspect of e-commerce is governed by the Serious Fraud Investigation Office (SFIO) under the Ministry of Corporate Affairs which looks into complaints against fraudulent e-commerce companies under the relevant provisions of the IPC. Unfair or restrictive trade practices are dealt with by the three-tier quasi-judicial bodies of consumer courts. Antitrust or anti-competitive practices and predatory pricing by e-commerce companies are looked into by the Competition Commission of India (CCI) under the Competition Act 2002.[22] Data privacy and protection, which emerged as one of the core concerns and one of the foremost aspects of consumer interests protection in the online domain and had been neglected so far by the government, is proposed to be dealt with by the new Data Protection Bill, 2019.

[21] *Draft e-commerce policy: DPIIT to work on inter-ministerial inputs.* https://www.thehindubusinessline.com/economy/policy/draft-e-commerce-policy-dpiit-to-work-on-inter-ministerial-inputs/article32498194.ece (Accessed December 2020).

[22] For instance, the CCI in 2018 ruled that Flipkart and Amazon did not enjoy a 'dominant position' in the online marketplace and were not in contravention of Section 4 of the Act. https://economictimes.indiatimes.com/small-biz/startups/newsbuzz/flipkart-amazon-not-dominant-hence-not-in-contravention-of-competition-act-cci/articleshow/66534244.cms?from=mdr (Accessed 24 March 2020). However, the CCI ordered an investigation against unfair trade practices of Amazon and Flipkart in 2020 under Section 26 of Act, which was stayed by the Karnataka High Court and counter petitions have been filed by both parties as of February 2020. https://economictimes.indiatimes.com/small-biz/startups/newsbuzz/ktaka-hc-stays-cci-probe-order-against-amazon-flipkart/articleshow/74135156.cms?from=mdr (Accessed 24 March 2020).

There remains confusion regarding the regulation of e-pharmacies, which were to get regulated by the end of 2018[23] and are being regulated differently in different states.

2.4 Case Law Analysis

Case studies are important to go into the details and look at finer aspects of how consumer protection works on the ground. In the present context, these concern how consumer complaints regarding e-commerce are dealt with in consumer courts in the three-tier structure of 'consumer courts' those go by the names of 'District Consumer Disputes Redressal Commission', 'State Consumer Disputes Redressal Commission' and 'National Consumer Disputes Redressal Commission' corresponding to consumer courts at local/district, state and national levels, respectively. The case law approach has been pursued here to analyse the implications and workings of the consumer protection framework with respect to e-commerce in India. These case laws have been selected from the period when the e-commerce sector was a specific category with respect to consumer grievances up to 2017 and the subsequent developments in the cases cited up till 2020. In this sense, they can be treated as examining the consumer protection framework prior to July 2020, when the new Consumer Act, 2019 came into force.

Tables given under respective sections corresponding to cases that reached different Consumer Dispute Redressal Commissions present an outline of the case laws discussed in detail further below, in terms of the focus matter of litigation, Acts involved, the legal forum which resolved the cases and the final judgement.

3 District Consumer Disputes Redressal Commission (Earlier District Forum)

The CPA, 2019 which came into force on 20 July 2020 renamed the erstwhile District Consumer Forum as District Consumer Disputes Redressal Commission (District Commission in short) and raised its pecuniary jurisdiction up to Rs. 1 crore, apart from imparting other powers such as referring matters for 'mediation' and settlement among parties. Starting from an analysis of cases in the District Commission as consumer disputes reach the higher fora, namely, the State Consumer Disputes Redressal Commission and National Consumer Disputes Redressal Commission, only by way of appeal against the decision of the District Commission, it may be observed that the number of cases filed and the type of cases that arise vary in different geographical locations across India. Thus, the National Capital Territory

[23] *E-pharmacies may be regulated by December 2018.* https://www.livemint.com/Politics/psEfbkQxDphWg4F9cBtaiO/Epharmacies-may-be-regulated-by-Dec.html (Accessed 17 July 2018).

Table 1 Case examples, District Commission

S. No.	Forum	Nature of disputes	Name of case	Act	Case outcome
Case No. 1	District Forum, North West Delhi	Stay order demanding halting disconnection of electricity supply by a distribution company which takes payment electronically	*Kunal versus TPDDL and Ashraf Ali versus TPDDL*	CPA 1986	Stay order granted in favour of the appellant
Case No. 2	District Forum, North West Delhi	Cases against various educational institutions filed by students and parents	*(a) Jyoti Bhandari versus Resonance Education For Better Tomorrow* *(b) K. M. Pooja versus Indraprastha Institute For Higher Education and Others* *(c) Nitesh Gupta versus OPJS University* *(d) Raghav Ahuja versus Chandra Prabhu Jain College*	CPA 1986	(a) Order not finalised (b) Case not disposed of (c) Order not updated in database (d) Case is in hearing stage, next hearing in January 2021
Case No. 3	District Forum, North West Delhi	Deficiency in service by Spice Retail and its service centre	*Smita Bhatia versus Spice Retail Ltd.* and *Ankit Rana versus Spice Retail Ltd.*	CPA 1986	Spice Retail held guilty of unfair trade practice and deficiency in service

of Delhi has relatively many more cases than states like Bihar, Chhattisgarh, Assam and even Maharashtra at the level of district consumer courts (Table 1).

Case No. 1: Kunal versus TPDDL[24] and Ashraf Ali versus TPDDL,[25] North West Delhi District Consumer Court

In both instances, the consumer complaint was regarding the interim stay from the disconnection of electricity supply by the electricity distribution company and also

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[24] CC/1300/2015. https://cms.nic.in/ncdrcusersWeb/GetJudgement.do?method=GetJudgement&caseidin=8%2F7%2FCC%2F1300%2F2015&dtofhearing=2015-12-04 (Accessed 20 April 2020).

[25] CC/305/2017.

parties/complainants were directed by the court to submit a portion of the total immediately to the opposite party (OP) in a week and deposit the rest of the electricity bills on time henceforth. A stay order was passed stopping the disconnection of electricity.

Case No. 2: Cases Against Educational Institutions, North West Delhi District Consumer Court

There were cases even against the educational institution under the e-commerce category—Resonance Education for Better Tomorrow,[26] Indraprastha Institute for Higher Education,[27] OPJS University[28] and Chandra Prabhu Jain College[29]—which perhaps point to perhaps the indiscriminate mushrooming of private educational colleges/institutions of dubious quality. Although the case against the Indraprastha Institute dates back to 2017, it has not been disposed of and no final judgement is available. The case against Chandra Prabhu Jain College is in the hearing stage.[30]

The listing of cases against educational institutes under the 'e-commerce' category is interesting as further case search at the NCDRC Forum during the last 3 years does not list any educational institute in this category. Moreover, in a recent judgement, it has been ruled by the NCDRC that an 'Educational Institute'—public, private or vocational, barring coaching centres—is not a 'Service Provider' and as such does not fall within the purview of the CPA.[31] A clutch of petitions was clubbed together and the matter was decided keeping in view the Supreme Court's order in *P. T. Koshy & Anr. versus Ellen Charitable Trust & Ors.* (2012), which did not regard students as 'consumers' and education as a 'service'.

Case No. 3: Cases Against E-Commerce Companies Selling Electronic and Electrical Goods, North West Delhi District Consumer Court[32]

Two different consumers filed a complaint against an e-commerce company in the same court in the same year; in these two cases, Spice Retail Ltd.[33] was the OP. This company operates 'Saholic.com', an online shopping portal for electronic gadgets

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[26] Jyoti Bhandari versus Resonance Education for Better Tomorrow CC/539/2017. "Order Not Updated or not Finalized".

[27] K. M. Pooja versus Indraprastha Institute for Higher Education and Others. CC/457/2017.

[28] Nitesh Gupta versus OPJS University. CC/485/2017. "Order Not Updated or not Finalized".

[29] Raghav Ahuja versus Chandra Prabhu Jain College. CC/453/2017. Next hearing slated for 13 January 2021.

[30] While the cases against Resonance Education and OPJS University have been disposed of, judgement order is unfortunately not available in the database.

[31] Deepak Tyagi & 14 Ors. versus Shree Chhatrapati Shivaji Education Society & ANR. Case No. CC/2238/2018, NCDRC. Case disposed on 20 January 2020.

[32] Smita Bhatia versus Spice Retail Ltd. CC/293/2017 and Ankit Rana versus Spice Retail Ltd. (Authorised Service Center) CC/302/2017. Both cases disposed of but final judgement of latter not available in the database.

[33] Huge stake in the e-commerce arm of the company, viz., Spice Online Pvt. Ltd. was acquired by a Chinese company, which seems congruent with the idea that Chinese companies are far ahead in acquiring cutting-edge technology start-ups in Israel or profitable commercial start-ups in India.

like mobiles, laptops, tablets and accessories as well as ties up with e-commerce companies to sell its products. In the first case, the consumer purchased a certain Spice mobile handset through Snapdeal.com from a certain seller on the platform. As the mobile was defective, it was given for repair at the authorised service centre (OP 2). Despite repeated requests, it was not repaired/replaced, following which a complaint under Section 12 of the CPA, 1986 was filed. The consumer court held Spice Retail guilty of unfair trade practice and deficiency in service. The outcome of the second case is not available in the database,[34] though the case is listed.

These cases represent the marriage of offline and online retail which presents a problem typical with e-commerce where accountability is avoided by both. Considering further consumer complaints and cases related to electronic goods or electrical appliances, it seems that consumers face a lot of problems regarding such goods bought through online means. This is clear from the data—out of a total of 131 cases under 'e-commerce' category in 2017 in the same court (North West Delhi District Consumer Court), most cases related to such goods delivered by the e-commerce platform.[35]

These instances reveal as to how in different parts of Delhi there are differences in nature and volume of complaints, seemingly very less or negligible in the richer areas as compared to other districts. This may indicate that these regions do not go for online ordering and rely on offline retail stores/malls, etc., or that the product/service delivered here are of better quality that does not generate complaints in the first place or if there are any, these are resolved promptly by the Consumer Care which does not necessitate resorting to Consumer Forums.

4 State Consumer Disputes Redressal Commission (SCDRC)

The SCDRCs form the second tier of the consumer court architecture in India. As per the latest Consumer Law, 2019, their pecuniary jurisdiction has been extended to up to Rs. 100 million (Table 2).

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[34]Confonet database lists cases against e-commerce entities at district, state and national consumer fora.

[35]Electronics Shoppe (Naveen Electronics), Spice Retail Ltd., IFB Industries Ltd. (manufacturer of engineering goods and domestic appliances), Toshiba India Pvt. Ltd. & ANR. Akshal Electronics, Anugrah Electronics & Appliances, Satyam Electronics (Dealer), Saragam India Electronics Pvt. Ltd., O General Air Conditioner, Plaza Telecom (mobile phone dealer), Hariom Retail Pvt. Ltd., Prakash Refrigeration and Electrical, Guru Kripa Enterprises Apps Daily, Max HD World, LG Electronics India Pvt. Ltd., Air Chill Electronics, M/S Juneja Electricals & ORS., Akshal Electronics, Samsung India Electronics Pvt. Ltd., Videocon Industries Ltd., Croma, Vardhaman Electronics & ANR. and Godrej Service Centre.

Table 2 Case examples, SCDRC

S. No.	Forum	Nature of disputes	Name of case	Act	Case outcome
Case No. 1	SCDRC, Andhra Pradesh	Appellant, an e-commerce entrepreneur, is a ‘consumer’ of owner franchise or not	*M/S. S. Kumars Online Ltd., And … versus C. Ravi Kumar Medak*	Section 2(i)(o) of the CPA, 1986	Respondent, not a consumer as per Act
Case No. 2	SCDRC, TRIPURA	Liability of online platform or e-commerce company	*Amazon Seller Services Private Limited (ASSPL) versus Dulal Ray Karmakar and Ors*	Section 2 of the CPA	Ex-parte order of District Forum set aside, it agreed that the Forum had served notice to the wrong party and gave chance to file evidence afresh
Case No. 3	SCDRC, Chandigarh	Liability of online platform or e-commerce company when it’s the third party between online buyer and seller	*Amazon Seller Services Private Limited versus Gopal Krishan and Ors*	CPA 1986	The e-commerce company is ‘vicariously liable’ along with the manufacturer/seller for defective goods. Inordinate delay amounts to a ‘deficiency of service’

Case No. 1: ***M/S. S. Kumars Online Ltd., And … versus C. Ravi Kumar Medak*****, Andhra Pradesh SCDRC**[36]

Facts of the Case: Here, an educated unemployed youth had sought to establish and maintain a network of computers through Very Small Aperture Terminals (VSATs), to provide services to customers by owning a franchisee. The appellant party is the OP at the District Forum which has appealed against the decision of the District Forum, Medak, in the then united Andhra Pradesh. The services that were to be provided by the appellant (S. Kumars Online) to the OP (Ravi Medak) were not provided and the latter demanded a refund with interest and other charges from the owner of the franchisee. Both parties had entered into a Franchisee Agreement where Ravi Medak was to sell services to customers after getting access to the VSAT network of the owner company.

Ruling of District Forum: The District Forum ruled that the company did not provide equipment and it amounted to 'deficiency of service'. Averment by the District Forum was that the service was deficient as the violation of contract/agreement was at the stage of supply of equipment and not a deficiency in activation of service.

The Argument of Appellant (at SCDRC): At the state consumer court level, the appellant argued that the District Forum had no jurisdiction (it was limited to Mumbai courts), that the complainant was not a consumer under Section 2 of CPA but a franchisee, that there was no hiring of services under Section 2(i)(o) of the CPA by the complainant; instead the appellant hired his services to expand their business, i.e., they were the consumers, not complainants. Also, they paid installments and in between the government policy for VSATs changed, due to which supplying VSATs was beyond their control along with pointing out as to how other franchisees were operating without the VSATs, so there was no 'negligence'. It prayed for dismissal of complaints with costs on the ground that the District Forum made an error of law.

The Argument of the Respondent: Assuming the agreement was a franchise agreement only, it applies only to *supply of service* (connecting Internet through an appellant network), not the supply of goods (VSAT equipment). This distinction has not been noticed so far by any State or National Commission and that since under Article 141 only judgements of the Supreme Court and High Courts are binding precedents to the lower courts and tribunals, the previous decisions of NCDRC should not bind other SCDRCs.

Observation of the Court: It did not agree with the contention that the appellant provided the complainant with an alternative mode of connectivity as there was no evidence for the same. It agreed with the appellant that the complainant was not a consumer. The Andhra SCDRC went by previous cases decided by the NCDRC[37] The National consumer forum had held rights of the franchise holder does not mean

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[36]*M/S. S. Kumars Online Ltd., And … versus C. Ravi Kumar Medak*, Andhra Pradesh, SCDRC F.A. 1743/2005.

[37]*General Manager, Madras Telephones & Ors. versus R. Kannan* (1994), *Prof. P. Narayanankutty versus Uptron India Ltd. & Ors., I* (1996).

s/he hires service of franchise grantor, instead the franchise holder renders service to the grantor of the franchise holder who is rendering service to the grantor of the franchise. In another case before NCDRC,[38] where there was a breach of contract by an oil selling company to appoint a particular person as a selling agent; the court observed that remedy lied in civil court not consumer court as the contract was a commercial contract and the person was not a 'consumer' as he purchased goods where *no defects* are alleged by him.

Thus, the decision of the District Forum was set aside and appeal allowed, but without any costs.

Case No. 2: *Amazon Seller Services Private Limited (ASSPL) versus Dulal Ray Karmakar and Ors.*, Tripura SCDRC[39]

Facts of the Case: An appeal had been filed by Amazon Seller against the order of the District Forum in favour of the respondent. Respondent No. 1 (D. R. Karmakar) ordered one kitchen chimney via online shopping from Amazon.in website but the product shipped by the seller (Hindustan Trading Company) via Blue Dart (Respondent No. 2) was received in broken condition upon which he immediately informed the same to Amazon. Despite immediately informing the appellant, no suitable reply was received after which a complaint was filed and the District Forum gave the order in favour of the complainant.

The Ruling of District Forum: It passed an order against 'Amazon Development Centre (India) Private Limited'.

The Argument of the Appellant (Amazon Seller): The complainant filed a complaint intending to harass the appellant and for extorting money. The District Forum had erroneously passed judgement against Amazon, without hearing its argument and its side of the case. Also, Amazon does not sell any product directly but only acts as a technology platform/facilitator/online marketplace, and thus it is *not responsible for any product and listings* on its website *nor is it involved in the transactions* between customers and third-party sellers.

The Argument of the Respondent (Dulal Ray Karmakar and Ors): With the impugned judgement in favour of Respondent No. 1 (Karmakar), he appeared before the SCDRC in person and stated the following:

(a) He had read the terms and conditions on the website before placing the order for the kitchen chimney.
(b) He paid money through Amazon.in website.
(c) He made various correspondences with Amazon and got no response.
(d) Even if Amazon Development Centre Private Limited who is not a direct party to the case received the complaint, it could have very well communicated to the real party—ASSPL, but it did not and took the plea of ignorance.
(e) He asked for dismissal of the appeal.

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[38]Mysore Sales International Ltd. versus M.N. Misra, II (1996).

[39]*Amazon Seller Services Private Limited (ASSPL) versus Dulal Ray Karmakar and Ors.*, Tripura SCDRC, III(2016)CPJ6 (Trip.).

The Judgement of the District Forum: It ordered Amazon to replace the damaged chimney with a new one or refund the full price of the chimney plus compensation cost for causing mental agony and harassment (Rs. 5000) and the cost of litigation (Rs. 2000) to the complainant, failing which interest has to be paid until the payment was made.

Observation of SCDRC/State Consumer Court: The court observed that point of contention was if the District Forum was justified in allowing the complaint in a one-sided manner when the other party could not defend and if the judgement of District Forum was liable to be set aside. To the court, Amazon appeared to be a mere mediator or facilitator with Hindustan Trading Company being the seller and, thus, a necessary party to the complainant. Also, ASSPL is a necessary party. The order passed by the District Forum was not 'proper, legal and justified' and so it was set aside by the Court to send back the case to the forum, with some directions, to be decided afresh.

Case No. 3: *Amazon Seller Services Private Limited versus Gopal Krishan and Ors.*, Chandigarh SCDRC[40]

Facts of the Case: In this case too, Amazon India is the appellant but this time, not Amazon Development Centre (India) Private Limited[41] but ASSPL. Here, the respondent purchased a 'Xiaomi Redmi Note 3,'[42] which was found defective after purchase. As evidence, a copy of the bill was attached by the consumer and also the complainant filed a rejoinder to the replies filed by all the six OPs,[43] and a complaint was filed at the Forum only after all the OPs did not respond satisfactorily.[44] It was for a refund of paid amount *and* compensation for mental and physical harassment and legal expenses.

While last time the appeal was to *stay* the order of the Forum, this time it seems the learning has been fast and Amazon filed an appeal against the District Forum's order to *allow* a complaint of the complainant (Gopal Krishan). To reclaim the amount from Amazon, Krishan was supposed to submit a 'dead on arrival report' but he could not get it from OP Nos. 1 and 2 (Xiaomi). But after getting a legal notice, Xiaomi admitted that the mobile was received for repair and after the repair, it *was* sent to the complainant but he failed to collect the same.

The Ruling of District Forum: It admitted the complaint against ASSPL and other OPs after going into the facts of the complaint.

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[40]*Amazon Seller Services Private Limited versus Gopal Krishan and Ors*, Chandigarh SCDRC MANU/SF/0038/2017 (or First Appeal No. A/27/2017).

[41]That is Amazon.in; ASSPL is Amazon Seller Services Private Limited.

[42]Worth Rs. 9998, similar to the last case which was around Rs. 10,000.

[43]It is to be noted that despite case number (A/27/2017), specific names of all respondents and, most importantly, all OPs are not available in the database of Chandigarh Forum after search on Confonet as on 17 September 2017. But from a reading of the judgement, it appears that OP No. 1 is a Customer Care Executive of Xiaomi Company; OP No. 2 is the owner of the premises from which the mobile was to be collected, again related to Xiaomi; it is not clear who is OP No. 3, OP No. 4 and OP No. 5; OP No. 6 is ASSPL.

[44]He did not get the mobile repaired or get any response from Amazon from where he purchased the set.

The Argument of Appellants: Here as well, Amazon applied/argued for the same defence that it was ‘merely a facilitator’ and not responsible for the behaviour of the seller and consumers and, thus, it had no liability. Further, it appeared that there was no deficiency on the part of it so the complaint against OP No. 6 was dismissed.

Observation of SCDRC: It noted that the OP did not send the mobile after the repair and that handset had major defects,[45] and acknowledged that the mobile was repaired and intimated to the complainant too, but he had filed a complaint before the District Forum before getting the notice about the repair. Most importantly, its judgement stating that ‘inordinate delay’ on the part of seller and facilitator amounts to ‘deficiency in service,’[46] that there *was* a manufacturing defect in the mobile at the time of purchase itself and on these grounds, provided the consumer relief.[47] It ruled that an agent who sells a defective product, shall be “vicariously liable” along with the manufacturer of the product, citing an NCDRC judgement of March 2016 (while delivering judgement in February 2017).[48] Stating that appellants could not convince the court to merit interference in proceeding before the District Forum, it dismissed the appeal and upheld the order of the Forum.

The difference in approaches to resolving consumer disputes among state consumer fora in different regions of the country is obvious and this raises questions on the uniformity of the approach to dealing with consumer disputes in e-commerce. Also, an important point is how accessing the database is essential to analyse the case law at the levels of the district, state and national consumer courts. However, it is found that much of the data, especially relating to recent cases where the courts have concluded, are also not available on the e-commerce portal, which requires reform in data maintenance for the benefit of other consumers, who can see what kind of evidence is needed, which forum is appropriate (consumer courts/tribunals for unfair trade practice, etc.) as well as a better understanding of consumer rights in e-commerce in India.

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[45]Where it even reproduced a portion from an affidavit filed by the Deputy Manager (Legal) HCL Services Ltd. to highlight the same.

[46]“…he lost faith in OPs and filed a consumer complaint. The service rendered was absolutely poor and pathetic”.

[47]“The inordinate delay on the part of the OPs in repairing of the telephone tantamount to a deficiency in service on their part. The complainant has been deprived of the service of his mobile handset for which he has already paid. The OPs cannot be permitted to hold the complainant at ransom by their callous attitude in attending the problem of the consumer. It is further found that the motherboard, which is the backbone of the mobile handset in question, has been replaced by the OPs after finding it defective. Under these circumstances, it proves beyond doubt that the mobile handset, which the complainant had purchased, was having a manufacturing defect on the date of its purchase.”

[48]“An agent, who sells a product, is duty-bound to ensure its quality, and if the product is found defective, the agent shall be vicariously liable for the loss caused to the purchaser, along with the manufacturer of the product”. It was so held by the Hon’ble National Consumer Disputes Redressal Commission, New Delhi, in the case titled as *Emerging India Real Assets Pvt. Ltd. & Anr. versus Kamer Chand & Anr.* Revision Petition No. 765 of 2016 decided on 30.3.2016.

5 National Consumer Disputes Redressal Commission (NCDRC)

The NCDRC remains the top-most tier of consumer courts. It exercises administrative power over the State Commission and under the new CPA, 2019, its pecuniary jurisdiction extends to matters above Rs. 100 million (Table 3).

Case No. 1: *Mallika Verma versus Union of India* (2015)[49]

Facts of the Case: A class of consumer cases deals with cases of consumers of goods/services of bigger e-commerce companies that are themselves e-commerce businesses and, thus, not a 'consumer' under the consumer protection law. This was the case in Mallika Verma versus Union of India (2015), where the appellant Mallika Verma, an e-commerce entrepreneur, filed an 'instant complaint' against Union of India, before the NCDRC. She had availed of VVP and EVPP[50] services of India Post.

Appellant's Argument: An economic loss was suffered by the complainant, and the aggrieved was a consumer as per the CPA as she had availed of the courier service on payment of consideration. This was on grounds of deficiency in courier service by India Post[51] which hampered her e-commerce business (M/s. D. D. Impex).

OP's Argument: Interestingly, in this case, unlike other cases that involve private parties, the OP, the Postal Department, Government of India, did not have to argue anything in defence as the court gave a very short and clear judgement against the complainant. Also, there was counsel from its side to argue in the court.

Observation of the Court: The court *prima facie* seeing that the complainant does not come under the definition of 'consumer' heard arguments on the *maintainability* of the complaint. The court observed that the VPP/EVPP service, as availed for E-sale of goods and services, was for cash on delivery, not for own personal consumption as a consumer under Section 2 of CPA. The consumer complaint could not be maintained and was rejected 'undisputedly'[52] stating that the appellant can seek redressal at an appropriate forum, though not naming the same.

Case No. 2: Paras Jain versus Amazon Seller Services Pvt. Ltd.[53]

Facts of the Case: This is an interesting and important case where the appellant dragged Amazon to court over '*false and misleading*' Easy Return Policy and filed

[49] 2015 SCC Online NCDRC 950.

[50] Value payable system by India Post is designed to meet the requirements of persons who wish to pay for articles sent to them at the time of receipt of the articles and for those traders and others who wish to recover the value of article supplied by them through the agency of the Post Office, akin to a cash-on-delivery service.

[51] By tampering with packets and misappropriating them.

[52] 2015, SCC Online NCDRC 950.

[53] This is the only case shown under the 'e-commerce' category type case under NCDRC as of 17 July 2017. Paras Jain versus Amazon Seller Services Pvt. Ltd. CC/930/2017.

Table 3 Case examples, NCDRC

S. No.	Forum	Nature of disputes	Name of case	Act	Case outcome
Case No. 1	NCDRC	Deficiency of service by India Post	*Mallika Verma versus Union of India (2015)*	Section 2, CPA	Consumer complaint rejected undisputedly; complainant not a 'consumer'
Case No. 2	NCDRC	False/misleading advertisement—class-action suit	*Paras Jain versus Amazon Seller Services Pvt. Ltd.*	Section 12 CPA (Consumer Protection Act, 1986. https://ncdrc.nic.in/bare_acts/Consumer%20Protection%20Act-1986.html (Accessed 19 March 2020)), ASCI	Judgement reserved

in his capacity as a complainant on behalf of various consumers.[54] The case had been filed on 24 April 2017, with subsequent hearings on 8 May and 23 May. All hearings in the case have been concluded and the judgement had been reserved on 15 September 2020. The case primarily deals with false/misleading advertisements. This is a subject matter under the Advertisement Standards Council of India but it also falls under ambit of other regulators[55] and multiple statutes.[56]

The Argument of the Appellant: From the available records of hearings, multiple hearings were held wherein the complainant claimed punitive damages under Section 12 (1) (C) of the CPA. He submitted many rejoinders and applications in reply to documents submitted by Opposite Party's counsels who argued that the court did not have pecuniary jurisdiction over the case. The Appellant also submitted documents as to treat the case as class suit on behalf of many consumers. The complainant also averred if there is a duty to disclose a material fact but it is not disclosed, it also amounts to a 'false or misleading representation'.

Observation of Court: In the first hearing, the court asked the complainant to submit information about the statutory provisions concerning the Advertising Standards Council of India (ASCI) under which it could investigate into the issue of misleading advertisement by Amazon, which was allowed to be submitted on the day of the second hearing. In the third hearing, the court issued a show-cause notice to Amazon as to why the complaint should not be treated as a complaint under Section 12 (1) (C) of CPA.[57] In the last hearing upon which the judgement was reserved, the OP argued that the Commission (NCDRC) had no pecuniary jurisdiction to entertain the The outcome of the case will be important to watch as it will have wider repercussions on other e-commerce companies' advertisement policies, touching upon refund and exchange policies as well.

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[54] https://barandbench.com/amazon-ncdrc-easy-return/ (Accessed 18 April 2020).

[55] IRDA, TRIA, SEBI, RBI and MCI. Consumer Education Monograph Series-2 Misleading Advertisements and Consumer Centre for Consumer Studies, IIPA. https://consumeraffairs.nic.in/WriteReadData/userfiles/file/misleading_advertiesment_and_consumer%20(1).pdf (Accessed September 15, 2018) and https://consumeraffairs.nic.in/sites/default/files/file-uploads/misleading-advertisements/misleading_advertiesment_and_consumer%20%281%29_0.pdf (Accessed 18 April 2020).

[56] Drugs and Magic Remedies (Objectionable Advertisements) Act; Cable Television Network Regulation Act and Rules; Food Safety and Standards Act, 2006; Drugs and Cosmetics Act, 1940; Bureau of Indian Standards Act, 1986; Infant Milk Substitute, Feeding Bottles and Infant Foods (Regulation of Production, Supply and Distribution) Act, 1992 and Infant Milk Substitute, Feeding Bottles and Infant Foods (Regulation of Production, Supply and Distribution) Amendment Act, 2002; and Cigarettes and other Tobacco Products (Prohibition of Advertisement and Regulation of Trade and Commerce, Production, Supply and Distribution) Act, 2003.

[57] 'Class Action Suits' under CPA can be filed for the benefit of all the consumers, as per the judgement of NCDRC in *Ambrish Kumar Shukla & 21 others versus Ferrous Infrastructure Private Ltd.* 2016. https://www.livelaw.in/class-action-suits-under-consumer-protection-act-can-be-filed-for-the-benefit-of-all-the-consumers-ncdrc-fb/ (Accessed 19 July 2017).

6 Competition Commission of India

Both statutes—the Competition Act, 2002 and the CPA, 1986—deal with unfair trade practices. Consumers approach both forums but it is interesting to note that while the CCI is interested in investigating and looking into allegations of collusion/monopolistic tendencies/cartelisation in the market to hold charges of unfair trade practice against the defendant party, under Section 3 of the Competition Act, 2002,[58] it is not the same case under CPA. In the latter, unfair trade practices as dealt under Section 2(1)(r) are entirely different—misleading or false promises/warranty/guarantee/advertisement on any good/service offered, withholding information about gift/prize/lottery, or giving misleading facts disparaging trade, good or service of any person. Consumers approaching an unsuitable or inappropriate forum to get remedy against them increase their costs of litigation and it becomes a hassle to get a remedy (Table 4).

Table 4 Case examples, others

S. No.	Forum	Nature of disputes	Name of case	Act	Case outcome
Case No. 1	CCI	Alleged anti-competitive practices by Snapdeal and SanDisk	*Mr. Ashish Ahuja versus Snapdeal.Com*	Sections 3, 4 and 19(1)(a) of the Competition Act, 2002	Online and offline markets are not separate but part of the same relevant market for a product. Respondents do not violate the Act
Case No. 2	CCI	Illegal and unfair business practices	*Deepak Verma versus Clues Network Pvt. Ltd. and 22 Ors*	Section 19(1)(a) and 33 of the Competition Act, 2002	Matter concerns deficiency in services and defects in goods rather than competition issue. Broadly, Sections 3 and 4 are not violated by OPs
Case No. 3	CCI	Unfair business practices by Flipkart, Snapdeal, Myntra, Amazon and Jabong	*Mohit Manglani versus Flipkart India Private Limited and Ors*	Sections 3, 4 and 19 of the Competition Act, 2002	None of the Ops enjoy a dominant market share, do not violate Sections 3 and 4 of the Act

[58] Anticompetitive Agreements.

Case No. 1: Mr. Ashish Ahuja versus Snapdeal.Com, 2014[59]

Facts of the Case: The informant Mr. Ahuja entered into an online agreement with Snapdeal in 2013 for the sale of goods through the online website portal Snapdeal.com. Following the said agreement, the informant started to sell various products like pen drives, hard discs, laptops, etc., through the web portal. However, after the stopping of sale of its products by Snapdeal without notice, because products of the 'SanDisk' brand can be sold only by the distributors of one of the four authorised national dealers of SanDisk, the present information was filed by him under Section 19(1)(a) of the Competition Act, 2002 against Snapdeal[60] and SanDisk Corporation,[61] alleging anti-competitive practices in contravention of the provisions of Sections 3 and 4 of the Competition Act.

The Argument of the Informant: He had entered into an online agreement with Snapdeal and as such the company should have allowed him to sell the products on its website which had been sourced from offline/wholesale markets. Not allowing him to do so after receiving a request from the SanDisk Corporation of the USA amounts to a monopolisation of the online markets of portable consumer storage devices[62]; this is unlawful under Section 3 of the Act. He prayed the Commission for an investigation into the matter and to direct Snapdeal to allow him to sell his products also because it was allowing other resellers who were not the authorised dealers of SanDisk.

The Argument of Respondents: OP No. 2, SanDisk, argued that it had a limited list of four authorised bona fide national distributors via whom all SanDisk products were imported and sold in India; there was only one distributing channel and doing otherwise would impact the brand quality and image.

Commission's Observation: The CCI observed that both the online and offline markets for such consumer storage devices were not two different product markets but different media of the same market. As consumers had ample choice to shift to online or offline distribution channels, depending on the price, there was no attempt at monopolisation. Also, the informant had no evidence to show his products did not belong to one of the four authorised distributors, which does not violate Section 3 of the Act. Also, the conduct of SanDisk cannot be said to violate Section 4 of the Act. Based on these facts, it ordered to close the information as per Section 26(2) of the Act.

Case No. 2: Mr. Deepak Verma versus Clues Network Pvt. Ltd. and 22 Ors[63]

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[59] https://www.cci.gov.in/sites/default/files/172014.pdf (Accessed 15 April 2020).

[60] Through Mr. Kunal Bahl, CEO as OP No. 1, Snapdeal.

[61] Through Mr. Rajesh Gupta, Country Manager, Gurgaon as OP No. 2, SanDisk.

[62] Which includes pen drives, SD cards, etc. of various brands, one of which is the OP No. 2, SanDisk.

[63] 2016 SCC OnLine CCI 42.

Facts of the Case: This case is particularly interesting as all pertinent issues of consumer rights in e-commerce are brought into focus by the concerned informant but before a wrong forum. Another aspect is the sheer number of OPs, all of the e-commerce companies or sellers registered on e-commerce websites, including the big ones like Amazon Seller Service Pvt. Ltd., Cloudtail India Pvt. Ltd., Jasper Infotech Pvt. Ltd.[64] and Yepme as well as lesser-known companies like Clues Network Pvt. Ltd., R. S. Fashion Pinnacle, Fashion Lounge, Kitchengiftonline.com, etc.

The information was filed under Section 19(1)(a) of the Competition Act, 2002 by Mr. Deepak Verma alleging these companies of illegal and unfair business practices on grounds of non-delivery of the product despite successful online payment, poor quality, overcharging, cancellation of order due to incomplete address, not generating VAT invoice of items sold, item sold without indicating MRP, manufacturing and expiry date and fake VAT invoice.

The Argument of the Informant: The informant prayed for compensation of Rs. 50 lakh for financial loss and mental harassment, correction of a deficiency in goods and services and discontinuance of unfair and restrictive trade practices by all 23 parties from the CCI. He also prayed for interim relief under Section 33 of the Act, requesting compensation for expenditures like filing information with the Commission, grievance documentation, etc.

Commission's Observation: It observed that the informant had made allegations which primarily concerned deficiency in services and defects in goods[65] rather than competition issue which, thus, did not merit inquiry under the Competition Act. Still, the court went ahead to analyse the matter broadly under Sections 3 and 4 of the Act. It cited the cases of *Mohit Manglani* versus *Flipkart India Private Limited, Bharti Retail Limited and Future Retail Limited,* and *Ashish Ahuja versus Snapdeal.com* where CCI had observed, respectively: "Irrespective of whether we consider the e-portal market as a separate relevant product market or as a sub-segment of the market for distribution, none of the OPs seems to be individually dominant", "consumers have ample choice in terms of the number of options available to them" in the online retail market and "two markets are only two different channels of distribution and are not two different relevant markets", concluding that no contravention of the provisions of either Section 3 or 4 of the Act has been made by the OPs.

Case No. 3: Mohit Manglani versus Flipkart India Private Limited and Ors. (23 April 2015—CCI)

Facts of the Case: Violation of Section 4 of Competition Act was alleged by the informant against e-commerce portals/companies like Flipkart, M/s. Jasper Infotech

[64] Whose subsidiary is Freecharge, a popular recharge site.

[65] As per the CCI, the issues raised were as follows: items delivered by OPs were either pirated or defective or of low quality; non-delivery of the product(s) despite successful online payment; some of the bills received by the informant were fake VAT invoices; the informant received different items than what he ordered for and sellers had charged higher price.

Private Limited, M/s. Xerion Retail Private Limited, M/s. Amazon Seller Services Private Limited, M/s. Vector E-commerce Private Limited and others.

The Argument of the Informant: He alleged that e-commerce companies and sellers were engaging in various unfair and restrictive practices. First, they were entering into 'exclusive agreements' to sell selected products on specific portals to the exclusion of other online and physical channels, which made product price, delivery terms and conditions, etc., non-negotiable for a consumer. Second, the supply of products was controlled by secret agreements between sellers and e-commerce companies which created an appearance of scarcity and a dominant position in the market for those goods.[66]

The Argument of Respondents: The e-commerce companies are mere platforms bringing the two parties together (third party platforms). The contention of the informant that OPs are creating an exclusivist market is fallacious as it does not rely on actual agreements as a manufacturer is free to sell products on its website and physical stores. The exclusivity, if any, is limited to online portals only and does not violate Section 3(4) of the Act as there is no 'appreciable adverse effect on competition' (AAEC) in the market due to ample competition in the retail market and even in the e-portal market.

Commission's Observation: The CCI observed that no single OP enjoyed a dominant share to cause any competition concern based on the factors laid down in Section 19(3) of the Act like "creation of barriers to new entrants in the market; driving existing competitors out of the market; foreclosure of competition by hindering entry into the market; accrual of benefits to consumers; improvements in production or distribution of goods or provision of services; and promotion of technical, scientific and economic development through production or distribution of goods or provision of services to assess the effect of such exclusive arrangement between manufacturers and e-portals."[67] Secondly, even after assuming that there is a pre-existing/secret agreement/arrangement between the OPs, based on the touchstones of the above factors, the Commission concluded that such agreements did not have the effect of being anti-competitive as there were many online portals and no single OP seemed to enjoy dominant market share. Customers can compare prices with new e-portals entering the market every year and more convenience due to door-step delivery of goods.

[66]For example, the informant argues how Flipkart had the exclusive rights to sell the book *Half Girlfriend* online.

[67]Competition Commission of India Case No. 80 of 2014, page no. 8 from https://www.cci.gov.in/sites/default/files/802014.pdf (Accessed 15 September 2019).

7 Conclusion

Very few consumer complaints reach consumer courts given the fact that thousands of complaints across various formal and informal channels lie unaddressed. Nevertheless, for those cases which reach courts, the right to redressal is exercised as the chain of consumer courts offers a cheap and fast way of consumer grievance redressal, with litigants being refunded the cost of litigation in all cases where the consumer courts deem fit. Still, the enforcement of the orders of district consumer courts remains a problem as most often big e-commerce companies almost invariably do not implement orders of district courts despite receiving execution petition, hiding behind the technicality of wrong notices or stating how their very nature as a third party platform frees them of any involvement in the contract between sellers and buyers.

A few cases reveal the confusion among consumers as to which appropriate forum to approach for redressal of specific grievances. Also, a difference in the approach of consumer courts when dealing with government agencies as respondent versus private companies can be seen in some cases.[68] Further, it appears that for district forums, e-commerce cases are unfamiliar which leads to an error of law. The complex corporate arrangements e-commerce party enters into lead to confusion, further appeals and longer litigations, especially at the local district level. Conflicting arguments are presented by big e-commerce companies and separate corporate entities (such as Amazon.in versus ASSPL) are used by them not to execute the District Forum's order.

There also seems to be a difference in the capacity of individual consumers as well as the consumer fora across states to adequately deal with consumer issues. While a consumer in Chandigarh was able to file a rejoinder to the replies of six OPs apart from the evidence of a bill, a consumer in Tripura at the same forum of SCDRC was not able to file it, suggesting that consumers in far-flung areas need to be more aware. Similarly, an analysis of cases of the same nature at different SCDRCs points to an interesting fact that the difference lies not just in interpretation but capabilities of different SCDRCs. As far as the overall legal-policy framework of consumer protection in e-commerce is concerned, one could observe policy flip-flops caused due to political factors and lack of knowledge about finer aspects. This results in rules or policy being framed without stable foundations leading to withdrawals or modifications.

Possible solutions to resolving consumer issues in e-commerce include, firstly, strengthening the legal dispute resolution mechanisms by increasing the strength and making the infrastructure of consumer courts better; and, secondly, strengthening alternative dispute resolution mechanisms to handle the enormous volume of consumer complaints in e-commerce. In this regard, the new provisions introduced by the new CPA, 2019 on 'mediation', electronic filing of complaints and alternative dispute resolution are commendable initiatives. How these measures, given

[68]*Mallika Verma versus Union of India* (2015); *Gaurav Chaudhary versus Blue Dart Express Limited (2016).*

legal recognition under the new law, pan out in the future must be carefully studied along with a comparative study of the performance of consumer courts before and after the enforcement of the new law mainly to see whether the performance of consumer courts has improved over time. Despite all forms of alternative settlement of disputes, the protection of core consumer rights depends much on robust consumer courts which are still our best bet to strengthening and protecting consumer rights in e-commerce as well as other sectors in India.

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Chapter 10
Mediating Financial Inclusion Through Digital Technology: A Critique

Tara Nair

1 Introduction

Digital technology has transformed the financial service sector in revolutionary ways. All facets of financial service provision and consumption have been affected by disruptive innovations, making it difficult to systematically assess their actual impact and develop appropriate regulatory responses. In India, the great push for the adoption of digital technology in the financial services sphere coincided with the launching of the ambitious project of Aadhaar in 2010 and the accelerated diffusion of smartphones and internet connectivity. The second wave of financial inclusion that started around 2015 leveraged the Aadhaar infrastructure to open bank accounts (under a scheme called Jan Dhan Yojana or JDY) on a mass scale and make all government benefit payments digital and direct-to-account. The financial inclusion programme currently rides on what is known as the JAM (Jan Dhan-Aadhaar-Mobile) trinity.

In this paper, we will trace the trajectory of the financial inclusion initiatives in India over the decade 2010–19 in an attempt to understand how digital technology mediates social policies in an economy straddled with deeply embedded structural–institutional maladies. This paper first describes the digital technology-driven financial inclusion measures as the culmination of a long-evolving programme to build an inclusive financial system. We will then explore the architecture of digital finance in India and its implications for financial inclusion, keeping the social banking experience of India in the 1970s and 1980s as a point of reference. We end the paper with some questions and concerns for the ongoing discourse on digital inclusion.

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_10

2 The Financial Inclusion Discourse

Even before the term financial inclusion became a buzz word in the development literature, banks and financial institutions were very much part of the social policy architecture in India. Recognising the inherent tendency of financial institutions to grow biased to profitable sectors such as trade and large urban industries, the state and the central bank introduced several measures since the late 1960s to urge them to expand reach to rural areas. For instance, the Reserve Bank of India (RBI), in its credit policy statement of 1967–68 urged commercial banks to augment credit flow to sectors such as agriculture, small-scale industries and exports. On the heels of this statement was enacted the Banking Companies Acquisition and Transfer of Undertakings Act 1969, by which 14 banking undertakings whose total deposits exceeded Rs. 500 million were nationalised 'to serve better the needs of the development of the economy in conformity with national policy and objectives'. More than half of all the bank branches in the country at the time were impacted by this measure (Cole 2009). It may be noted that the 1960s were difficult years for India politically and economically as it went through the pangs of two wars, successive droughts, and low economic growth (Reddy 2018). Bank nationalisation was thought of by some as a step in the direction of ensuring optimal distribution of financial resources in an economy saddled with imperfect credit markets (Raj 1974).[1]

The formalisation of the concept of and guidelines for priority sector advances (PSA) in 1972 was a critical regulatory intervention that followed bank nationalisation. This formed the crux of the much-debated directed (targeted) credit programmes that formed the key elements of the interventionist approach pursued in the 1970s and 1980s to reinforce the development commitment of banks. Through this arrangement, financial resources have been channelised to designated priority sectors,[2] geographies and population segments that are seen to be weaker or marginalised socially, or unappealing to investors for their riskiness (Kohli 1997).

The decade also witnessed some institutional innovations to promote overall rural development like area approach to rural banking and the scheme to designate lead banks to coordinate district level banking activities (Nair 2016). Another novel approach was introduced in the late 1980s known as the Service Area Approach (SSA) was introduced in 1989, wherein each bank branch in the rural and semi-urban area is designated to serve the bank credit needs of a select area comprising of a cluster of villages. An elaborate institutional architecture was crafted in the subsequent two decades to expand the reach of banks to rural areas and small production sectors. While rural branches of commercial banks, cooperative societies/banks and regional rural banks (RRBs) (set up through legislation in 1976) were the principal channels of expansion, directed credit to distinct population segments/priority sectors and subsidised interest rates were the major instruments to redistribute financial

[1]The decision to nationalise banks was fiercely contested by some sections of political leaders and economists. See Reddy (2018) and Torri (1975).

[2]https://rbidocs.rbi.org.in/rdocs/Content/PDFs/77070.pdf.

resources. Further, specialised apex institutions such as National Bank for Agriculture and Rural Development (NABARD) and Small Industries Development Bank of India (SIDBI) were set up (in 1982 and 1990, respectively) to provide sectoral leadership and financial support. 'These institutions and their mandates/approaches have collectively articulated a distinct notion of financial inclusion, a notion amply informed by the political vision of welfarism under the mixed economy model' (Nair 2016, p.280).

By the late 1980s, studies had emerged in India calling for a policy rethinking on the relevance of social banking and targeted lending. The critiques mainly emerged from diagnostic studies of the large flagship anti-poverty programme of the government of India—the Integrated Rural Development Programme (IRDP)—that was launched during the Sixth Five Year Plan period (1980–85). These studies brought to light many shortcomings in the design and implementation of the programme. There were questions about the relevance of the core strategy of the programme, i.e. subsidised credit, in reducing poverty as also the viability of the banks in financing beneficiary projects (Nair 2011). The most eloquent critique emerged from the Committee on Financial System (Government of India 1991) with M. Narasimham as the chairman. The Committee held directed priority lending, fixed interest rates and high administrative cost as factors that caused deterioration in portfolio quality and erosion of profitability of banks (Kohli 1997).

Incidentally, the 1990s was a decade of important financial inclusion experiments in India in the field of microfinance. The regulator made lending to informal groups called self-help groups a legitimate banking activity in 1996 (Nair 2015). Such groups started increasing in number across most of the states. Other microfinance institutions also emerged as an alternative channel of microcredit delivery financed mainly by grants and soft loans. Though the microfinance clientele and operations expanded significantly, the state and the banking regulator were unwilling to count them in the on-going discourse on financial inclusion, which has centred decisively on banking institutions.

India's 'official' strategy of financial inclusion led by banks was given shape by the Committee on Financial Inclusion (Chairman Rangarajan) that submitted its report in 2008. The committee prescribed a basic individual bank account as the central instrument that can coordinate multiple fund flows—savings, small credit, overdraft, payments, money transfers—from and into excluded households. It recommended the use of agents—business facilitators/business correspondents (BF/BC)—to expand banking outreach with the help of appropriate technology. It may be noted that the RBI had already introduced a novel type of basic bank account—'no-frills' account—in November 2005, that could be opened with 'nil' or very low minimum balance. The initiative was expected to make bank accounts accessible to all segments of populations. Thus between the 1970s and the 2000s, the idea of financial inclusion had traversed a long distance from one that promotes social and priority banking and demands resource commitment from banks to that of individuals owning bank accounts, which form the fulcrum of their financial decisions. For the beneficiaries of government transfers, the bank accounts are expected to act as windows to the grand world of finance, though having a bank account is no guarantee that they receive all services offered by financial institutions.

India embarked on its structured programme of bank-led financial inclusion drive in 2011 with the launching of the *Swabhiman* scheme by the central government. The scheme aimed to create a branchless system of financial services to ensure that access to banking services is available to all villages irrespective of the population size. By March 2012, banking outlets were opened in close to 98% of the villages with a population above 2000[3] and in August 2012, the nomenclature 'no frill' account was changed to Basic Savings Bank Deposit Accounts (BSBDAs) with zero minimum balance. These accounts came with ATM card/debit card facility, zero charges on deposits and up to four withdrawals in a month. This was hailed as India's moment of announcing the right of all individuals to open a basic account. Banks were even advised by the RBI to provide small overdrafts in such accounts to meet emergency credit requirement.[4]

3 The Architecture of Digital Innovation in Finance

In the adoption of technologies in banking, India is considered a 'late bloomer' by some scholars (Rishi and Saxena 2004). The major technological innovations in the banking sector in the 1980s such as computerisation/automation of bank offices centred on increasing the efficiency of retail operations. As the phase of banking reforms ushered in the 1990s avenues were opened up for private and foreign banks to expand their footprints in the Indian market and introduce novel products and processes enabled by technology. Technologies like automatic teller machines (ATMs), phone banking and internet banking made their foray during this period (Bansal 2016). Aided by information and telecommunication technology and caught in increasingly competitive markets, banks have diversified into other businesses like investment banking, mortgage financing, credit cards etc.

Scholars identify the years since the mid-2000s as a phase of acceleration and consolidation of digital technologies that impacted banking operations as also user behaviour significantly. These technological changes have been leveraged effectively by successive governments to create the infrastructure for financial inclusion. In the context of the latter, two innovations have been very critical—the gradual building of an all-encompassing payment architecture and the Aadhaar project or the project of assigning unique identification numbers to all the residents of the country. The coming together of these innovations is at the base of India's much-celebrated success in digital financial inclusion in the 2010s. We will briefly explain these innovations here.

[3] https://www.business-standard.com/article/current-affairs/why-government-s-financial-inclusion-plans-are-floundering-115112301163_1.html (accessed June 26, 2020).

[4] Speech delivered by Deepali Pant Joshi, Executive Director, Reserve Bank of India at the Mint Conclave on Financial Inclusion, Mumbai on November 28, 2013.

Interventions to upgrade the payment architecture began since the late 1990s. The pace of efforts accelerated from the mid-2000s onwards with the launching of RTGS (Real Time Gross Settlement), National Electronic Fund Transfer (NEFT) and the National Electronic Clearing Service (NECS) that were meant to enable faster transfer of funds across accounts and destinations. In December 2007, the Payment and Settlement Systems Act 2007 (PSS Act) was enacted. The National Payments Corporation of India, registered as non-profit company, was set up in 2008 to act as the umbrella organisation that provides the infrastructure for physical as well as electronic payment and settlement system for all banks.

By the end of the 2000s, banks started allowing customers to pay for purchases at their point of sale (POS) terminals through credit or debit cards. The Prepaid Instrument (PPI) operators entered the payments market around the same time with prepaid cards, smart cards and mobile/internet wallets wherein customers could store value for future use. With the operationalisation of Immediate Payment Service or IMPS in 2010 immediate peer-to-peer fund transfer through multiple channels like mobile, internet, ATM, SMS and bank branches were made possible. For high volume transactions that are repetitive and periodic, NPCI introduced the National Automated Clearing House or NACH, an offline web-based system (Kant and Dhal 2019). Following on RBI's endeavours to introduce a domestic card, NPCI introduced the RuPay card in March 2012. As India lacked such a domestic card payment system most of the card-based transactions were costly and carried out in association with international card associations having overseas switch. RuPay was an important innovation towards realising the central bank's vision to move away from paper-based payments to the safer and more efficient electronic modes of payments.

As for the Aadhaar, it may be noted that the idea to develop a centralised database of the citizens of the country with a system of issuing a unique identification number/card formed part of the recommendations of the National Statistical Commission (Chairman: Rangarajan), which envisaged such a system to benefit both citizens as well as the administration (Government of India 2001). Eight years later in 2009, the Unique Identification Authority of India (UIDAI) was set up as an attached office of the erstwhile Planning Commission. The main mandate of UIDAI is to issue Aadhaar or Unique Identification numbers (UID) that are robust enough to eliminate duplicate and fake identities and easily verifiable/authenticable. Demographic and biometric (10 fingerprints, two iris scans, and facial photograph) de-duplication ensures the uniqueness of Aadhaar.[5]

The UIDAI eco-system has two elements—the enrolment system and the authentication system. The former consists of registrars or entities authorised by UIDAI for enrolling individuals. Registrars appoint enrolment agencies that are responsible for collecting demographic and biometric information of individuals with the help of certified operators/supervisors.[6] Several authentication service agencies (ASAs)

[5] https://uidai.gov.in/what-is-aadhaar.html.

[6] https://uidai.gov.in/ecosystem/uidai-ecosystem.html.

and authentication user agencies (AUAs) have been appointed from both government and non-government organisations to provide online and real-time authentication services. Real-time, scalable and interoperable banking services are possible anywhere in the country through Aadhaar authentication embedded into micro-ATMs or POS devices. The state promotes Aadhaar as a versatile policy lever to streamline the delivery of a wide range of government welfare schemes and benefit transfer programmes. While its use is encouraged as a permanent financial address by all, it is particularly hailed as a tool of distributive justice in the context of financial inclusion.

The UIDAI was established as a statutory authority in July 2016 under the provisions of the Aadhaar (Targeted Delivery of Financial and Other Subsidies, Benefits and Services) Act 2016 (Aadhaar Act 2016) under the Ministry of Electronics and Information Technology of the Government of India. The authority's centralised database is one of the largest data systems anywhere in the world, which stores encrypted biometric information on fingerprints of all 10 fingers and iris scans of both eyes of the resident enrolled along with digital photographs of their face, and some personal and demographic information (Jacobsen 2012). India's UID system is known to be the world's largest implementation of biometric technology and a global pioneer in public digital and data infrastructure (Singh 2018).

4 Leveraging Technology to Achieve Inclusion

It is on the foundation of the distinct architecture enabled by Aadhaar and the payments systems that the government at the centre launched its financial inclusion scheme *Swabhiman* in 2011. Aadhaar-enabled bank accounts and Aadhaar-based Micro ATMs operated by BCs were the two pillars of the Aadhaar-enabled delivery of services, which came to be treated coterminous with bank-led financial inclusion. It may be noted here that since 2008 the central and many state governments had made efforts to link social safety net programmes (NREGS wages, scholarships, pensions, health benefits and other types of income support) to banks to ensure transparent flow of payments to the targeted beneficiaries without duplication and leakage. In his budget speech of 2011, the then Finance Minister of India referred explicitly to the intention of the government to 'move towards direct transfer of cash subsidy to people living below the poverty line in a phased manner'.[7] The Task Force for Direct Transfer of Subsidies (Chairman: N. Nilekeni) proposed a general solution framework for the direct transfer of subsidies to beneficiaries and made specific recommendations for kerosene, LPG and fertilisers. 'Just as a real-time transfer of funds takes place when people top up their mobile talk time, the Government will transfer the cash component of subsidies directly and in real-time to the bank accounts of beneficiaries. Beneficiaries may then access these funds through various

[7]Budget 2011–2012 Speech of Pranab Mukherjee, Minister of Finance, February 28, 2011. https://www.indiabudget.gov.in/budget2011-2012/ub2011-12/bs/bs.pdf (accessed June 26, 2020).

banking channels such as bank branches, ATMs, business correspondents, internet, and mobile banking. Achieving full financial inclusion is crucial for direct transfer of subsidies' (Government of India 2011: p.1).

The integration of Aadhaar and payment innovations made it possible for the state to roll out direct benefit transfer (DBT) in January 2013. The Aadhaar Payment Bridge (APB), the payment system implemented by NPCI uses Aadhaar number of the beneficiary as a central key for electronically channelising the benefits and subsidies to their Aadhaar Enabled Bank Account (AEBA). By July 2013, the DBT coverage included 28 schemes extended to 121 districts across states. The roll-out of the direct benefit transfer in India, however, has progressed hesitantly and in phases between 2013 and 2015, mainly due to factors like the unevenness in preparedness across states, technology bottlenecks like lack of connectivity, widespread financial illiteracy and the resultant poor operation of accounts. Further, the BCs lacked motivation as they were remunerated poorly, while people found it difficult to trust mobile BCs (Nair 2016).

The DBT project received a fillip in 2014 as the Pradhan Mantri Jan-Dhan Yojana (PMJDY) was announced in August as a national mission for financial inclusion by the newly elected government at the centre. The mission has been implemented as a drive to universalise bank accounts using the branch and BC network. JDY promises to impact financial inclusion in three ways: (1) securing transactions (digital banking with no leakage), (2) securing household economy (bank accounts to channelise credit and subsidies to support economic activity and livelihoods) and (3) social security (insurance, pensions). By March 2015, 145 million accounts (60% in rural areas) were opened under the scheme. The number of accounts increased by about 165% over 2015–20 and as of March 2020, a total of 383 million JDY accounts are with Indian banks.[8] Majority of these accounts (about 76%) were also issued the RuPay card.

With the opening of a massive number of Jan Dhan accounts seeded by Aadhaar, the coverage of DBT schemes has expanded manifold since 2015 (Table 1). As of March 2019, benefits were directly transferred to beneficiary accounts in 441 schemes across 57 departments/ministries as against 28 schemes and 10 ministries in 2013–15. The total amount transferred grew from Rs. 463 billion in 2013–15 to Rs. 3300 billion in 2018–19. As the number of schemes expanded, the relative share of those that dominated the transfers in the initial years like MGNREGS and Pahal or DBT(LPG) has declined significantly. The share of Pahal declined from 32% in 2013–15 to 10% in 2019, while that of MGNREGS came down from 43% to 14%. DBT to beneficiaries of various initiatives within rural development forms a third of all transfers in 2018–19 as against 58% in 2013–15.

[8] https://www.pmjdy.gov.in/Archive.

Table 1 Progress of DBT

	Amount of transfer (Rs. billion)					% Share in total DBT				
	2013–15	2015–16	2016–17	2017–18	2018–19	2013–15	2015–16	2016–17	2017–18	2018–19
PAHAL (DBTL)	147.8	214.2	158.8	235.0	346.0	31.9	34.6	21.3	12.3	10.5
UJJWALA Yojana*	0.0	0.0	0.0	13.4	58.1	0.0	0.0	0.0	0.7	1.8
NSAP (Old Age, Widow, Disabled pension)	69.6	83.6	54.1	96.8	83.3	15.0	13.5	7.2	5.1	2.5
MGNREGS	200.1	258.6	373.1	337.5	461.8	43.2	41.8	50.0	17.7	14.0
Pradhan Mantri Awas Yojna Grameen	0.0	0.0	0.0	652.4	454.0	0.0	0.0	0.0	34.2	13.8
DAY-NRLM**	0.0	0.0	0.0	0.2	11.2	0.0	0.0	0.0	0.0	0.3
MoRD Total	269.7	342.3	427.2	1088.6	2423.9	58.2	55.3	57.2	57.0	30.6
Total DBT	462.9	619.4	746.9	1908.7	3298.0	100	100	100	100	100

Source https://dbtbharat.gov.in/page/frontcontentview/?id=NjU =

5 Digitisation of Payments: Towards a Less Cash Society?

It is important to analyse how the various initiatives to promote an electronic mode of financial transactions is faring in India. The payment space has indeed expanded phenomenally over 2011–12 and 2019–20. The expansion was effectively catalysed by both global and domestic initiatives in transitioning towards digital transactions. 'The Better than Cash Alliance' created in 2012 was a major international collaborative initiative among governments, businesses and international organisations to accelerate the adoption of digital payments.[9] With its headquarters in United Nations Capital Development Fund (UNCDF), the alliance emphasises the need for collaboration to help developing and emerging countries overcome the complex constraints on the path to fast digitisation of the finance sector. India joined the alliance in September 2015 as the PMJDY completed its first anniversary. The scheme has attracted great international attraction and was hailed as a unique experiment to achieve digital inclusion at scale.

Another major partnership was announced between the United States Agency for International Development (USAID) and the Indian government—Catalyst: Inclusive Cashless Payment Partnership—in October 2016 as a multi-stakeholder partnership. The press release of USAID on the occasion states that 'This launch marks the next phase of partnership between USAID and India's Ministry of Finance to help catalyse the rapid adoption of digital payments in India as a step toward achieving Prime Minister Narendra Modi's vision of universal financial inclusion to end "economic untouchability" in India'.[10] It aimed to increase cashless payments 'exponentially' in select geographic locations. India was already pushing for the 'JAM number trinity'—Jan Dhan, Aadhaar, mobile phone—to 'effectively target public resources' and 'efficiently allocating resources' to boost long-run growth (*Economic Survey* 2015: 21).

The year 2015–16 was especially important in the timeline of events that transformed India's payments and settlement system in other ways too. The Ministry of Finance issued the guidelines for promoting payments through cards and digital means in 2016. A host of private sector players have emerged in India by then. As per a NASSCOM report, more than 120 players made up the Indian payments ecosystem in 2016 operating across sectors such as ATM/POS operators, transaction gateways and platforms, online mobile wallets, remittance service providers, cash card operators and Bitcoin web wallets (NASSCOM 2016). It also reported that beginning from January 2016, the payments sector in India attracted investments of about 1.1 billion USD. The mobile payments and commerce platform, Paytm (founded in 2010) alone, mopped Rs. 650 million investments in 2015.

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[9] https://www.betterthancash.org/.

[10] https://2012-2017.usaid.gov/india/press-releases/oct-14-2016-usaid-launches-catalyst-drive-cashless-payments-india#:~:text=This%20multi%2Dstakeholder%20partnership%20is,payments%20in%20select%20geographic%20locations.&text=Catalyst%20will%20support%20these%20efforts,purchases%20cashless%2C%E2%80%9D%20Addleton%20said.

The open API (Application Programming Interface) policy announced by the government in 2015 must be mentioned here as it aimed at providing access to programmers to propriety software applications. The India Stack, the digital foundational infrastructure, was built on the strength of this policy as a public good that can be leveraged by both public and private sector participants to develop technological innovations. With Aadhaar, the unique digital identity system, at the base various platforms for verification, digital signature and payments have been developed over it. Each platform solves a distinct purpose and is built as a public good. Each such platform rail serves as an infrastructure for other applications to stack up. In this manner, transaction costs of infrastructure development could be reduced for every new player (D'Silva 2019). As of 2019, India Stack had four layers as shown in Table 2.

The NPCI was particularly active during the period 2015–16. It came out with the Aadhaar-enabled Payment System (AePS) in January 2016 to enable basic transactions of any bank to be done at Micro ATMs of BCs with the help of Aadhaar authentication. In the same year in August, it introduced UPI or Unified Payments Interface as an immediate real-time payment system that uses a mobile platform to instantly transfer funds between two bank accounts. The interface allows multiple bank accounts on a single mobile application. The Bharat Interface for Money (BHIM) app developed by NPCI and released in December 2016 came as the next major innovation. The app was meant to make digital transactions easier without the requirement of a third-party wallet that stores cash. Consumers can link their bank accounts with BHIM and make direct payments for purchases and services. BHIM also allows the users to transact with QR codes, mobile numbers and Virtual Payment

Table 2 India stack - different layers

Layer	Provider	APIs/Functionality	Uses
Presenceless	UIDAI	Authentication	Service delivery Authentication Direct benefits transfer
Paperless	UIDAI	KYC	Bank account opening, SIM isuurance
	CAs	eSign/Digital signature	Contracts, Agreements
	Meity/Digilocker	Document	Consented document sharing
Cashless	NPCI/UPI	Payments	Retail payments, including P2P, P2M, Govt. through mobile
	AEPS Aadhaar pay	Payments	Cash deposit/withdrawal, transfers, merchant payments using biometric auth
	IMPS	Payments	Remittances, Mobile payments
Consent	NBFC AA	Financial data	Personal finance management, Loan processing

Source Raghavan et al. (2019)

Addresses (VPA).[11] NPCI has subsequently released the National Electronic Toll Collection (NETC) programme (2016) for electronic tolling requirements and Bharat Bill Payment System or BBPS (2017). The BBPS works as an integrated bill payment system offering interoperable services through a network of agent institutions.

5.1 Progress of Electronic Payments: An Overview

The dramatic announcement of the Prime Minister of India demonetising currency notes of denominations Rs. 500 and Rs 1000 depriving them of their legal tender status on 8 November 2016 appeared like the big push towards advancing the dream future of the cashless nation in one stroke. Now that it is clear that the many different explanations for the sudden withdrawal of Rs. 14.2 trillion of currency notes like curbing corruption, black money and counterfeit currency do not stand to empirical scrutiny (Reddy 2017), the only concrete outcome of demonetisation seems to be the nudge to accelerate the growth of plastic and digital payments.

The available data signal an upward shift in the use of cards over December 2011 and December 2019, especially since 2016. The number of outstanding credit cards increased from 18 to 55 million during this period. The growth in the number of debit cards was much faster, especially since 2015. Overall their number grew from 263 million in 2011 to 958 million in 2018 but registered a decline to 805 million in 2019. As Fig. 1 shows, over these years, banks have curtailed the number of ATMs and increased the points of sale (POS), where customers could use their credit and

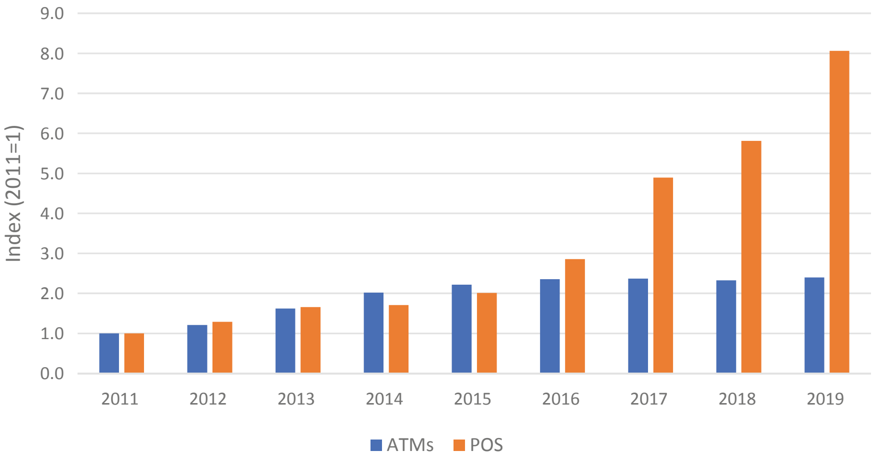

Fig. 1 Growth in Number of ATMs and POS. *Source* https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

[11] https://razorpay.com/learn/bhim-app-growth-rural-upi-payments/.

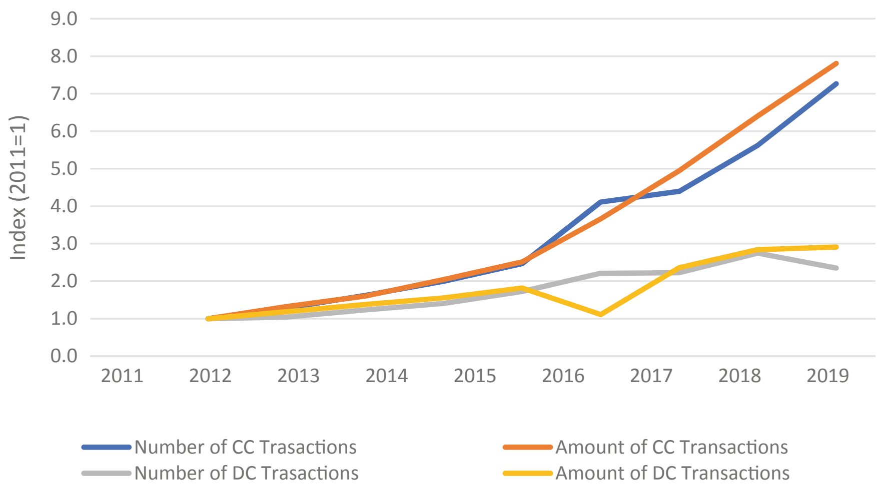

Fig. 2 Growth in Card Transactions—Volume and Value. *Source* https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications. *Note* CC-Credit Card; DC-Debit Card

debit cards to make purchases without withdrawing cash. The growth of e-commerce and the massive issuance of RuPay debit cards under PMJDY since 2015 were the main reasons for the increased usage of debit cards (RBI 2020). While in absolute terms, debit card transactions are many times more than credit card transactions, the growth in number and value of credit card transactions far exceeded that of debit cards (Fig. 2). We have also analysed the monthly data on credit and debit cards since September 2016 to know the recent trend and found a sharp rise in the number of outstanding credit cards compared with debit cards as shown in Fig. 3.

Coming to the progress of electronic payments, the data for the period 2012–13 to 2018–19 reveal interesting patterns. Table 3 suggests that the absolute size of both number and value of transactions of the relatively newer modes of payments like PPIs and IMPS increased substantially after 2015–16. In other words, these modes have significantly broad-based payment sector in India. However, they constitute a minuscule share of the total volume of transactions. In terms of the number of transactions, the combined share of PPIs, NEFT, mobile banking and IMPS/NACH increased from less than 2% in 2012–13 to 45% in 2018–19, but their share in value was just about 2% in 2018–19. Notably, the transaction volume of these modes registered a steep jump in the post-demonetisation phase.

It must be noted that in terms of the value of transactions across all digital modes of payments, RTGS, which represents the continuous process of settling interbank payments involving large-sized funds has the largest share—59% in 2018–19 (Table 4). Retail electronic clearing modes (ECA, NEFT, IMPS and NACH) with a sharply rising share in the number of transactions have about 9% share in value. The shares in payment value of both PPIs and mobile banking are extremely small. However,

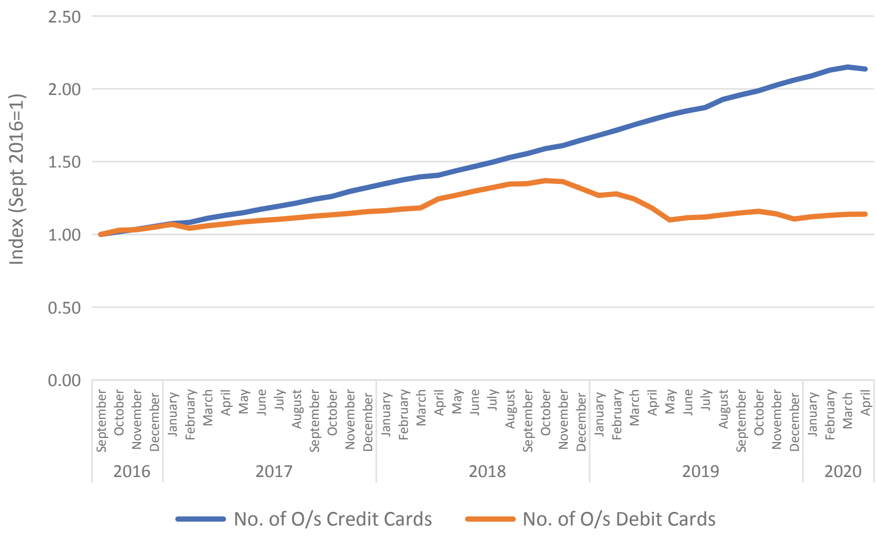

Fig. 3 Number of Outstanding Credit and Debit Cards—Recent Trend. *Source* https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

the number of payment transactions through these modes improved consistently over the years.

Among the various modes of retail clearing options, one can see a significant and consistent decline in the share in the volume of NEFT transactions and a rise in IMPS (Fig. 4). NACH that was rising faster till the mid-2010s in terms of transaction volume registered a decline after 2015–16.

The growth in the volume of mobile-based payments, especially since 2015–16 (Fig. 5), is an indication that increasing mobile density and mobile internet user base are leveraged by providers of payment services (RBI 2020). Mobile banking services are available through three modes—SMS, USSD (Unstructured Supplementary Services Data) and mobile applications. Among PPIs, mobile wallets have grown in terms of volume of transactions until 2017–18, driven mainly by Paytm, one of the pioneers in the market. The advent of UPI as an open-source platform ended up in redefining the market dynamics since 2016. On the one hand, mobile wallets lost their distinctive appeal as consumers can now make digital payments directly from their bank accounts, and on the other hand, new competitors like Google (Google Pay) and Flipkart (PhonePe) have forayed into the payments market redefining its contours and dynamics (Osawa 2020). It must be noted that the volume of retail electronic clearing using UPI increased from 179 million in 2016–17 to 53 0.53 billion in 2018–19, while the value of transactions rose from Rs. 69 billion to Rs. 8770 billion (https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications).

Table 3 Progress of digital payments by mode

	Number of Transactions (in billion)						
	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
1. RTGS	0.69	0.81	0.93	0.98	1.08	1.24	1.37
2. EFT/NEFT	3.94	6.61	9.28	12.53	16.22	19.46	23.19
3. PPIs	0.67	1.34	3.14	7.48	19.64	34.59	46.04
4. Mobile banking	0.53	0.95	1.72	3.89	9.77	18.72	62.00
5. IMPS	0.00	0.15	0.78	2.21	5.07	10.10	17.53
6. NACH	0.00	0.87	3.40	14.04	20.57	25.03	30.35
7. All modes	83.20	98.02	117.18	151.26	195.61	244.99	343.81
8. PPIs, mobile banking, IMPS and NACH	1.20	3.30	9.05	27.62	55.05	88.45	155.93
% Share 8/7	**1.45**	**3.37**	**7.72**	**18.26**	**28.14**	**36.10**	**45.35**
	Value of Transaction (in Rs. billion)						
1.RTGS	1,026,350	904,968	929,333	1,035,552	1,253,652	1,467,432	1,715,521
2. EFT/NEFT	29,022	43,786	59,804	83,273	120,040	172,229	227,936
3. PPIs	79	81	213	488	838	1416	2129
4. Mobile banking	60	224	1035	4041	13,105	14,739	29,584
5. IMPS	4	96	582	1622	4116	8925	15,903
6. NACH	0	215	1221	3802	7916	10,736	14,762
7. All modes	1,329,239	1,519,235	1,682,461	1,835,103	2,282,412	2,556,563	2,919,618
8. PPIs, mobile banking, IMPS and NACH	143	616	3051	9953	25,975	35,816	62,377
% Share (8/7)	**0.01**	**0.04**	**0.18**	**0.54**	**1.14**	**1.40**	**2.14**

Source https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

Table 4 Share of Digital Modes in Total Payments

Year	% Share—Number of Transactions				% Share—Volume of Transactions			
	Retail Electronic Clearing	RTGS	PPIs	Mobile Banking	Retail Electronic Clearing	RTGS	PPIs	Mobile Banking
2012–13	8.34	0.82	0.80	0.64	2.40	77.21	0.01	0.00
2013–14	11.31	0.83	1.36	0.97	3.15	59.57	0.01	0.01
2014–15	14.40	0.79	2.68	1.47	3.89	55.24	0.01	0.06
2015–16	20.77	0.65	4.95	2.57	4.98	56.43	0.03	0.22
2016–17	21.59	0.55	10.04	4.99	5.80	54.93	0.04	0.57
2017–18	26.05	0.51	14.12	7.64	7.55	57.40	0.06	0.58
2018–19	36.26	0.40	13.39	18.03	9.16	58.76	0.07	1.01

Source https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

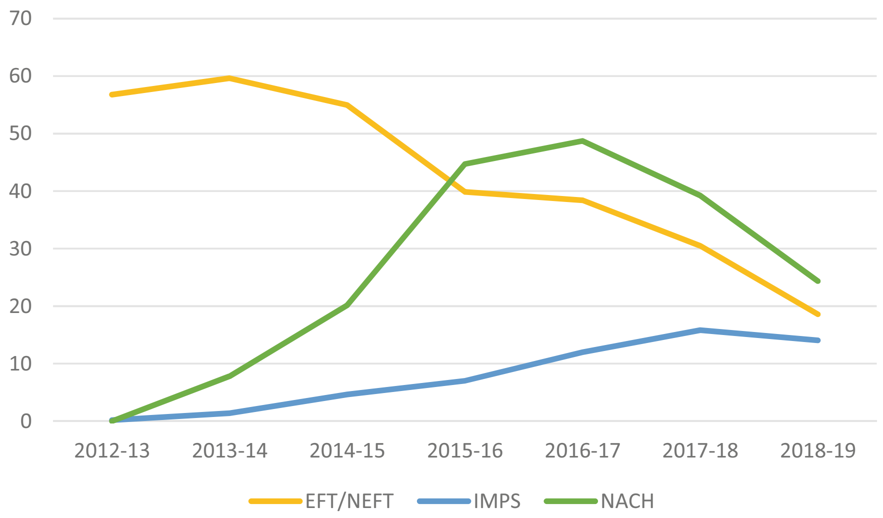

Fig. 4 Movement in Shares of Retail Electronic Payment Options. *Source* https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

6 Conclusion

The financial service sector in India has been at the centre of the country's digital transition. The policy thinking around financial inclusion that focused on benefit transfer to targeted populations as the mode of inclusion has been concerned with issues of identification and traceability of the potential beneficiaries since the mid-2000s. The Aadhaar infrastructure was hence thought to be the foundation of digitised financial inclusion. This was accompanied by innovations in payments and settlement system,

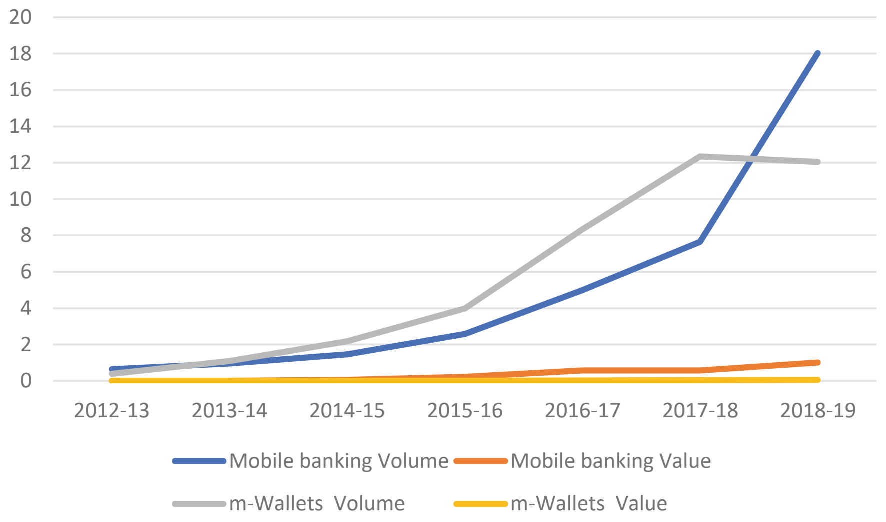

Fig. 5 Growth in mobile payments. *Source* https://dbie.rbi.org.in/DBIE/dbie.rbi?site=publications

which soon got integrated with the Aadhaar system to spawn further innovations like APB and India Stack.

While the developments so far put India in a leading position concerning digitisation of financial services, there are no clear signals that such leadership has translated into effective financial inclusion. As per the Global Findex data for 2017, only 7% of individuals above the age of 15 could avail credit from banking institutions. The Jan Dhan accounts have consistently low balances in them. The activity increase in the case of newer digital payment instruments like m-wallets and mobile banking is observed only in terms of the number of transactions and not volumes. This heightened activity seems to be indicative of the rising competition among small digital and e-commerce businesses offering a host of consumer products and services leveraging innovations like India Stack. In that sense, what we experience in India in the name of financial inclusion is a partial extension of financial services to the conventionally non-bankable population, and a disproportionate expansion of the space for digital ventures often financed by global capital. In other words, digital financial inclusion seems to benefit financial system players much more than those who are excluded from it in myriad ways.

More importantly, many of the concerns voiced by scholars and activists about the privacy and security vulnerabilities of the Aadhaar architecture still remain unaddressed. Some of these concerns relate to the very suitability of biometric technology, a technology that originated to aid surveillance of individuals, to the purpose of e-governance and service provisioning. That Aadhaar is pooled and stored centrally and is irrevocable in case of breach are issues that have come up repeatedly in public debates (Abraham 2018). In the sphere of finance, new biases are likely to crop up, say for instance, if providers start making credit decisions linking multiple databases.

These anxieties notwithstanding the Indian state aggressively pushes through its agenda of digital financial revolution assuming unproblematically that financial inclusion is its *fait accompli*.

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Chapter 11
Future of Work in Information Technology and the Analytics Industry: Understanding the Demand

Nausheen Nizami

1 Introduction

The Fourth Industrial Revolution is marked by a fusion of digitalization, artificial intelligence, robotics, automation, quantum computing, internet of things and emerging technology breakthroughs. Application of the same into the manufacturing of goods and services is likely to boost production efficiency and accelerate the industrial and overall growth rate of the economies. The impact of the Fourth Industrial Revolution (4IR) on demand for labour is a highly debatable area of concern and in-depth studies on its current and estimated impact on different industries needs to be undertaken. Technological changes tend to affect not just productivity but also nature of work. Industry 4.0 is likely to create new jobs requiring new skills through technical progress. This brings about an important question on the gap between new jobs created and skill gap of the existing workers.

This chapter discusses the impact of the 4IR on the nature of workand demand for labour in India's Information Technology and Data Analytics industry. The Information Technology industry is one of the fastest-growing industry in India's service sector and its contribution to Gross Domestic Product has gone up from 1.2% in 1998 to 7.7% in 2017.[1] The analytics, data science and big data industry in India have been growing at a healthy rate of 33.5% CAGR. It is considered as a sister industry of IT industry. Research suggests that automation and artificial intelligence are expected to affect not just back-end and low-skill work in the IT industry but also affect similar routine tasks in the other sectors. By automating mundane tasks, Industry 4.0 is expected to leave more productive time for the human capital which

[1]NASSCOM Report. The National Association of Software and Services Companies is a registered body of India's IT and BPM industry.

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_11

can be used for more analytical work. Up-skilling and re-skilling will be the two new requirements from the workers for sustainable jobs. How an industry adapts to the fourth industrial revolution depends on how efficiently it is able to predict the global demand and technological change and how it is able to re-skill the workforce.

There are two ways in which technology can affect employment in general. Firstly, the existing workers may lose their jobs directly due to technological change which is known as displacement effect. Secondly, new jobs requiring new skills will be created across industry pushing up the demand for more skilled labour which is known as productivity effect (Keynes 1937). Automation of work in Information Technology can hold wider implications for the labour market in India. The reasons are twin-fold: Firstly, India is a labour-abundant country with a very high number of English-speaking engineering graduates. Till the last decade, India has had a cost advantage in terms of labour which helped expand it as the IT hub of South Asia. However, with the waves of the 4IR originating from and touching work in the IT industry, the labour cost advantage is no more going to be the driving force of India's IT industry. The comparative advantage lies now on cost and production efficiency and automation of work enhances the same. Secondly, studies on the ongoing automation of work in the IT industry are extremely important to signal the changing dynamics of skill demand and supply in the IT industry. Certain skills are becoming redundant and certain new skills are now in demand. This skill gap needs to be known by the education and training hubs to be able to equip new labour market entrants in the IT industry with the required skills. This research aims to provide vital findings to the new labour market entrants and alternative options to existing IT workforce in case of job-change or job-loss owing to automation in IT companies.

2 IT and Analytics Industry in India: The Present State

IT revenues grew at a rate of 9% in the year 2016–17. Together the IT-BPM sector of India received revenues worth USD 143 Billion and was the largest private employer giving jobs to nearly 3.9 million. Together the IT-BPM sector constituted approximately 45% share in the services exports and a 9.3% share in India's GDP. New technologies dominating the year were process transformation, analytics and automation which altered the value propositions and landscape of the IT industry. The services which drove the market were largely testing in retail and health care as well as traditional services. In India's case, the Digital India movement drove up the demand for IT services. India's share in global outsourcing stood at 67% in the same year. In the next ten years, revenues in India's market are estimated to grow by 10–11%. With more than 16,000 firms, the IT industry has in recent years transformed its global image from serving back-office operations to bringing business transformation. The sector has also witnessed a boom in the number of start-ups with 1200 start-ups in 2016–17 alone. India secures a rank of 3 for giving a home to the world's largest number of start-ups. Most of these were in the domain of analytics, Internet of things and payments which are also the emerging areas in this dynamic industry. IT has been one of the fastest drivers of service exports in India in the post-liberalization period. Back-office tasks, data entry, call centres, software development and similar services have been offered by Indian companies to foreign clients at cut-piece rates. The industry has been dynamic and has undergone a major transformation in the last five years with the increased demand for analytics in emerging areas like data science, artificial intelligence and big data. On one hand, IT is driving technology in other sectors in India; it is also an industry which has been most impacted by digital and automation technologies. Over the years, technological changes in various industries are resulting in new types of work (say data mining, data scientist, AI consultant) and have started contributing to rising productivity. Growth of ecommerce and technology-based aggregator models is giving rise to new job creation. These days cloud platforms are available for commercial usage by leading tech companies and this is resulting in low-cost and easily accessible data centres. This technological diffusion in the commercial landscape is also expected to directly benefit small businesses and start-ups and preventing entry barriers. In terms of revenue, USA (60%) is a leading contributor for the Analytics industry followed by UK (8%) and Australia. Table 11.1 depicts the source of revenue for India's analytics industry (Fig. 11.1).

The demand for IT professionals has been constantly rising for the last two decades. The proportionate increase in the demand for Software development and technology skills is similar among most of the technology-intensive countries (Fig. 11.2). In India, the demand for these skills is around 42%.

As per the World Bank report, 69% of the jobs in India are at risk of automation. As technology streamlines routine tasks, there would be a rise in the demand for both high-skill and low-skill jobs and middle-skill jobs like clerical workers and machine operators are facing a reduction in demand. However, the waves of Industry 4.0 would be felt sooner in developed countries compared to developing countries as the latter are more labour-abundant, relatively less globalized and technologically less

Table 11.1 Top 12 countries with analytics revenues in India

Countries	Revenues ($millon)
USA	11,199
UK	169.6
Australia	109
India	85.2
Canada	52.4
Netherlands	37.3
Germany	34.6
France	21.9
Philippines	21
China	11.7
Sweden	11.7
UAE	8.4

Source Analytixlabs (2017)

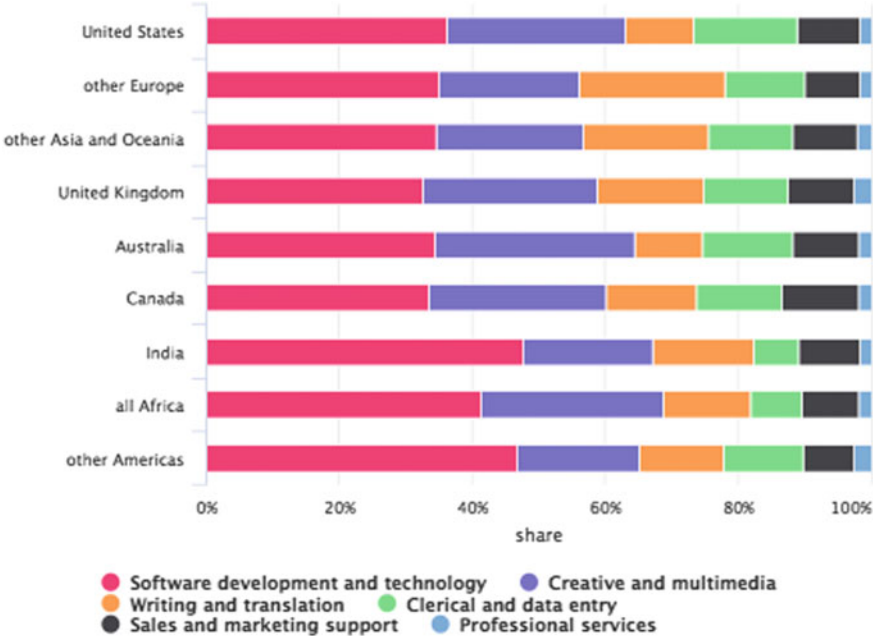


Fig. 11.1 Occupational distribution across countries. *Source* (Kassi and Vili 2018)

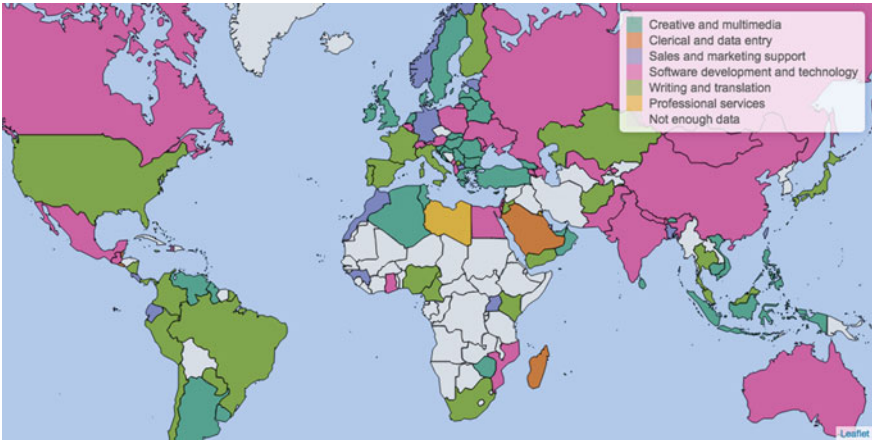


Fig. 11.2 Where are top online workers located? *Source* (Kassi and Vili 2018)

innovative. Unless the low-cost new technology is developed indigenously, future jobs in developing countries are likely to remain less automated and more a labour-automated capital mix.

There are estimates that there is a 70% probability that 47% of the current jobs will be displaced by digitalization wave in the coming decade (Frey 2013). It is being widely estimated that the key technologies that will drive business in the IT/Analytics sector are Internet of things, Machine learning/artificial intelligence, big data, cloud and robotics/automation. Jobs that are based on routine processes like software development would be most impacted by automation in software development value chain.

3 Impact of Emerging IT Technologies on Work

Worldwide, debates on the probable impact of the 4IR on work are taking place. Studies have taken place on the implications of artificial intelligence and automation on the demand for labour, wages and employment. They have found evidence of displacement effect of AI and automation on labour and productivity effect on demand for labour which is counteractive. It has been argued that some tasks have to be produced by labour and some by capital. Automation deepening leads to cost savings which can be used to hire more labour on tasks which cannot be automated (Restrepo 2018). Empirical studies have predicted the effect of automation, robotics and artificial intelligence on employment. In the first approach, the impact of technological breakthroughs on labour markets in previous industrial revolutions and how new jobs were created at the cost of older jobs has been examined. The second approach is based on research on the jobs that are at the highest risk of automation. The third approach focuses on assessing the impact of automation on employment. Citing several empirical studies, it was found that the use of robotics is still not very common and is mostly limited to manufacturing sectors. The assessment of the impact of AI on demand for labour in non-manufacturing industries is a difficult task (Petropoulos 2018).

Empirical studies have also examined positive effects of robotics on productivity, competitiveness, new job opportunities, wages and even labour productivity. After reviewing several studies on the dark side of automation, negative effects on jobs, it has been asserted that automation does not lead to job substitution but rather re-allocation of both jobs and tasks wherein robot complements and augments human labour by performing routine or dangerous tasks. Concerns on the impact of automation on jobs and social security funds have to lead to the introduction of robot tax though the authors believe that this tax is highly unwarranted due to the positive effects of robotics on employment and wages. Robotics and automation are likely to affect tasks which are monotonous, repetitive like physical tasks or data processing and will not affect tasks requiring high creativity, empathy, persuasion, understanding of which knowledge should be applied in which situation, etc. (The International Frontier of Robotics). Frontier economics recently published a report on *The impact of Artificial Intelligence on Work- An evidence review prepared for the Royal Society and the British Academy*. The report primarily examines the impact of Artificial Intelligence on work by 2030. The report says that recent automation does not seem to have led to an overall decline in employment levels except for the low-educated workers employed in the manufacturing sector. The report concludes that the impact of AI on employed will not only be influenced by technology but also cultural, economic and social factors. As an industry-focused study has not yet undertaken, there is limited evidence on how AI is being used now and how it is changing a worker's life.

The probable impact of Artificial Intelligence can be categorized into three waves. In the first Algorithmic wave (the early 2020s), simple computational tasks and structured data analysis would be automated. In the second Augmentation wave (the late 2020s), there would be dynamic interaction of technology and clerical support. Clerical tasks will be easily undertaken by semi-controlled robots in warehouses. In the third wave, it is being estimated that a lot of real-world human skills like problem-solving, manual labour, data analysis, quality testing would be possible to automate. The long-run impact is said to be positive on the economy (Price Waterhouse Coopers). There is a strong inverse correlation between risk of automation and level of education among people in their paper 'Automation and Occupations: A comparative analysis of the impact of automation on occupations in Ireland'. One out of every fifth job is likely to get substantially impacted by automation. Transportation, agriculture, forestry and fishing are facing a 50% higher risk of automating their jobs. Education, human health, social work activities and Information and Communication face the least risk of being exposed to automation (Doyle 2018).

Countries tend to differ on their automation adoption path depending on the socio-political factors, and this deviation is directly linked to automation adoption by industries. Moreover it also depends on whether the technology to be adopted is indigenously developed leading to lower cost or purchased from tech vendors. The study has identified activities like collection and processing of data, highly structured and predictable physical activities at the risk of automation which are mostly found in industries like manufacturing, accommodation, food service and retail trade. Technical, social and economic factors will together determine the pace and extend of automation. Studies have also taken place to analyze the automation potential of the global economy, the factors that will determine the pace and extent of workplace adoption and the economic impact associated with its potential (Institute 2017). The prospects of automation in the Indian labour market have been analyzed using NSSO data of 68th round. As per the data, 58% of the labour force is currently engaged in low-skilled work and 19% is unskilled, both of which face the highest risk of automation. The sectors those are likely to see high automation are agriculture, forestry and fishing, transportation and storage, manufacturing, construction and wholesale and retail trade. Together these sectors employ around 28.4% of the workforce (Ilavarasan 2017).

Selected papers in the area of technology, automation and employment have been reviewed in which it has been found that increasing automation and robotics does not seem to reduce the aggregate employment. Low skilled workers are likely to suffer from job losses. Demand for new types of skilled workers or specialization will increase within occupations. It is being discussed that how new technologies are leading to a rise in productivity do not necessarily imply a reduction in demand for labour. The challenge is to augment labour supply with the right skill shortly (Ramaswamy 2018). Another study has examined the employees' perceptions of workers in India's IT industry about the impact of automation. The methodology of the study is based on exploratory research. Different parameters have been used to assess an employee's awareness about Robotic Process Automation (RPA) such as (i) whether an employee is prepared for such a technological change, (ii) practical aspects for implementing process automation, (iii) type of worker response towards process automation, (iv) possible hurdles in implementing such RPA at workplace and (v) issues in customer support. IT companies have already started investing in process automation and the IT hiring needs to change accordingly (Varghese 2017).

Positive effects of automation on industry namely: own industry output effects, cross-industry input–output effects, between-industry shifts and final demand effects have been found. In order to assess the association between labour demand and technological progress, cross-sectional data has been collected across different industries and countries. The methodology of the study is based on the period of 1970–2007 and is limited to 19 developed countries of the European Union. It was found that technological progress is broadly labour augmenting. However, labour's share in industry value-added falls because owing to technological progress the industry market share of labour-intensive firms fall and of capital-intensive firm rises (David and Anna 2018). Digitalization and software industry has been automating a number of routine tasks performed by senior workers in retail and commercial services. Industry 4.0 is bringing new technology that eases the supply chain management of the firms, performs detailed financial analysis, helps in report development and even diagnosis of possible deviations in business outcomes (Brynjolfsson 2014).

4 Nature of Work in IT and Analytics Industry

Advanced automation is already disrupting job futures around the world. India has high automation potential. However, the bulk of the labour force is still low-medium skilled in the country. Adoption rates of automation are likely to be high in few industries like IT services, financial and legal services. Labour market of IT-BPM Services is characteristically different from traditional industries owing to several reasons: (i) Demand for labour in IT and Analytics industry is specifically for the technically qualified segment and the workspace is in a relatively sophisticated set up with access to all basic amenities. Lesser seed capital is needed as the industry is human capital intensive. The basic work infrastructure of an IT firm is mainly high-speed internet, cloud platforms, computer and related accessories, telephone and a decent seating arrangement. Most of the IT firms provide access to other amenities as well (such as pantry, washrooms.). It is also to be noted that the ratio of fixed capital per employee is comparatively low (Datar 2004), (ii) Firms in the IT-BPM Sector are registered by law and so fall in the formal sector. However unlike in traditional industry, the work contract between employer and employee is not permanent, rather than, is a fixed contract, subject to renewal based on employee performance. This often results in job insecurity among employees as the industry is technologically dynamic and requires constant re-skilling and up-skilling, (iii) another important feature is the overlapping nature of tasks and lack of clear task division as per different designations. This results in multi-tasking and challenges in time management as many a times workers in a team are expected to resolve unattended or unsolved project issues of their colleagues. This tends to affect their own productivity, (iv) Re-skilling and up-skilling is a constant requirement for sustaining jobs and workers are often seen enrolled in life-long learning, (v) Labour demand-supply gap persists owing to poor education infrastructure, lack of direct recruitment platforms, fast-changing skill requirements rendering fresh graduates jobless if their educational experience lacked industry exposure and other regulatory challenges (Nizami 2019).

Highly specialized areas of work like cybersecurity, data analysis and cloud computing are expected to emerge but these opportunities would be limited to workers with requisite skills.

5 Need to Review Labour Regulations?

Industry 4.0 is expected to have different impacts on the labour community depending on their socio-demographic characteristics which often ease/restrict their technological progression. This is so because women in India still have limited access to technology gains. Lower levels of education and skill limit their capacity to leverage new digital opportunities. NASSCOM has recognized the probability of job losses in the IT sector, however, there are also prospects of job creation due to new requirements of the industry. Interlinking current lay-offs purely with automation and technology need further investigation. A focused study is required to identify the exact reason for lay-offs which are also possible owing to poor worker performance, slowdown in the industry at global level leading to lesser projects (and so less labour requirement), etc. Workers in the industry are also generally aware about the importance of re-skilling and up-skilling to be able to contribute productively in their work. Industry 4.0 is expected re-orient the business opportunities in favour of IT-BPM Companies based in India if the dynamism in skills is matched with the dynamism in technology.

State governments govern the labour laws prevalent in the IT and Analytics industry which falls in the Shops and Commercial Establishments framework. Unlike the traditional manufacturing industries which are governed by the Factory laws, IT industry has been exempted from a few labour laws for the first 1–2 decades in order to accelerate its growth rate and establish global competency. Research points out that flexible arrangements in IT industry have often led to long working hours and work pressure among the employees (Nizami and Prasad 2011). It has been observed that in few states, formation of labour unions in the IT industry has been permitted and the exemption of labour laws has been revoked in order to strengthen labour rights. Similarly, Industrial Disputes Act 1947 is now applicable to IT industry in Tamil Nadu. Such moves are expected to bring more transparency in matters related to lay-offs and anarchy at workplaces. Provision of such norms in the industry has received mixed response from the workers as well as employers. However, it has certainly proved that there is a need for rethinking labour reforms in services like IT and Analytics as the nature of work is different from not only traditional industries but also other service sector counterparts (Nizami 2017). The industry being global in nature is prone to external shocks which directly affects the demand for labour. There is a need for amendments in the labour regulations in the IT analytics sector to ensure the well-being of the workers.

6 Methodology and Main Findings of the Study: Current Skill Demand in the IT-Analytics Sector

The methodology of the study is based on twin objectives: Understanding the skill demand in IT/Analytics sector and estimating alternative employment opportunities for the currently employed workforce in case of job loss owing to automation. To ascertain the skill demand in the IT and analytics sector, this study has examined the job advertisements of the ten leading IT and analytics companies in India. Data on the type of roles offered, role description, pre-requisites has been collected from the company websites. Qualitative techniques have been used to analyze the data. Content analysis has been used to understand the type of skill demand and the future of work in the IT-BPM sector. The job descriptions and eligibility requirements have been studied to understand the common requirements across jobs in the sector. To understand the alternative employment possibilities for IT workers, a primary survey was undertaken on a sample of 78 IT Industry employees and employers. Non-random sampling method has been used to collect data and snowball sampling technique has been used to contact the target respondents. Descriptive statistics have been used to analyze the sample results. Graphical representations of data explain the numeric and characteristic details of the target sample.

Skill demand-supply gap analysis is essential to help the country take meaningful initiatives under Skill development mission and help in reaping the demographic dividend. Compared to the IT sector, demand for labour is now rising at a higher rate in the Analytics sub-sector. In the past few years, Analytics has become one of the fastest rising sectors in IT-BPM and services. There has been a growth in Analytics companies of all sizes. Nearly 40% of analytics professionals are employed in large-sized companies (>10,000 employees). Midsize organizations employ 33% of analytics professionals. Start-ups employ 27% of analytics professionals in India. There is an equal need to develop an associated skills base as there are concerns about the availability of big data skills within the existing labour pool. This concern is rising as the increase in the supply of specific technical skilled workers is much slower than the demand. The job requirements in the Analytics industry though seemingly similar are quite different from the IT industry. A strong background of Statistics/Mathematics/Economics is a must for data-driven roles in this industry. It has been found that the most commonly advertised roles for big data staff are for developers, architects, analysts and administrators. In a study in the UK, it was found that technical skills most commonly required are SQL, Oracle, Java, Agile software development, test-driven development, etc. Similar is the case of India as here also the job roles commonly advertised by Analytics companies require similar skillsets. An analysis of skill requirements across different roles has been presented in Table 11.2.

Table 11.2 Skill requirements in the analytics industry in India

Designation	Role	Demand (Requisites)
Senior Manager	• Manage client relationships and work closely with Business Unit Heads to understand overall business goals and contribute strategic value beyond day-to-day operational tasks • Formulate Business analytics solutions for customers • Deliver advanced analytics insights and decision management solutions • Promote benefits of analytics for various industry verticals and client's divisions	• Graduate degree or specialization
Big Data Architect	• Independently work with clients and deliver large scale Big data systems • Mentor a team of 5–10 people and deliver to exceed client expectations	• 5–8 hands-on experience on large-scale Big data systems • Strong background in DW/BI Concepts, Proficiency in tools like Spark, Hive, Pig or similar tools
Senior Analyst	• Independently handle the delivery of analytics assignments • Mentor a team of 3–10 people Responsible for technical skill-building in the organization	• Great analytical skills, detail-oriented approach • Strong experience in R, Python, SAS, SPSS, SQL, MATLAB, etc
Business Consultant	• Provide business solutions • Processing, cleansing and verifying the integrity of data • Use predictive modelling Develop models and tools to monitor and analyze model performance and data accuracy	• Understanding of statistical techniques • Problem-solving • Deliver intelligence and data discovery capabilities • Strong data management and analytical skills
Hadoop/Bigdata Engineer	Skills needed: Hadoop, Hbase, Pig, Hive, BigQuery, HDFS	• Experience: 1–5 years • Experienced Big data and Hadoop developer

(continued)

Table 11.2 (continued)

Designation	Role	Demand (Requisites)
Head-Delivery	• Deliver products and solutions using appropriate agile project management methodology, learning and iterating frequently • Work with team, client and other stakeholders • Lead the collaborative, dynamic planning and execution process • Matrix-managing a multi-disciplinary team of data engineers and data scientists	• Graduate in Computer Science, Engineering, Economics or related field • 6–10 years of work experience in technology delivery domain • Exposure in analytics, data science, data visualization, BI
Big Data Project Manager	Oracle, Netezza, Business Objects and Hyperion Together with ETL and Agile Software Development-PRINCE2	• Management skills
Data Scientists	Hadoop, Java, NoSQL, C++, AI, Data mining and Analytics	• Specialization in Statistics or Mathematics

Source Author's compilation

In addition to the specific quantitative skills, management skills are an asset as the majority of the middle-level roles require team handling. A sound combination of Statistics and Programming is the necessary background required for a majority of the roles.

It can be inferred that the skill requirements in the industry are technical and specific skill-oriented. Being knowledge-intensive, the salaries of such positions are generally higher than those for IT staff. In the past two years, the demand for such positions has been constantly rising in India as well as abroad. The use of business analytics is increasing in every domain. From improved business decision-making, cost reduction, operational efficiencies, enhanced planning and strategic decision-making to fraud detection, waste reduction and increased business agility, big data and related technologies are important both in scope and scale. Attracting the right talent for successful implementation of big data solutions and delivering client requirements is a major challenge for this nascent industry today (Fig. 11.3).

In the case of the UK, it has been found that the demand for Big data staff has constantly risen from 2007–2012 by nearly cent percent. Demand for Business Intelligence/data warehousing jobs has fluctuated over the years. However, when combined with knowledge of big data, this skill set is an asset to a worker. The demand for IT staff has started falling from 2007 to 2012 by nearly 90%. This change in demand is similar in the IT-BPM sector in India also as can be seen in Table 11.3.

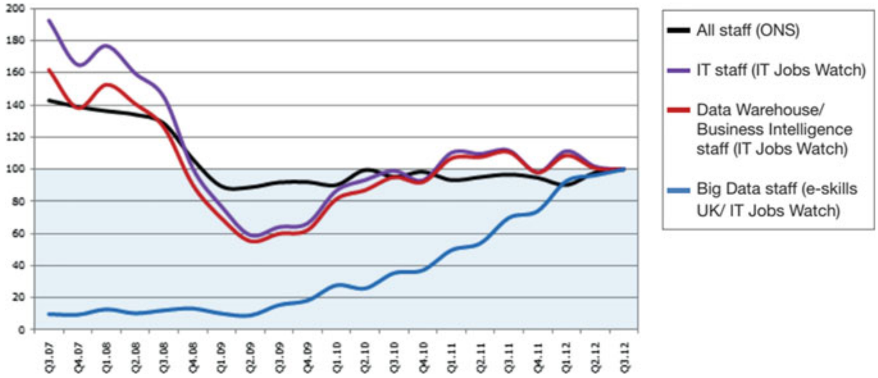


Fig. 11.3 Demand Trends for IT/Analytics sector in the UK during 2007–12. *Source* (Big Data Analytics: An assessment of demand for labour and skills, 2012–17, January 2013)

The skill demand in the IT sector is observably different from the skill requirements in the Analytics sector as presented in Table 11.2. In the Information Technology industry, demand for software and database knowledge and skills like JAVA, SQL, ORACLE, etc. is more compared to the knowledge of advanced statistics/mathematics. The academic background required for the roles is also mainly engineering or computer applications, unlike the Analytics industry where a Statistics/Mathematics graduate is preferred. This difference in skill requirements has important implications for the labour market of the IT-BPM sector because it reflects that the skills of IT workers are not easily transferrable to Analytics sector. A primary survey has been conducted on workers working in the IT industry in India to examine the impact of automation on different tasks and to study the feasible skill transfers from IT to allied industries. Snowball non-random sampling method has been used to collect data from the sample constituting of 78 workers and managers of IT industry primarily from Bengaluru, Delhi-NCR, Mumbai-Pune and Hyderabad cluster and has revealed some interesting insights on the perception of workers of similar skill requirements in other industries as seen in Table 11.4.

As can be observed in the above chart, majority of the IT employees perceive that they are likely to get jobs in banking and insurance industry (47%) followed by digital marketing (40%). Other industries which require workers with skillset similar to IT are Teaching and lectureship (36%), BPO (16%) and manufacturing industries (13%). This implies that these five industries have the potential to absorb the impact of automation on IT industry and more jobs requiring IT skills can be created in these sectors to ensure sustainable employment and decent work for IT workers as per the perception of IT workers based on their skillsets. These findings hold importance as the industry is dynamic in terms of technology and consequently mandates the workers to adapt to the skill dynamism consistently to drive the industry growth to sustain emerging competition in the times of fourth industrial revolution.

Table 11.3 Skill requirements in information technology industry in India

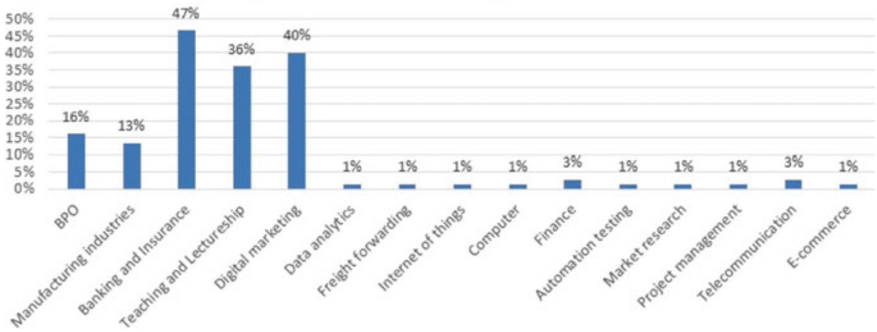
Designation	Role	Demand (Requisites)
Service Delivery Manager	• Day to day operation tracking, team management • Governance report and presentation with stakeholder	12–15 Infrastructure experience
Big data Scala developer	• Consultancy	Bachelors (General Law/computer science/ engineering/technology) Big data, Hadoop, Java, MapReduce, HDFS, Hive, Pyspark, Spark, AWS
Web Architect	• Application architecture solutions and design • Set up for application code deployment, security, performance review	Cloud computing, GIT, J2EE, Java, Microservice, Springboot
Data scientist		5–10 years' experience; Masters in Python, R, Machine learning algorithms, R packages. Experience in developing python scripts for machine learning. Mathematical skills, Teradata, MongoDB, OBIEE, Shiny package; Bachelors in Engineering
Associate functional consultant		Angular JS, HTML5, CSS, RESTfull API, Postgre SQL,ORACLE
Senior software engineer		JAVA, REST web services, KAFKA, MongoDB
IOS developer	Design technology lead	With Agile work experience, GitHub, Swift, Objective C, Selenium. Graduate: BTech/MCA
Power BI Consultant		Experience in Microsoft PowerBI, Integrating SSRS PowerBI, MSAzure, R, Python, SQL Server, Data warehousing. Graduation: B.Tech/BE/BCA/MCA

Source Author's compilation

7 Discussion and Conclusion

Technological unemployment is a major concern with the constantly changing skill demands in the industry. Automation is a sign of technical progress and with the progress of human civilization and technology, it is assumed to penetrate in most of

Table 11.4 IT worker's perception of similar skill requirement in other industries



Source Primary survey

the production tasks and services. Automation is not to be seen as a job destroyer but is to be seen as job creator also. It is likely to change the skill requirements in industries and to some extent reduce the demand for manual skills too. However, automation also requires extensive knowledge of the workers to sustain it and thus would need such skilled workers for its sustained usage and benefits. Industries, as well as workers, need to be prepared for the same and it is in this context this paper seeks to examine the preparedness as well as awareness of workers in the IT industry.

With increasing automation of processes, concerns are also being raised on its impact on employment creation. While a negative correlation between employment creation and automation is a cause of concern for some, the positive correlation between economic growth and development and automation is cheerful news for the policymakers and investors. The pace of automation is still slow in developing countries due to the huge capital constraints and background study required for implementing the same, yet it is important to predict the probable impact of automation. A proper study on the same can help prepare an industry to cope with the changing nature of work and changing skill requirements and an efficient information network can convey the changing requirements of the industries to curriculum designers. A planned policy route of action can help reduce the unemployment of human resources already employed in the industry.

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Chapter 12
Technology for Information Democracy: Case of GIS Enabled Entitlement Tracking System

Sushmita Patel, Tenzin Chorran, Kunja Shrestha, and Shivanyaa Rawat

1 Introduction

According to the Census of India 2011, 68.3% of the total population of India lives in rural areas.[1] Out of the total number of rural households, around eighty million households suffer at least one form of deprivation recognized by the Socio Economic Caste Census 2011.[2] This raises certain important questions, the answer to which could be crucial for not only maintaining but also deepening democracy in India. It remains pertinent to ask whether there are systematic barriers that impede them from working towards breaking the shackles of deprivation? If the latter is true, how can these systematic barriers be addressed? 'Right to Information' bears testimony to the fact that democratizing access and use of information possesses the potential to amplify voices which have been marginalized due to various factors, often beyond the control of this subset of the population. "When the Right to Information Act was passed in 2005, there was widespread exhilaration at the potential power that this tool had to change the work culture of the Indian society and state" (*EPW* 2017). However, initiatives such as this Act were catalysts for the spread of information democracy. 'Information Democracy' would broadly mean to ensure that no individual is hindered from being an active agent of change owing to factors such as the inability to read or speak a particular language, his/her caste or class position etc. Policy level changes have attempted to address these systematic barriers but there is still considerable scope for existing efforts to be translated into their fullest potential.

[1]Rural-Urban Distribution of Population Census of India 2011. https://censusindia.gov.in/2011-prov-results/paper2/data_files/india/Rural_Urban_2011.pdf.

[2]Provisional Data of Socio Economic and Caste Census (SECC) 2011 for Rural India Released, Press Information Bureau, Government of India, Ministry of Finance, available at https://pib.gov.in/newsite/PrintRelease.aspx?relid=122963 (Accessed October 14, 2019).

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_12

To address this, the power of technology has been leveraged by governmental as well as non-governmental initiatives.

This chapter explores the potential of one such technological platform called GIS Enabled Entitlement Tracking System (GEET), in paving the way for a new wave of information democracy. It begins with an enquiry into the congruence of the move towards an information society and growing use of information and communication technologies (ICT). Following this, it delves into the use of ICT's for improving the reach of social security schemes in India. Further, it details out the evolution of social security in India and makes the argument for social security being recognized as a basic human right. This is followed by an analysis of concerns associated with the use of technology to facilitate change and initiatives that are attempting to address these issues.

Finally, the chapter explains what GEET is, how it functions and what it aims to achieve. Additionally, it reveals key considerations and emerging lessons that could be used by others seeking to develop similar platforms. The chapter concludes by exploring the policy context in which such platforms operate since it could have important implications for the impact that they seek to make.

2 The Information Society

The last few decades have witnessed a gradual but strong emergence of informed societies across the world. This trend, to a large extent, can be accredited to the rapid developments and expanse of ICT. In fact "ICT has been a key catalyst to an "information movement" in all aspects of governance and management, in the government as in the corporate sector" (Niranjan 2005, p. 4870). Advances in ICT have made it possible to transfer huge amounts of information to large sections of the population in extremely short time period. This is not to say that information processing and transfer were absent before this but the scale and speed are incomparable. Additionally, it has also provided the space for the development of a two-way communication process between the governors and the governed, whose interests the former had been chosen to represent.

The existence of enlightened and well-informed citizens is the cornerstone of a healthy democracy. It is based on the principle that information empowers people by adding value to their awareness and improving their understandings. The MacBride Report states that communication holds immense potential to influence the minds and behaviour of people and can be a powerful tool for promoting the democratization of society and expanding public participation in decision-making processes (ICSCP 1980). Thus, the right to information extends the idea of democracy itself.

The foundation of the information society particularly concerning governance is laid upon the principles of accountability and transparency-two essential pillars upon which the very idea of democracy rests. Article 19 of both the United Nations' Declaration on Human Rights and the International Covenant on Civil and Political Rights (ICCPR) emphasizes that the right to freedom of expression not only includes freedom to impart information and ideas of all kinds, but also the freedom to seek and receive it regardless of frontiers and in whatever medium. The United Nations highlights that access to information is a prerequisite to ensure that voices are heard and participation is enabled in a democracy. It also encompasses the core principles of democratic governance, namely, participation, transparency and accountability.[3] Khanwalker (2011) emphasizes that in the Indian context, "The fundamental rights enshrined in our Constitution guarantee, among others, the right to free speech and expression. The prerequisite for enjoying this right is knowledge and information. Authentic information is a must. Therefore, the right to information became a constitutional right being an aspect of the right to free speech and expression. The Supreme Court in a case held that the right to freedom of speech and expression includes the right to receive and impart information. The apex court made it clear that the right to information is implicit in the right to free speech and expression. It is an inalienable component of freedom of speech and expression guaranteed by Article 19 of our Constitution". To instil transparency, accountability and openness, every citizen must have a right to information under the control of public authorities (Khanwalker 2011). Lack of transparency and authentic access to information defeats the purpose of welfare. Therefore, the right to know becomes important to handle the affairs of the executive and also provides a platform for citizens to participate in governance with adequate knowledge. This is not to say that dissemination of information and use of technology alone lead to accountability transparency participation in decision making and thereby deepening of democracy. Various issues associated with the same have been discussed in subsequent sections.

One of the key areas on which the government and citizens interact is social security schemes.

3 Social Security Schemes

The Union and State governments of India have introduced various social security schemes and programmes intended for the well-being of the marginalized sections of the country. These schemes and programmes are aimed towards providing social welfare, enhancing livelihoods, promoting education, providing healthcare and access to basic utilities such as fuel, electricity, water etc. In the development discourse, social security has been defined in a variety of ways giving rise to multiple conceptions of what it entails.

The International Labour Organization (ILO) (2006) defines social security as "the set of institutions, measures, rights and obligations whose primary goal is to provide income security and medical care to individual members of the society." (Cichon and Hagemejer 2006, p. 5).

[3] 'Freedom of Information, Opinion and Expression', Australian Human Rights Commission. https://www.humanrights.gov.au/our-work/rights-and-freedoms/freedom-information-opinion-and-expression (Accessed October 14, 2019).

The Asian Development Bank, however, defines social security as a "set of policies and programmes designed to reduce poverty and vulnerability by promoting efficient labour markets, diminishing people's exposure to risks, and enhancing their capacity to protect themselves against hazards and interruption/loss of income."[4]

The definitions above lay bare the fact that the conceptualization of social security is dependent on larger socio-economic contexts. Consequently, there is a considerable amount of difference between conceptualizations of social protection in the Global South and the Global North.

In the Indian context, the colonial, as well as the early post-independence era, was characterized by a focus on the economic security of labour in the organized sector, congruent with the focus of successive governments on industrial development. The form that this conceptualization took in practice was contributory. Workers and (sometimes) employers were expected to make equal contributions under these social security programs. This is not to say that non-contributory forms of social security did not exist then. The era also saw the beginning of non-contributory social security schemes and programmes. The expansion of the scope of social security to include basic rights like food, housing, livelihood, etc. and benefits for workers employed in the unorganized sector, was a gradual process. Social Rights inclusive of social security, falls under the Directive Principles of State Policy, enshrined in Part IV of the Constitution of India. The Directive Principles of State Policy serve as guiding principles for policy formulation. Despite their non-binding nature, the Supreme Court of India, as well as the High Courts, have played an indispensable role in creatively interpreting Social Rights as Fundamental Rights on various occasions, transforming the understanding of what constitutes social protection in India (Kothari 2014).

Social security in India has indeed come a long way, some challenges that we still grapple with cannot be overlooked. The Government of India spends 1.3 per cent of its GDP on social welfare. Out of the total vulnerable population of the country, 14 per cent receives non-contributory cash benefits, 5.4 per cent of people with severe disabilities receive cash benefits, and 19 per cent of the population is covered by at least one social security benefit (ILO 2017). According to ILO estimates, in 1996, the Government expenditure on social security was 2.6 per cent of the GDP, indicating a significant decline between 1996 and 2015 (ILO 2001). Numerous national and international reports reveal that the reach of social security schemes is low in India. An assessment undertaken by the World Bank reveals that "only 41% of the grains released by the government under the public distribution system reach households. In 2001, the Planning Commission estimated this leakage of grains at 58% nationally" (World Bank 2011). While most evaluations of the implementation of schemes blame its unsatisfactory performance on leakages in the system, lack of information for these schemes is also a major factor behind the same. According to a study conducted on the utilization of geriatric welfare schemes by the elderly population in various parts of India, it was ascertained that the awareness levels differed from scheme to scheme

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[4] 'Social Protection and Labour', Asian Development Bank. Accessed on June 25, 2019, from https://www.adb.org/themes/social-development/social-protection.

and group to group. For instance, in rural Dehradun, only 34.3 per cent of the study populations were aware of geriatric schemes. In addition to this, disparities between awareness levels of males and females and above and below poverty line populations were also noted. The awareness level was ten points larger among men compared to women. "The elderly belonging to below poverty line (BPL) households are the main target for social security schemes, slightly more elderly in above poverty line (APL) families than BPL families were aware of pension scheme" (Srivastava and Kandpal 2014, p. 382).

Congruent with the rapid developments in information and communication technologies (ICTs), "National governments across the world have recognized the potential of web-based IT as being an integral part of outreach programs to citizens post early 1990s" (Lee et al. 2011, p. 445) Much like the rest of the world, with the information technology boom in the 1990s, the Government of India started leveraging these ICTs to strengthen governance mechanisms, with the ultimate aim of social and economic growth. This proliferation of ICTs in governance unfolded primarily to improve service-delivery, enable transparency and reduce corruption, increase the speed of information transmission, cut down costs, empower citizens through access to information and knowledge, decrease the gap between the government and the people and increase access of unserved groups (Prasad 2012). However, dissemination of information through technology did not prove to be the silver bullet that it was expected to be.

4 Information Dissemination Through Technology: Associated Issues

With technology being touted as an effective tool for impacting societies and social protection, access to such technology is, without a doubt, an important precursor for the same. However, uneven access and usage of such technologies clubbed with persisting socioeconomic factors have polarized inequalities within the country and also within local communities.

Degree of Digital Development

For technology to be a viable medium for the dissemination of information particularly to the marginalized sections of the society, one of the most obvious conditions is the degree of development of the digital infrastructure in the country, especially in the rural areas. Estimates indicate that the penetration of the internet for the total population is not even 20 per cent (Fig. 1).

It must also be noted that even though the penetration of internet is still very low and needs to be augmented, a report by Kantar IMRB (Fig. 2) indicates that the number of internet users in India would rise to 627 million in 2019, and this growth would be majorly led by rural India as the rate of the proportion of internet users in rural India is rising at a much faster rate as compared to that in urban areas (ICUBE 2019).

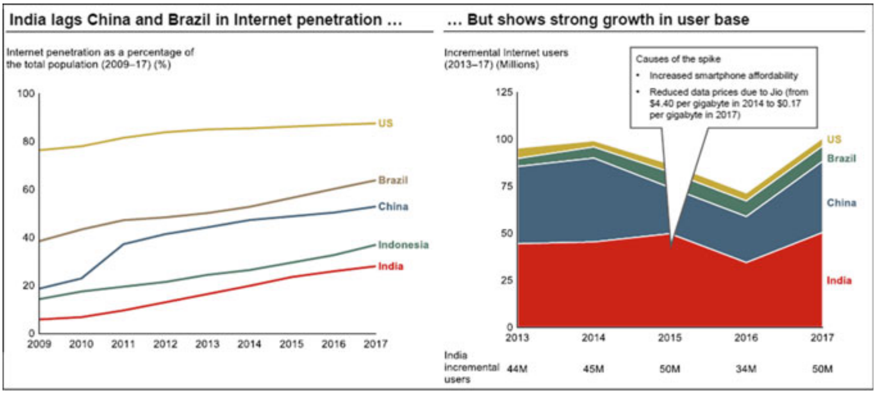

Fig. 1 Internet penetration and trend of internet users in India (*Source* Unlocking Digital Bharat: $50 Billion opportunity', Bain & Company, Google, Omidyar Network. Accessed on June 25, 2019, from https://www.omidyar.com/sites/default/files/Unlocking%20Digital%20For%20Bharat_Final.pdf)

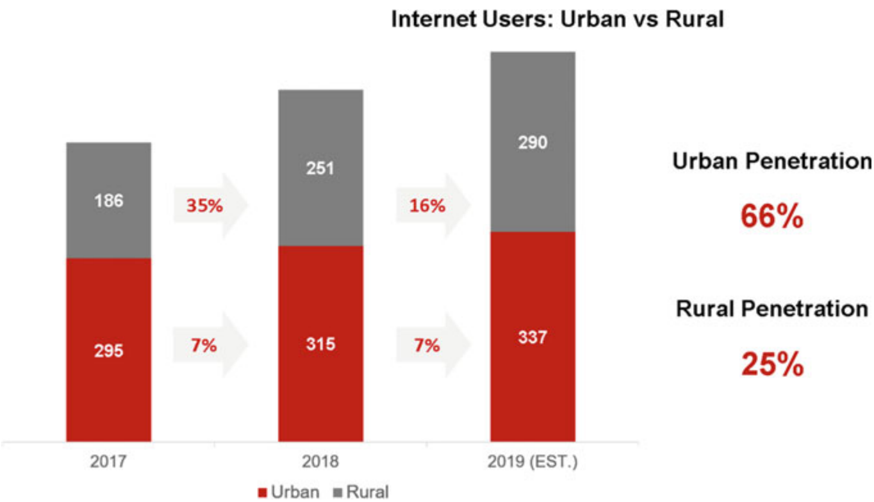

Fig. 2 Internet penetration in India: urban versus rural (*Source* ICUBE (2019), '21st Edition ICUBE: Digital Adoption & Usage Trends', Kantar IMRB, Accessed on June 25, 2019, from https://imrbint.com/images/common/ICUBE%E2%84%A2_2019_Highlights.pdf)

In terms of mobile application downloads also, India crossed the threshold of 10 billion downloads per year in 2017, mainly due to the increase in smartphone use from 23 to 45 per cent between 2015 and 2017 (ITU 2018).

Access to Information and Technology

While it is true that information coupled with ICT has emerged as a powerful mechanism to enhance accountability and transparency, it must not be assumed that an informed society automatically leads to the same and results in increased productivity, collaboration, enhanced participatory democracy and improved quality of life (Marchionini 1999). Global experience shows that 'technology as a solution' approach has overlooked the social structures that it operates within, which determines both access and impact. Social structure is indeed a key factor in determining who can access technology and benefit from its use (DN 2001). Marginalized groups often lack access to technology as well as information on their basic rights and entitlements, public services, health, education, work opportunities, public expenditure budgets, etc. Information dissemination especially through mobile technologies does not occur in a vacuum but gets embedded in the socio-cultural context of the place. Gender and regional disparities concerning internet penetration and usage of mobile technologies bear testimony to this fact (Fig. 3).

Differing Informational Requirements

Besides getting embedded in the already existing fractures of the socio-cultural fabric of the place, the platforms might also lead to an amplification of these fractures by failing to ensure proper diffusion. This is the case, particularly while dealing with relatively sophisticated technology platforms that require a certain level of pre-existing technical capacity (Mansell 2012). This is also the case when information disseminated is in a form that may not be partially or fully understood by the population that it is meant to serve. The capability of the people to comprehend and appropriately respond to the medium as well as the information are some of the key factors which determine the potential of information to have an impact on society. Limited access of the vulnerable sections towards education often hinders their ability to optimally

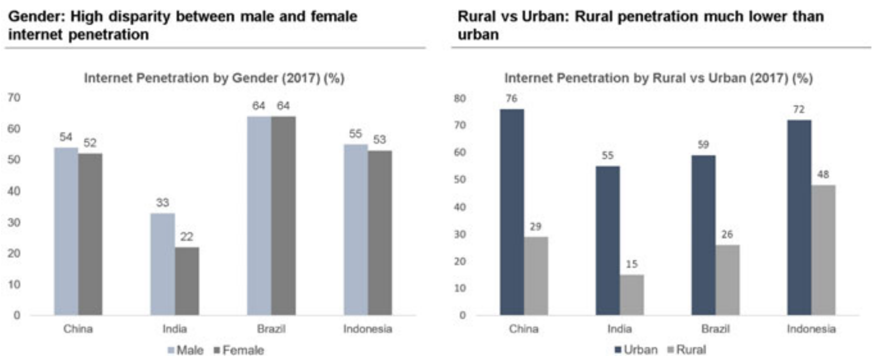

Fig. 3 Disparity in internet penetration based on gender and region (*Source* 'Unlocking Digital Bharat: $50 Billion opportunity', Bain & Company, Google, Omidyar Network. Accessed on June 25, 2019, from https://www.omidyar.com/sites/default/files/Unlocking%20Digital%20For%20Bharat_Final.pdf)

understand and appropriate technologies. A study by Lee et al. (2011) states that countries with a high rate of educated human capital tend to adopt the application of ICT faster. However, ICT has an advantage that a semi-literate or the less literate can access them. At this point, it becomes imperative to understand the meaning of literacy. Literacy is not a bipolar divide between those who absolutely can and cannot read. There are various levels of literacy towards functional, vocational, civic, literary and scholarly purposes. Physical access to books alone does not constitute a criterion for literacy, but it can also be gathered through education, communication, work connections, family support and assistance from social networks. Based on these considerations, it must be recognized that different social groups may have different informational requirements.[5]

The Digital Divide

The continuous lack of access to ICTs and informational capabilities of the most excluded and marginalized groups threatens to undermine their "inclusiveness" and thus can derail the overall goals of improved participation due to existing disparities (Gigler et al. 2014). In literature, these disparities have mostly been understood through the lens of the digital divide. According to OECD, the term "digital divide" refers to the gap between individuals, households, businesses and geographic areas at different socio-economic levels about both their opportunities to access ICTs and to their use of the internet for a wide variety of activities. The digital divide reflects differences among and within countries.[6] Mohanty (2008) mentions three levels of measurement dimensions relating to the digital divide which capture disparities:

1. Unit of observation: Various types of divisions that exist in terms of geographies (such as the rural-urban divide), in between citizens or the type of work.
2. Independent variables: Variables that are codependent on units of observations. For example, if a citizen is the unit of observation, gender, education, level of literacy, age or ethnicity could be the independent variables.
3. Indicators: Which highlight the prevalent technology in use. For example, in India, telecom density, mobile users and probably the recent sporadic increase of internet users.

Initially, the divide begins with the concern of accessibility to technology, in terms of speed of adoption relying on factors such as communication infrastructure, indicating the availability of physical resources to support the digital economy and stimulate its development; human resources accounting for absorptive capacity towards technological innovations based on available knowledge and education. The next stage is when technology reaches a critical mass of diffusion and is accepted as a common standard, then issues of capacity building and required skills need to be considered to appropriate the technologies. Finally, when the technology matures, the

[5]UNDP. (2003). Access to Information: Practice Note. Accessed on August 9, 2019, from https://www.undp.org/content/undp/en/home/librarypage/democratic-governance/access_to_informationande-governance/access-to-information-practice-note.html.

[6]'The glossary of statistical terms'. https://stats.oecd.org/glossary/detail.asp?ID=4719 (Accessed October 11, 2019).

measurement priorities become more and more directed towards qualitative aspects of digitalization. In this regard, outcomes such as the impact on social and economic activities and the structure of production, consumption and employment, become increasingly relevant for technology (van Dijk 2012).

5 Bridging the Gap

Drawing on the discussion above, it can be established that the digital divide can never be contained in isolation as it is a complicated patchwork of varying levels of ICT access, usage and its applications among countries and people. Therefore, efforts towards reducing these gaps have to be multi-dimensional and multi-pronged. One of the approaches could be, designing appropriate digital platforms which present information in visual or audio-visual formats that can be easily understood by semi-literate as well as illiterate people. Such initiatives attempt to go beyond the dissemination of information and promote the democratization of information. The democratization of information empowers the community to use the information in a meaningful way to shape their narrative. At the micro level, the benefits of such initiatives have been documented in Kerala where mobile phone usage among fisherwomen benefitted both producers and consumers due to enhancement in information and better functioning of markets (Jensen 2007).

For increasing the reach of social security schemes, various technological platforms of different nature have been created by the government, social entrepreneurs as well as civil society organizations. Following are some examples of the same:

1. *Haqdarshak* is an online platform, which consists of a comprehensive database of state and centrally sponsored schemes as well as private schemes, in an easy-to-understand format. It aims to "transform the way citizens access their entitlements" through technology. It seeks to put in place a system of village-level entrepreneurs who act as enablers by taking the platform to the doors of the citizens and helping them discover and apply for the schemes in return for a nominal fee. Through collaborations with governments, corporates and foundations, they seek to strengthen the entire delivery system and overcome challenges that they might face in the process.[7]
2. *Schemopedia* is a similar online platform which collates information regarding government schemes from various sources and assists citizens in applying for the ones that they are eligible for, to generate increased demand for these schemes.[8]
3. *The Indian Iris* is another comprehensive online platform of state and centrally sponsored schemes that aims to enable the citizen with information regarding all the state and centrally sponsored schemes, government policies and programs.[9]

[7] Haqdarshak available at https://haqdarshak.com/home (Accessed on July 31, 2019).

[8] Schemopedia available at https://schemopedia.com/ (Accessed on July 31, 2019).

[9] The Indian Iris available at https://www.theindianiris.com/about-us/ (Accessed on July 31, 2019).

The GIS Enabled Entitlement Tracking System (GEET) is a similar effort that seeks to demystify and democratise scheme related information to enable citizens to claim what is entitled to them.

6 GEET: Leaving No One Behind

To address issues such as information deficit, digital divide and inability to understand or access information, the Ministry of Rural Department (MoRD) with support from the United Nations Development Programme (UNDP) collaborated with the Foundation for Ecological Security (FES) to develop GEET. GEET was developed as a platform intended for enhancing the reach of information pertaining to welfare schemes and programmes under the 'Governance and Accelerated Livelihoods Support' (GOALS) project which targeted improving livelihoods of marginalized communities by enabling a proactive and responsive means of governance. The initiative focuses on building the capacity of communities and other stakeholders by generating awareness, mobilizing youth for participatory planning, and enabling convergent planning and implementation of development programmes. The UNDP played a central role in providing the policy support and technical assistance to the ministry, state agencies and FES, to improve the linkage of communities with Panchayati Raj Institutions (PRIs).

In this endeavour of leaving no one behind, every household and individual must be able to avail their entitlements and have access to programmes that enhance their livelihood options. The platform not only helps communities identify and access various government schemes and programmes that they are eligible for at a single platform, but also provides information pertaining to those schemes, the required documents to apply for the schemes and the concerned departments to approach. Furthermore, the tool also allows them to track the progress of their applications and notifies them through an SMS once their applications are approved by the respective government departments. The system also helps various government officials at the state, district and panchayat levels to monitor and track the reach of entitlements and services to each individual and household. It allows officials to view and assess the reach and progress of various schemes through a map of their region to enable informed action for reducing the shortfalls.

As part of the project, GEET has been deployed in the states of Jharkhand and Odisha in collaboration with the respective State Livelihood Missions. The states were selected due to higher levels of poverty and deprivation in every district, as observed by the UNDP. The National Rural Livelihood Mission (NRLM) institutional framework in the states, with the State Rural Livelihood Mission (SRLM) and the community based organisation (CBO) structure provides the platform for this work in Jharkhand and Odisha. The process at the community level is planned as a collaborative engagement between the project functionaries working in close tandem with the District and Block Mission Management Units of the SRLM, the functionaries of the community institutions and the gram panchayat. GEET has also been implemented in FES's project regions in the states of Karnataka, Maharashtra and Rajasthan.

Initially, for effective implementation, self help groups (SHGs) were chosen as the unit for intervention in Jharkhand and Odisha. SHG seemed to be an ideal unit, considering its inclusive approach as an institution, and its success as micro-financing entities. Since women SHG members were already equipped with the required skills and experience of managing the units, it seemed appropriate to build on their capacity as enablers of the system at the grassroots level which was further enhanced by providing them with the required training. For implementation in other areas, local resource persons were identified and trained accordingly.

The crux of these capacity-building initiatives is to make a pool of skilled resource persons available to cater to the service-based need of local communities while simultaneously fostering local stewardship. By targeting the local communities, these initiatives aid in informed decision-making and empower them to voice their entitlements. This has significantly helped in the widespread use of GEET in the targeted areas.

GEET is guided by the following objectives:

- **Enhancing community participation** in tracking their rights and entitlements as informed citizens.
- **Assisting monitoring** by the state, district and other government officials in assessing the reach of services to each individual/household.
- **Advancing community and government linkages** to make entitlement tracking an interactive process.
- **Updating** the database periodically through community workers.
- **Strengthening livelihoods** of small, marginalized, and landless households by providing access to social security schemes.

Keeping these objectives in mind, campaigns are one of the first steps towards implementing GEET. Intensive campaigns are carried out with the support of community institutions and local resource persons to raise people's awareness at the village and/or gram panchayat level towards various government schemes and programmes. The campaigns play the role of disseminating information, targeting awareness among the most marginalized communities (Fig. 4).

After the campaigns are conducted, the community institutions take the onus of organizing village meetings where GEET as a tool is explained. The entitlements that need to be tracked are decided by the community in a participatory manner. The tool also intends in making community institutions and members responsive in helping identify the most vulnerable households and prioritizing those households for entitlements first. The households are enlisted, and the local resource person or the data enumerator goes to each identified household or individual and records the household information. Upon registration, an entitlement card along with a number is generated through which the individual/household gets to know the schemes that they are eligible for. The entitlement card also tracks the entitlement records of the individual/household and updates the individual/household whenever they become

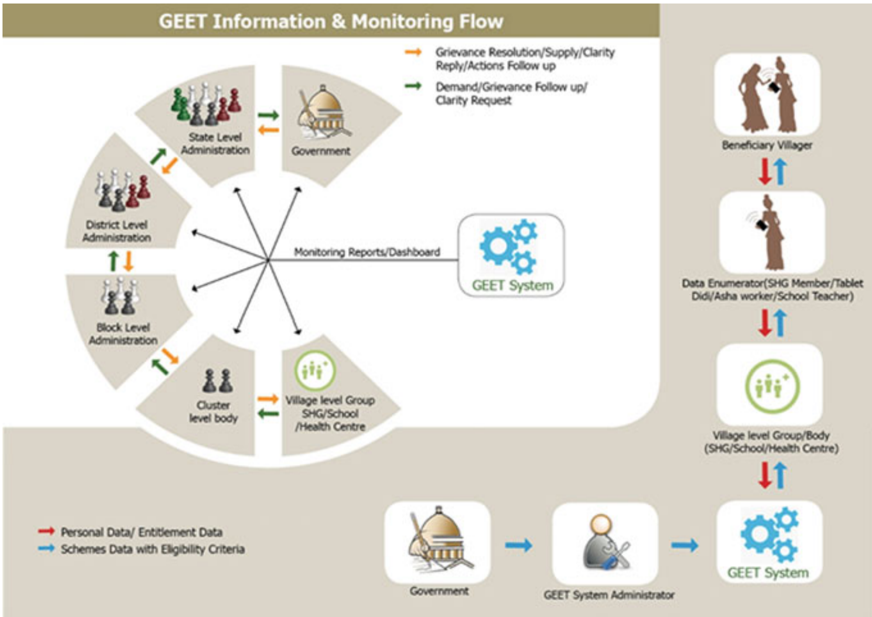

Fig. 4 GEET process (*Source* GEET User Manual, FES)

eligible for new or existing schemes. Furthermore, this unique ID also tracks the status of entitlement application at the village, block, district and state level (Fig. 5).

After knowing their eligibility, the individual/household gets to know the documents required and the department to approach to avail the scheme. The enumerator maintains a list of targeted members for a specified region which can be updated as and

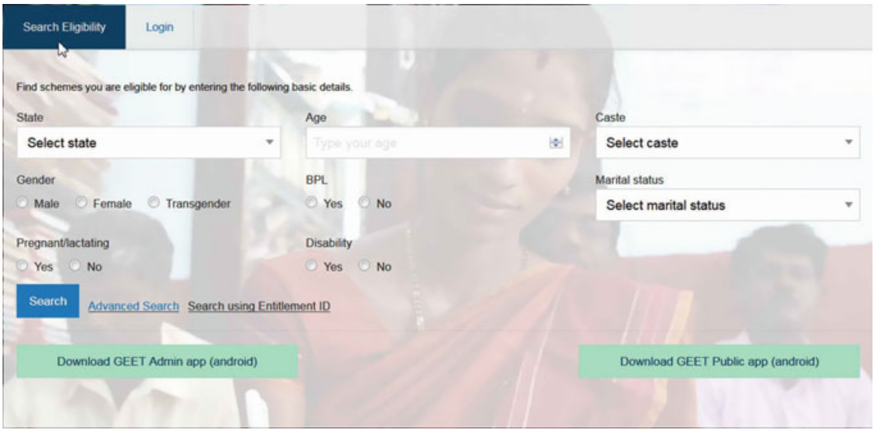

Fig. 5 GEET search engine with different parameters *Source* GEET User Manual, FES

when necessary. It allows them to maintain data quality as the system provides flexibility to make changes in the collected data; verify the data of an individual, generate an entitlement number for them, add new records of individuals or households and track their entitlements. An individual can also record his/her grievances related to the scheme/programme that he/she has applied for. The status of the grievances (whether resolved or unresolved) can also be tracked in the system. Simultaneously, as individuals or households apply for various schemes, the village level body (be it community institution or the gram panchayat) is periodically notified by the data enumerator and maintains a register which records all applications, their status and grievances.

To enable easy and efficient monitoring for government officials at the block/district level, the system generates info-graphics on the socio-economic and demographic data of the local area along with GIS maps that track the eligibility and implementation of the schemes and programmes. This assists the officials in informed decision making and efficient implementation of the programmes. Once the data is recorded in GEET to avail a particular scheme, it notifies the administrators across all levels (viz., gram panchayat, block, district and the state). These administrators can view the time of application along with the type of scheme a person has applied for. The system intends to alert the administrators by displaying the age of application through which a delayed response on part of the government can be held accountable.

7 Key Considerations and Emerging Lessons

While a systematic impact evaluation of the platform is yet to be undertaken, a preliminary examination of the key considerations and emerging lessons is essential and might be insightful for others seeking to develop similar platforms.

Information Democracy versus Information Dissemination

In today's information-rich world, big data sets are being used to inform important decisions by the corporate sector, the government as well as the civil society. However, as already established in the discussion above, the realization that data could provide important insights is not always followed up with meaningful action. Further, the 'last mile' (which should be treated as the 'first mile') reach of the information is contingent upon a variety of socio-cultural, economic as well as political factors. To address these gaps, the focus needs to shift from just 'Information Dissemination' by the information-rich sections of the society to 'Information Democracy' to ensure that no individual is hindered from being an active agent of change because of factors like the inability to read or speak a particular language, his/her caste or class position etc. Information democracy takes into cognizance the fractures that exist in the society and seeks to leverage the power of information to address those very fractures besides influencing short-term decisions. In practice, promotion of information democracy in the context of technology platforms like GEET, might translate into simple steps like usage of multiple languages or infographics, videos, provision of options for offline usage etc. “A significant part of the e-governance effort in India involves innovative forms of ICTs that allow citizens to use touch screens, integrated voice response systems, dedicated helplines (e.g., for farmers), videos, mobile applications, and community radio to overcome some of the problems of literacy” (Prasad 2012, p. 191). Therefore, the medium used, the form in which the information is presented as well as supporting offline activities are critical elements for scaling the gap between information dissemination and information democracy.

Means of Proactive Governance

A system designed while keeping in mind the principles of information democracy possesses the potential to influence governance positively by equipping the citizen with the information required to make reasonable demands from the government. Often, the poor reach of social security schemes in India is attributed to a lack of demand for the same. If not filling the demand gap, information may help in starting the journey towards addressing it. To do this, deliberate efforts need to be undertaken to design the architecture of the system carefully.

For instance, the architecture of GEET is such that it requires administrators at the panchayat, block as well as the district level to be active in the system. With the mechanism to produce a report along with a GIS map highlighting the state of social security schemes within a particular area administrators can see the status of her/his state, block or village. This enables them to prioritize certain schemes in their area or target certain areas that require greater attention. The system acts as a voice to the government to enable its response to society through informed action. It attempts to narrow down and converge the gap between the public and the administration while aiming to improve uninformed planning and implementation of schemes. Further, it seeks to promote transparency and accountability through mechanisms like provision of notifications to administrators across all levels when new data entry is made. This allows them to view the time and the type of scheme a person has applied for while creating pressure on him/her to respond as all the actors involved are aware of the demands generated from the community.

The Role of Critical Enablers

There is an increasing recognition of the fact that to ensure the sustainability of initiatives for change at the local level, there is a need to build ownership of the initiative, among the community members. Identification and capacity building of critical enablers within a community is one way of doing so. The deployment of GEET at the local level occurs through a rural cadre capacitated with different sets of skills to provide services to households and to assist village panchayats in facilitating the process of development. The key focus is on shaping them as stewards for their respective regions so that they can effectively play a part in influencing and working towards the development of the region. In Jharkhand, SHG members act as critical enablers of GEET at the local level. This not only helps in building ownership but also situates the initiative in already existing institutions, puts women at the centre of the process and builds on existing capacities. Whether the initiative is implemented by an existing cadre or a new cadre built specifically for the initiative, choosing critical enablers carefully may not only help in serving the purpose of that specific initiative but also create positive spin-off effects like empowerment of women, strengthening of existing institutions, etc.

The Significance of a Strategic Mix of Activities

It is often the case that the success of the initiatives which involve creating change through technological platforms is measured by the number of people that adopt the platform and start using it. In many cases, this leads to the usage of the platform by more number of people to become the ultimate aim. The issues that platforms like GEET seek to address go much beyond this. "Poverty alleviation is not a matter of service delivery, but one of enhancement of agency of the poor, based on the transformation of class, caste, ethnic and gender relations within which the poor exist. The 'technology as solution' approach ignores the social structures that determine both access and impacts" (DN 2001, p. 917). Therefore, if the aim is to promote information democracy, just creating platforms that collate information in easy formats is not enough. A strategic mix of online as well as offline activities needs to be undertaken to create the desired impact. Demystification of data on the platform along with campaigns, capacity building sessions for the community as well as administrators, deployment through a rural cadre is one such mix that GEET makes use of. The mix of activities was guided by the idea that it will potentially "ensure the uptake of the tool among the community engendering government responsiveness while simultaneously building an informed and empowered collective of users of public services" (Schaaf et al. 2018, p. 182). Thus, the use of tools and technology must not be treated as an end in itself but as a means to achieve a larger end.

8 Policy Context

"*We need to create an Indian Model of information system suited to our needs*" – Sam Pitroda.

As evaluated through the origins and discourse around the digital divide prevalent across the world and India, the dissemination of this information as through the internet, however, has been privy to only certain sections of this society, causing this transformation to be accused of lack of social inclusion. While GEET is indeed a step towards social inclusivity which enables the better functioning of a welfare state, it is vital to locate GEET and other tools developed for individual empowerment in the larger context of India's legal and policy regime. For, the success of GEET and other technologies that seek to impact the social change would find no meaning if they fail to be in congruence with the larger governance regime.

In its latest report, The McKinsey Global Institute identified 12 disruptive technologies for India that would transform lives, business and the global economy. One of them duly listed under "Smart Physical Systems" was the Advanced Geographic

Information Systems (Kaka et al. 2014, p. 2). This potential could serve as a major catalyst not only for impacting societal structures, but also in ensuring social inclusion of the marginalised. According to its estimates, roughly 50 per cent of government spending on basic services does not essentially translate into real benefits for people, with cumbersome government processes being an obstacle for investment and growth (Kaka et al. 2014, p. 8).

Moreover, while India ranks eighth in the world in terms of affordability of ICT, in the Networked Readiness Index, it is in the 91st position.[10] This Index measures "how well an economy is using information and communications technologies to boost competitiveness and well-being" and "shows how ready each country is to reap the benefits of that transition" (Breene 2016). This disparity in the rankings is demonstrative of the information gap, even in the country's transformation into a digital era. However, the government has created numerous platforms for the exploration of opportunities to use technology for influencing social change.

The first of these was to work for "technological empowerment and sustainable livelihoods at the grassroot levels", it brought out "SEED"—Science for Equity Empowerment and Development that sought to motivate scientists to take up action-oriented and location-specific projects with the preliminary aim of socio-economic upliftment of the poor and disadvantaged sections of the society through science and technological interventions. The outcomes of this program have been innovative water management techniques, development of cost-effective solar panels, creation of women technology parks etc.[11]

Under the Digital India initiative too, three national software policies, shortly referred to as Open API policy, Open Source Policy and Source Open policy are being operationalized through a platform called Open Forge, which the government hopes would "become a catalyst in helping lay the foundation of a truly modern era of open government".[12] The National Centre of Geoinformatics also currently makes use of only Open Source Software, with 240 applications across the Centre and States on land information, rural electrification, mining surveillance etc.[13]

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[10]Baller et al. (2016), Country Profiles, *The Global Information Technology Report 2016 Innovating in the Digital Economy*, p. 110. Retrieved July 31, 2019, from https://reports.weforum.org/global-information-technology-report-2016/economies/#indexId=NRI&economy=IND.

[11]Science for Equity Empowerment and Development (SEED), Department of Science and Technology. https://www.dst.gov.in/scientific-programmes/st-and-socio-economic-development/science-equity-empowerment-and-development-seed (Accessed August 1, 2019).

[12]'Open Governance Systems', available at https://openforge.gov.in/opengovernance.php (Accessed June 29, 2018).

[13]'National Centre of Geoinformatics—Open GIS Platform'. https://openforge.gov.in/opengis.php (Accessed July 29, 2019).

In 2014, along the same lines, the government also launched a participatory governance initiative called mygov.in platform, which created an interface for an exchange of ideas on policies, socio-economic issues and other decision-making processes of the country. It boasts of 7.9 million users and more than 10,000 posts per week.[14] In continuation of the recognition of the fact that data is an important precursor for the development of adequate technology for empowerment, kick-starting with the National Data Sharing and Accessibility Policy[15] in 2012, an open data license too has been formulated.

The Twelfth Five-Year Plan had equally sought to create ecosystems that would promote innovation in ICT for governance and for applications that can benefit the citizens, to better target welfare schemes of the central and state governments, to make available as much data as possible in the public domain for productive use by citizens (Planning Commission 2012). It is necessary that the country uses policy and regulation as an imperative tool to enable and support technology adoption.

In addition to facilitating institutional and policy regime changes, the government needs to adopt such technological innovations for providing its services, to establish the narrative for governance and service provision. This would require that many stakeholders, regulatory agencies and private entities be brought on board as effective participants. The McKinsey Global Institute also recommends that opening up data sets to the public would aid in the fostering innovation and transparency. With India ranking 63 out of 70 countries on data openness due to a formidable lack of machine-readable records and limited availability of timely data in bulk, it is time that the government develops mandates requiring the release of open data through incentives and mutual support. One of the methods that could be adopted internally by the government is to ensure that its ministries' and agencies' digital initiatives conform to the Ministry of Electronics and Information Technology (MEITY) guidelines for open application program interfaces (Kaka et al. 2019). Individuals and private entities seeking to create products could easily leverage such openly available data.

It is not however entirely correct to say that no such data is publicly available. While the Right to Information Act, 2005[16] has served as one of the statutory tools for extracting data from governments, platforms such as data.gov.in have also been created as umbrella portals for accessing data sets. While the website is an exhaustive space with "229,793 dataset resource, 4,431 catalogues contributed by 137 Ministry/Departments (85 Central add 52 States), 1,500 visualisations created, 7,860 Application Programming Interfaces (APIS) created, 196 Chief Data Officers (105 Central and 9 States)",[17] disarray and lack of comprehensibility associated with the data is one of its major drawbacks. Such information is rendered useless if it is

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[14] 'MyGov: An Overview'. https://www.mygov.in/overview/ (Accessed July 29, 2019).

[15] 'National Data Sharing and Accessibility Policy'. https://www.dst.gov.in/national-data-sharing-and-accessibility-policy-0 (Accessed July 28, 2019).

[16] Right to Information Act, 2005, Government of India. https://rti.gov.in/rti-act.pdf (Accessed July 28, 2019).

[17] 'IT Professionals Should Join Hands with the Government to Make India a Digital Society', November 1, 2018, Ministry of Electronics and IT, Press Information Bureau, Government of India. https://pib.nic.in/newsite/PrintRelease.aspx?relid=184542 (Accessed August 3, 2019).

hidden or access is limited to users. The futility of hidden data does not require to be underscored. The first step for overcoming such functional disparities could be India becoming a signatory to the International Open Data Charter, which is a collaboration between governments and organisations working to instil a culture of open and responsible data use in governments and their citizens.[18]

9 Conclusion

It, thereby, remains pertinent that for the development of technology and applications like GEET, the enabling policy environment accommodate necessary precursors and stimulants such as data availability. It is not, however, to say that this would be an end in itself, for a long battle ranging from cultural acceptability, privacy concerns, adaptability etc., remain. Despite such foreseen and unforeseen complications that are likely to arise in the adaption of ICT for societal change and social protection, efforts like GEET are stepping stones in the direction—democratising information and ensuring that 'no one is left behind'.

Implementation of major schemes has suffered in the past and continues currently owing to the lack of awareness about the scheme among the target stakeholders. In a vast democracy like ours, initiatives like GEET can play a transformative role in ensuring the delivery of schemes which would effectively aid in the nation-building process. This will also, in turn, enable policymakers to effectively strive towards achieving the sustainable development goals of ending poverty, gender in equality, etc. It may very well be argued that GEET is rather microscopic in the larger context of achieving information democracy in a country beset with assorted challenges, but it, however, cannot be denied that it is nevertheless, a catalyst for the very goal.

Acknowledgements This chapter captures the experience of designing and implementing GEET, a tool developed by the Foundation for Ecological Security (FES), to boost the 'first mile' reach of social security schemes in India by democratising critical information regarding the same. We acknowledge the efforts of Ashok Jani, Jay Patel and Himanshu Rana from FES who were instrumental in developing the tool and sharing insights from the experience of implementing GEET in the field. We would also like to thank Pratiti Priyadarshini for providing her valuable feedback on the chapter.

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Chapter 13
Mobile Application in Agriculture Development in India: Policy, Practices and the Way Forward

Vikas Kumar

1 Introduction: India's Approach in Perspective of S&T Policy and ICT

India's Science, Technology and Innovation Policy (STIP) may be traced to the 1950s when Prime Minister Jawaharlal Nehru introduced the scientific policy resolution (SPR) in the Indian Parliament. It revealed the Science and Technology (S&T) vision for peace, industrialization and its commitment to using S&T for solving India's social and economic problems. The period from 1947 to 1973 is usually considered the phase of 'policy for the Sciences' when the focus was on developing basic infrastructure for (S&T) in India (Ministry of Science and Technology 2013). The S&T plan during 1974–1979 aimed at attaining indigenous technology capabilities in various sectors. By the early 1980s, India has joined the global nuclear and space 'clubs', had experienced relative success in the 'Green Revolution' in food grain production and had brought in the 'White Revolution' in milk through agricultural research and technology. India had become self-sufficient in agriculture and its allied sectors.

The subsequent S&T policy was brought in 2003 which shifted its focus towards promoting globalization and exports. During this phase India's information and communication Technology (ICT) software, pharma, auto and telecommunication sectors witnessed a good deal of growth and dynamism. After a decade, in the year of 2013, a new STIP has introduced. Meanwhile the President of India declared 2010–2020 as the 'Decade of Innovation'. In the last few years, the government has identified several national flagship programs and missions which entail S&T, R&D and technological inputs and resources including financial and human skills. One such new flagship programme 'Digital India' aims to boost ICT software, e-governance and telecommunications. With massive diffusion of mobile phones in

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_13

India—over 950 million mobile phone users, next only to China—a platform has emerged to bridge the digital divide (Krishna 2016).

With this backdrop, the objectives of the chapter are (i) to study the role of mobile application in agricultural development and its challenges; (ii) to enquire into policy implementation and issues related to using mobile application at the field level; and (iii) to examine the impact of mobile use on farmers at the field level.

2 Digital India: An Evolution

During the mid-1990s, the journey of e-governance was initiated across India with a focus on citizen-centric services. Later on, in 2006, the National e-Governance Plan was started with 31 Mission Mode Projects covering a wide range of domains, viz., agriculture, land records, health, education, passports, police, courts,municipalities, commercial taxes, treasuries and others. In 2015, the new flagship programme 'Digital India' was launched to build upon India's relative success in the ICT sphere, e-governance and telecommunications sectors,as observed during the last decade. The goal of this initiative was to deliver governance through mobile phones throughout the country. It aimed at ensuring the last mile connectivity and internet access to the rural population through a National Optical Fibre Network (NOFN); it was to begin by connecting 250,000 villages (INDIGO Policy 2016).

Further, under the national policy framework, the central government has emphasized on increasing the use of ICT in the agriculture value chain, especially in marketing and communication. For this purpose, the government has launched a mission mode project (MMP) which was included in the national e-governance plan (NeGP) to provide information to the farmers on seeds, fertilizers, pesticides, government schemes, soil recommendation, crop management, weather and marketing of agricultural produce. In addition to this, the Department of Agriculture and Cooperation (DoA&C) has introduced numerous projects, for instance, ASHA in Assam, KISAN and e-Krishi in Kerala and Krishi Maratha Vahini in Karnataka. The two portals namely AGMARKNET and DACNET have been launched by the agriculture departments to lead the implementation of MMP in agriculture (World Bank 2017).

2.1 Mobile Application as an ICT Tool in Agriculture

The ICT provides a range of information to the farmers from planting to cultivation. Broadly, it helps to diffuse new technology, input management, land selection and preparation, securing finance, transportation, packaging, processing, and marketing of the agricultural produce. The mobile technology for communication is perceived to be a game-changer in the extension services space.

In this context, Kisan Call Centres (KCCs) were launched by the Ministry of Agriculture, Government of India in 2004 to answer farmers' queries over the telephone in their dialect (Ministry of Agriculture, 2020). Although, there are various modes of service such as internet-related, touch screen kiosks, agri-clinics, private kiosks, mass media, the Common Service Centres among this mobile telephony (whether internet based or offline) have been a significant tool for agricultural extension. Although, according to TRAI, there have been approximately 38 crore mobile telephone connections in rural areas till May 2014, internet connectivity has been low. Hence, SMS became an effective tool to deliver information and, as shown in Fig. 1, nearly 8.93 crore farm families were connected to this facility (mKisan.gov.in 2020a, 2020b). All these modes are operationalised the mKisan Portal, launched in June 2012 to provide information/services/advisories to formers in their preferred language based on the location.

As can be seen from Fig. 1 the highest number of farmers registered was from Delhi (63%), Haryana (53%) and Kerala (nearly 53%); it may be due to connectivity with urban areas and awareness about the programs. However, states with low registration include Bihar, Jharkhand, Madhya Pradesh and Karnataka. It is interesting to see the sector-wise number of information provided. Table 1 indicates that agriculture and horticulture-related sectors have been provided more advisories whereas in terms of messages sent, agriculture and animal husbandry sectors dominate. Based on the data, it may be held that because of Indian farmers are more depended on agricultural activities, queries related to crop, pest and weather were high.

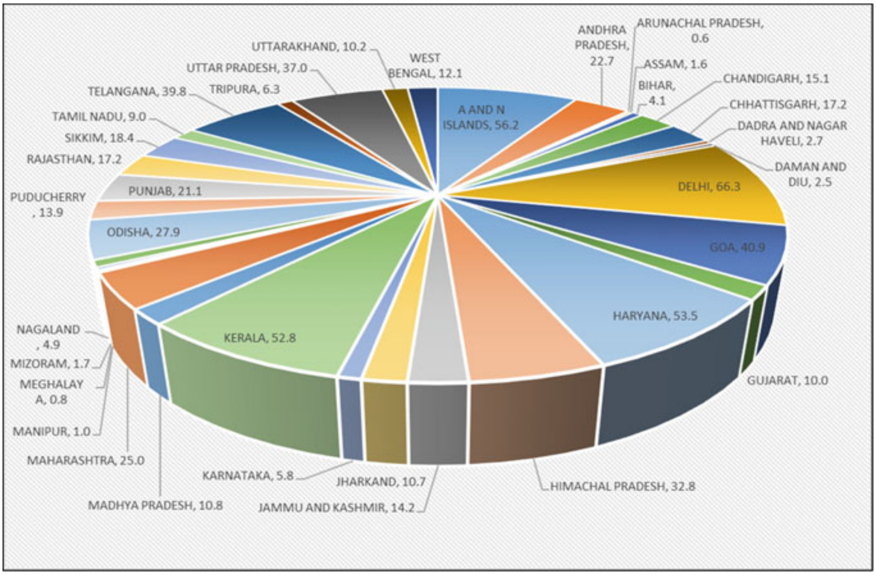

Fig. 1 State-wise percentage of farmers registered to access SMS facilities, May 2013–April 2020. *Source* Computed from https://mkisan.gov.in/dashboard.aspx, (2020) (Accessed on April 20, 2020)

Table 1 Sector-wise number of advisory and SMS sent, May 2013–April 2020

Sector	No. of advisory	In percent	No. of message	In percent
Agriculture	412,594	92.47	9,214,012,903	90.64
Animal husbandry	5304	1.19	416,553,600	4.10
Dairying	181	0.04	2,620,201	0.03
Fisheries	1723	0.39	26,841,916	0.26
Horticulture	23,960	5.37	396,622,051	3.90
Sericulture	1574	0.35	6,877,779	0.07
Sugarcane	839	0.19	101,962,630	1.00
Total	446,175	100	10,165,491,080	100

Source Computed from https://mkisan.gov.in/dashboard.aspx, 2020 access on 20 April 2020

Aker (2011) argued that mobile phone services in the agricultural sector have provided information on the market, weather, transport and agricultural techniques to contact concern agencies and departments. Similarly, several authors (Bayes et al. 1999; Goodman 2005; Kwaku et al. 2006; Donner 2006) have pointed out that mobile phones have given a new dimension to farmers to build tentative decisions much more easily than before. Mobile interaction facilitates greater social cohesion and a better social relationship between farmers and the business community. From this aspect, mobile phones are considered important for agriculture development and also for providing connectivity and offering benefits such as mobility and security to owners.

Zakar and Zakar (2009) stated that the mobile phone is a medium to transfer knowledge and information regarding land preparation, intermixture of cropping, water management, harvesting, and so many farm-related activities. Mittal and Tripathi (2009) conducted a study on the role of mobile phone technology in improving small farm productivity. The study concludes that the sharing of information through mobile phones improves farm productivity and rural incomes. Silva and Ratnadiwakara (2005) had conducted an empirical study in Sri Lanka about the use of ICT in agriculture. The study pointed out that mobile phones helped to reduce search costs at various stages. Masuki et al. (2010) studied the use of mobile phones in improving communication and information delivery for agricultural development in south western Uganda. The study shows that mobile phones could be used with greater efficiency by farmers in a rural setting as they were enthusiastic about using the phone to access information on agriculture and natural resources management. Table 2 shows various initiatives taken in India towards providing wide range of options in ICT models.

Fischer et al. (2009) observe that ICT plays an important role in the adoption of technologies that are newly started like no-tillage and the GM technology. The following section discusses the use and the impact of mobile applications with the involvement of various actors' who function at various levels as diffusion or commercialization of the technology concerning agriculture.

Table 2 ICT tools in India over the years

ICT	ICT tools
Tele-centre based	– Kissan Call Centers, GoI, 2004
Internet-based	– Village Knowledge Centres, 1998 – ITC e-chaupal, 1999 – E-sagu, 2004
Video-based	– Digital Green, 2009
Mobile-SMS based	– Reuters Market Light (RML), 2007 – Warna Unwired- Microsoft, 2007 – KVK's-NAIP, 2009 – Kisan Sanchar, 2010
Mobile-based application	– Fisher Friend- MSSRF, 2008 – Nokia-Life tools, 2009 – Tata-M Krishi, 2009
Mobile voice message based	– IFFCO Kisan Sanchar Ltd. (IKSL), 2007

Source Adapted from Mittal and Mehar (2012), p. 231

2.2 *Involvement of Key Actors in Mobile Application for Agriculture*

Broadly, different actors play their discrete roles in the channel of networks within a system. In order to adopt or promote mobile-based information are four types of actors are involved. The first and the dominant actors are the mobile network operator as in developing countries they decide which m-apps they want on their systems. The second actor is the mobile app providers; they develop the application. The companies are free to innovate and drive the development of m-apps. The third actor is users, who may be in of different types. Based on their goals, mobile apps target different types of user. Finally, the fourth actor is the content providers; this actor provides hyper-local information as a key part of their services. It is useful because this actor justifies information related to agriculture. In this process, several other players are also involved such as specilised service providers and civil society organisation as shown in Fig. 2.

3 Use and Impact of Mobile Application in Agriculture Development

Mobile application in agriculture can be seen in various forms and functions, for instance, in providing market information, increasing access to extension services,

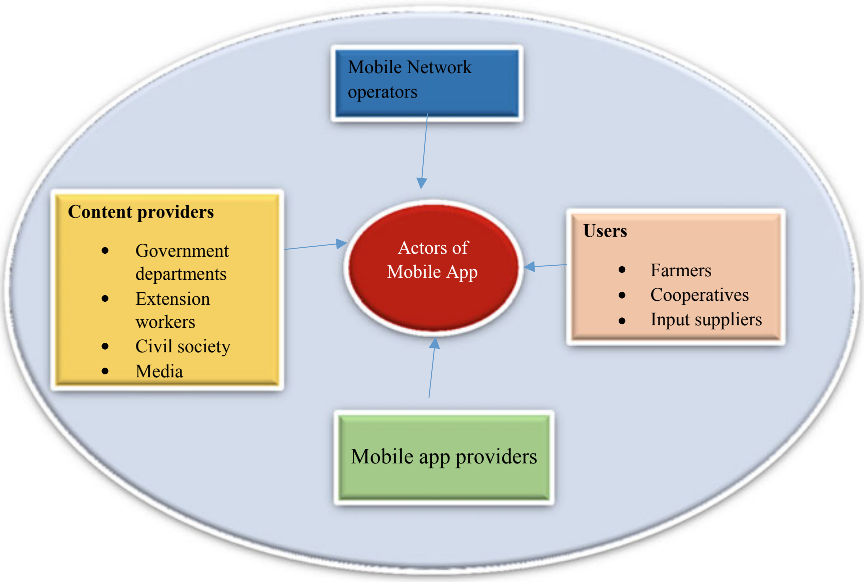

Fig. 2 Key actor of mobile application for agriculture development. *Source* Prepared based on available literature

and facilitating market links. Interestingly, users are not only farmers, but also include produce buyers, cooperatives, input suppliers, content providers, and other stakeholders who demand useful, affordable services. It helps to enhance economic and social benefits—among them, creating jobs, adding value, reducing product losses, and making developing countries more globally competitive (World Bank 2011) as shown in Fig. 3.

As can be observed from Fig. 3, broadly, there are four main uses of mobile application, namely, (i) better access to information; (ii) better access to finance; (iii) better access to extension services; and (iv) better market links and networks. All these use a link with each other whether directly or indirectly and provide benefit to farmers as well as traders and organizations in terms of higher income for small and marginal farmers through the access to market prices, generation of new opportunities for financial institution, improved traceability and quality standards for buyers and lower transaction, logistics and distribution costs for suppliers in terms of government extension services.

Aker and Mbiti's (2010) is study in Niger point out that mobile phones as new search technology have reduced nearly 50% of the search cost for farmers. It claim that mobile telephony is an active recipient of information comparison from other sources of information such as television, radio or newspapers etc. It also helps to access the quality of the information received. Kameswari's (2011) study in the state of Uttarakhand relates to agriculture information and seeking behaviour of farmers in the state. It observed that mobile phones were broadly accessible but mostly were

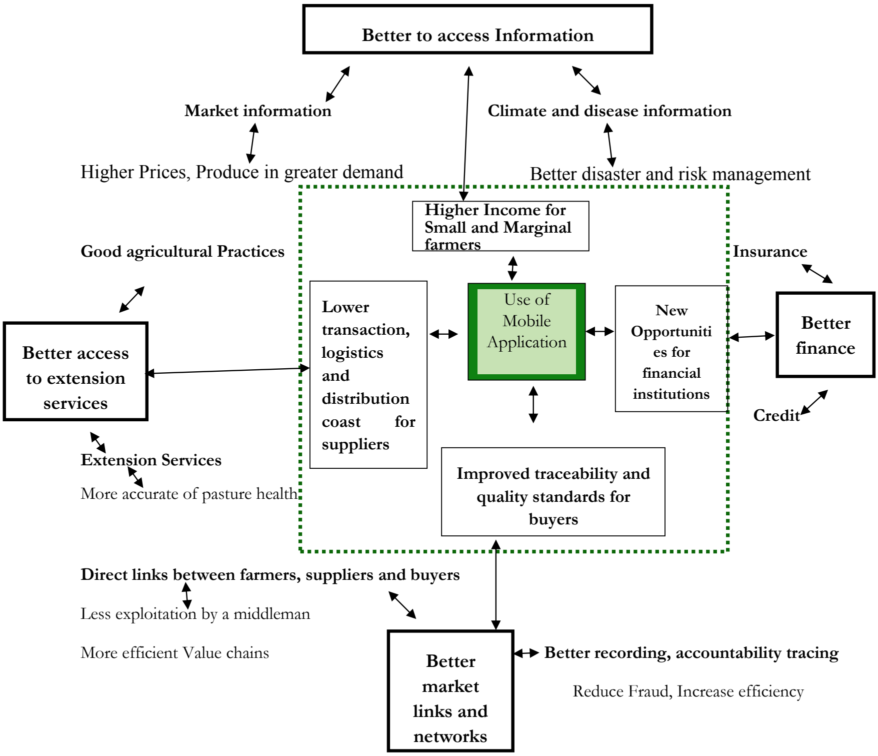

Fig. 3 Use of mobile applications and their benefits types for agricultural and rural development. *Source* Prepared based on the World Bank Report (2011)

used for post-sale inquiry rather than paddy negotiation, accessing markets or paddy information or increasing production efficiency.

Further, Saha et al. (2012) have studied m-Sahayak—the innovative android-based application for agriculture and health sectors in India. The study points out that the diffusion of the mobile phone brought in scientific expert advice to the farmers anytime and anywhere. It made a comprehensive impact on farming. Similarly, Razaque et al. (2013) stated that the mobile phone had created an opportunity for the farmers especially to access information about marketing and weather. It helps to keep them aware of the weather forecast for deciding on the agricultural inputs. The study found that mobile phones saved energy and time of farmers and improved their income. Broadly, it had given a new path and approach to farmers to communicate directly and share knowledge.

Bhalchandra et al. (2014) conducted a study in Pune district of Maharashtra about the role of information technology in agriculture marketing. It focused on how market information could be used for planning, production and holding stocks and found that the farmers (mostly, male and literate) in the age group of 30–50 were using IT effectively for their crop production. The study suggested that IT could be used not only for agricultural extension but also could be extended to agriculture research. Similarly, another study (Mohan 2015) looked into the significance of mobile in the diffusion of agriculture information among farmers in India. It found that various applications (namely, text and Multimedia Messaging Service or MMS and Voice Stream) were used to spread information in the farmers' community and these applications were modified based on subjectivity, for instance, literacy, usage pattern, social acceptance, Domain-specificity and lifestyle of rural farmers in several states.

Ghanshyam et al. (2016) studied an android application, namely Agronomy, that facilitates better decision making by farmers and also raises productivity and reduces stress. It also would enthuse the former to learn new technology, essential in this era of the digital revolution. Further, Mital and Mehar (2012) conducted a survey in 2011 covering around 1200 farmers in five Indian states; 64 per cent of respondents were small or marginal farmers. It concluded that farmers benefited from improved access to information including seed variety selection, best cultivation practices, protection from weather-related damage and handling plant disease.

Presently, all mobile applications and services registered in other sections of the m-Kisan Portal are easily accessible on any type of mobile phones in India. In the initial period, mobile apps are created for Android-based phones because of its largest share among the smartphones and subsequently, these will be developed for Windows and iOS. It is helpful to access information from the web without a laptop or computer. These apps are free to access and are developed through C-DAC, NIC, DAC and independent Android enthusiasts/private firms (m.Kisan.gov.in 2020a, b). Broadly, three recent apps are launched by the Ministry of Agriculture, Government of India to access information related to the agriculture sector in India. The apps and their features are described in Table 3.

Some of the apps are common-purpose ones and are useful for all the agriculture-related sectors; Pusa Krishi, for instance, helps to promote agribusiness within India and beyond. The Digital Mandi India app helps to check the latest Mandi prices of agricultural commodities across various districts and states in India. It facilitates farmers, traders and all other stakeholders to take interest in updated Mandi prices from anywhere. However, it is important to know the number of farmers benefited from these apps. Figure 4 presents the percentage of total users those downloaded the AGRIMARKET App from various states. This was developed in 2015 and used to provide information related to the market price of various crops within 50 km. It has been downloaded by 49,371 users from all over India with Maharashtra at the top having 9831 users (m.kisan.gov.in 2020a, b).

It may be observed from Fig. 4 that 30% of the users are from Maharashtra (20%) and Madhya Pradesh (10%). Gujarat and Tamil Nadu account for 9% each of the users. Least developed states like Bihar and Odisha have very low percentage of users at 2 per cent each; it may be because farmers grew their crops for own consumption, had less quantity to sell, and had no awareness regarding this app. However, states like Punjab, Haryana, Uttar Pradesh, Telangana also have low percentage of users of this app despite their farm potential and better infrastructure in comparison with other states. Similarly, another app Kisan Suvidha (developed in 2016) is designed to access information related to the weather of the current day and next 5 days, market prices of

Table 3 Agriculture-related mobile app and their feature

Name of the app	Year	Features
Kisan Suvidha	2016	This app provides information related to weather of the current day and next 5 days, dealers, market prices, agro advisories, plant protection, IPM Practices etc. The exclusive features like extreme weather alerts and market prices of the commodity in the nearest area and the maximum price in a state as well as India have been added to empower farmers in the best possible manner
Pusa Krishi	2016	This app helps to bring the linkage between the research community and the outside world. It is led by ZTM&BPD Unit; ICAR-IARI, New Delhi is leading 14 ICAR institutes of North Zone-I. It supports Agribusiness Ventures through technology development and commercialization for anyone whether it belongs to a corporate to an individual farmer
AgriMarket	2015	It can be utilized to get the market price of crops in the markets within 50 km of the device's location. It runs automatically to capture the location of individual using mobile GPS and gets the market price of crops in those markets which fall within the range of 50 km Although, there is another option too in case a person does not want to use GPS location for the information about market price

Source https://mkisan.gov.in/downloadmobileapps.aspx accessed on 20 April 20, 2020

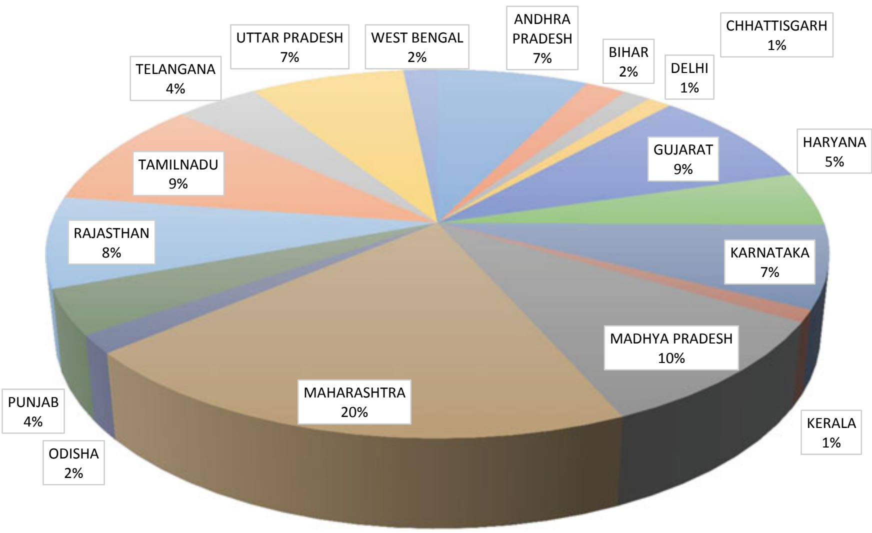

Fig. 4 Percentage of State-wise total users downloaded AGRIMARKET App, December 2015–April 2020. *Source* Computed from https://mkisan.gov.in/AppDownload.aspx (Accessed on April 20, 2020). *Note* Less than one per cent users of the States or UT data has not been counted for the suitability of figure

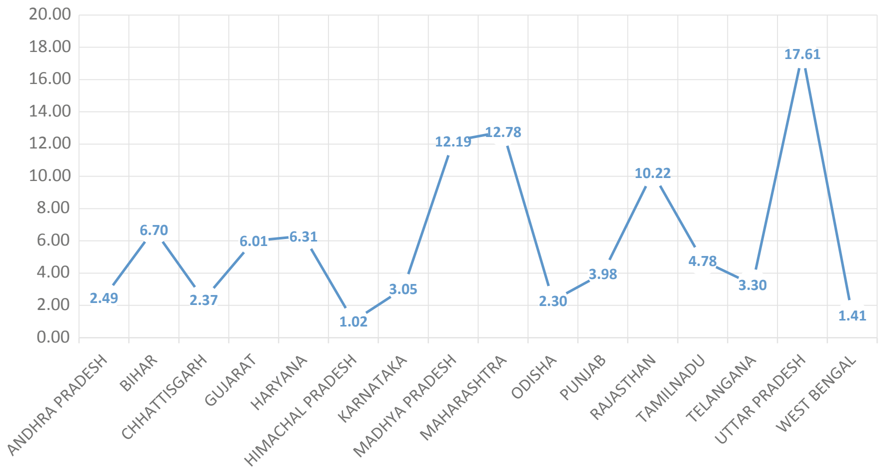

Fig. 5 Percentage of State-wise total users downloaded Kisan Suvidha App, March 2016–April 2020. *Source* Computed from https://mkisan.gov.in/AppDownload.aspx accessed on 20 April 2020. *Note* Less than one per cent users of the States or UT data has not been counted for the suitability of figure

the commodity in the nearest area and the maximum price in a state, as well as India. A total of 1,263,762 users had downloaded this app and out of this 222,595 users belonged to Uttar Pradesh (m.Kisan.gov.in 2020a, b). Details are presented in Fig. 5.

The figure depicts the distribution of total users downloaded Kisan Suvidha App. As may be seen from Fig. 5, on users of Kisan Suvidha App almost 18 per cent of the farmers belong to Uttar Pradesh followed by Madhya Pradesh and Maharashtra, with about 13 per cent each. However, West Bengal and Himachal Pradesh show low shares. It is helpful for small farmers who sell their produce to local traders and bargain with traders based on the current price. Also, farmers can decide on whether to take their produce to the mandi or delay based on information on current prices. Hence, it may be said that mobile-based information services influence the behaviour pattern of farmers and facilitate adoption of improved techniques leading to better yields. Another app, Pusa Krishi, launched in 2016, aims to provide information related to new technology and supports agribusiness ventures through technology development and commercialization for anyone belonging to a corporate or an individual farmer. Out of 41,669 current users, Uttar Pradesh (7665), Madhya Pradesh (5148) and Rajasthan (5067) acount for substantial share (m.Kisan.gov.in 2020a, b).

Figure 6 shows the proportion of state-wise total users those who downloaded the Pusa Krishi app. while 18 per cent of the users belong to Uttar Pradesh about 13 per cent each belongs to Rajasthan and Madhya Pradesh. However, in states like West Bengal, Odisha, Tamil Nadu and Telangana the share was below 2% below it may be because of a lack of understanding of the importance of app or lack of infrastructure like the internet and electricity. Lokanathan and De Silva (2010) state that there is a need to invest in ICT infrastructure and also in capacity building and awareness

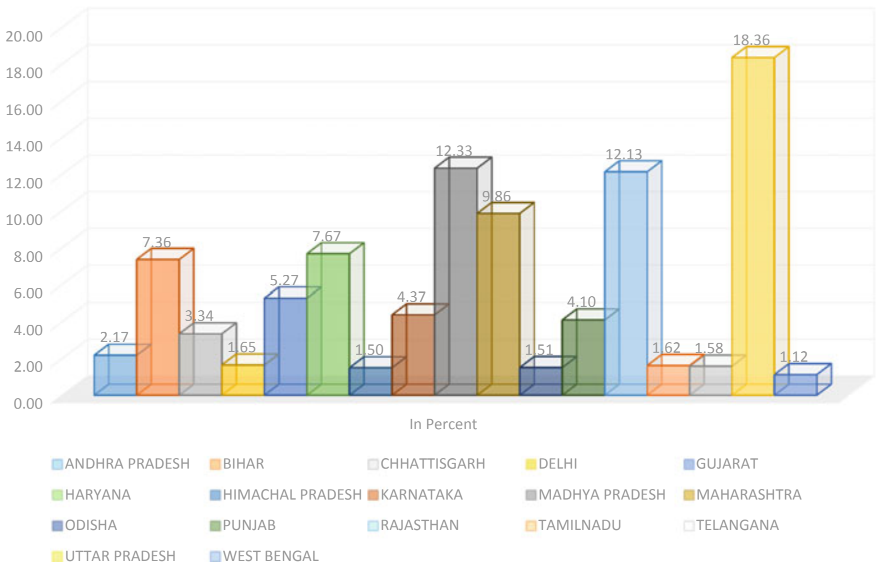

Fig. 6 Percentage of State-wise total users downloaded Pusa krishi App, March 2016–April 2020. *Source* Computed from https://mkisan.gov.in/AppDownload.aspx accessed on 20 April 2020. *Note* Less than one per cent users of the States or UT data has not been counted for the suitability of figure

campaigns to win farmers' trust in the system and to motivate them to shift to new modes of accessing information. The constraints of using mobile are discussed in the next section.

4 Issues and Challenges of Mobile Application for Agriculture Development

Despite the development of mobile applications for agriculture various issues and challenges remain to diffuse the same amongst farmers and other stakeholders. Hosseini et al. (2009) argued that lack of quality services by companies constrained the use of ICT in the farming sphere in developing countries. Similarly, a study by Manalo and Eligio (2011) conducted in the rural areas of the Philippines observed that the use of mobile phones was not the first choice among the farmers for sourcing information. The study indicated that various social issues did affect the use of it; for instance, illiteracy, socio-economic status and willingness and conditions to participate in ICT training were major concerns. These obstacles faced by farmers to use mobile phones are discussed in the following.

Organizational Efficiency: The nature and efficiency of the organization (public or private) providing the information services would be an important determinant of the quality of information—whether on extension services, financial sources or inputs—received by farmers. The organization such as extension services provider whether they are public or private play an important role to promote agriculture technology. In this regard, a study concerning the Malaysian experience observed that due to lack of infrastructure services and inefficiency of the government and other related organizations farmers faced several problems in obtaining information about agricultural markets and possibilities of investment. This prevented agro-processing entrepreneurs who would have made profits and also paid taxes through promoting their business (Shaffril et al. 2009).

Affordability: The purchase and use of android mobile phones turn out to be very expensive for most farmers in India who are typically small and marginal landholders. A study in rural Kenya by Frempong et al. (2007) holds that not only mobile phones are very costly but even recharging these is difficult to afford. Another study, World Bank (2011), also indicates that farmers who belong to developing countries may not be adequately equipped to afford and use the applications which are chargeable and also need enormous data usage; these pose large financial burden on the farmers.

Technical: The utility of the mobile phone hinges upon the internet, mobile bandwidth and connectivity. There is a need for adequate provision of electricity. As laying the internet infrastructure into the remote rural areas turns out to be prohibitively expensive, the high cost of service creates an obstacle for internet or mobile usage by small and marginal farmers. Another issue relates to the fact that most of the information shared through text SMS converts the content in local vernacular language and also creates the content within limited word space. This is despite the option of voice message, which is costly to send to the farmers. Aker (2010) holds that the proficiency of receiving the messages at any time is poor and also there is a cost of retrieving the information in the message. There is still a lack of proper network linkages with other stakeholders such as research institutes, farmers and other knowledge banks which are a likely source of suitable content for the customized timely information (Mittal 2012). It brings up the issue of sustainability in the delivery of appropriate content.

Illiteracy and Awareness: The latest mobile phone models are based on the android system that requires specific knowledge to access the information. As most of the farmers are illiterate in India, they are unable to use android phones to access the needed information on various aspects of farming. Baumüller (2012) argued that it might require a skilled person's comprehension and translation of the various complex functions to be performed on-farm, ambiguous information, and videos in other languages. Similarly, Akinsola et al. (2005) and Musa et al. (2008) argued that due to lack of knowledge or skills farmers could not contact extension service providers to access the information related to market, pesticides, etc. For the same reasons of illiteracy and lack of skills, farmers were unable even to contact their family and friends. As observed by Ashraf et al. (2005) and De Silva (2008), mobile phone uses by these groups to access market information were very low. Similarly, most of the farmers are not aware of the use of a mobile phone for agriculture. World Bank (2017) states that nearly 60 per cent of the farmers lack adequate access to information related to advanced agricultural technologies and, therefore, there is a huge gap in the adoption of new technology among farmers. Lack of access to any extension service and credible information source have constrained enhancing farm productivity.

5 Conclusion

The digitalization initiatives in India have fostered ICT and innovation related to the farm sector. For instance, the mobile app which helps to promote agriculture extension services has benefited farmers and other stakeholders as well. These digitaliszd services help to raise incomes and create more opportunities for farmers as well as other actors. However, the success of these services crucially depend upon the manner of their commercialization and use of innovative tools of ICT; these require strong infrastructure in terms of electricity, network connectivity and financial assistance. Internet provision in rural areas holds the key. Lack of knowledge to use the mobile apps and illiteracy among farmers in rural India act as constraints. It is known that less developed states like Odisha, Bihar and Jharkhand have low level of usage of these apps. In order to enhance the use of mobile phones-based information by farmers, especially small and marginal farmers there is a need to create awareness, provide training and subsidize costs related to mobile services. Moreover, as ICT-National Round Table Conference (2017) observes, there is a need to undertake policy-related research that helps bridge the gap between practice and policy and also evaluate the impact of ICT in agriculture. There is also a need for a platform where every actor involved in the system, producers and sellers, would share and use data and experience.

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Chapter 14
Open Research Data in the Global South: Issues and Anomalies in the Indian Context

Anup Kumar Das

1 Introduction

India, an emerging economy in the global South, has becomes one of the top three producers of peer-reviewed scientific publications in 2018, as indicated in a recent report of the U.S. National Science Foundation (Press Trust of India, 2019). The other two top countries are China and the United States. India contributed 5.31 per cent of the total world publications in science and engineering disciplines in 2018, while China and the U.S. accounted for 20.67 per cent and 16.54 per cent, respectively all global publications in the same year. This feat not withstand the scientific community as well as the channels of research publications have become much aware of the prospects of reproducibility of science. This requires a robust research ecosystem that facilitates a widespread adaptation of open science mandates by the scientific establishments and researchers of a country. Open science ensures the availability of research data reported in peer-reviewed scientific publications for the downstream researchers, in reusable, interoperable, and human- and machine-readable data format. Further, it ensures open access to public-funded research literature and advocates wider availability of research data to the scientific communities.

Globally, FAIR Data Principles are being accepted by the scientific communities and research funding agencies to achieve open science mandates. These Principles are the guiding force for the scientific community in the 21st century. FAIR stands for the Findable (independently by machines and humans), Accessible (under well-defined conditions), Interoperable (again, independently by machines and humans) and Reusable (under properly defined licenses and properly cited) research objects these including research data and associated tools and services. In March 2016 a consortium of scientists and organizations first deliberated these principles which was brought out as an article titled "FAIR Guiding Principles for Scientific Data

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Management and Stewardship", published in the *Scientific Data* journal (Wilkinson et al., 2016). International organizations such as the ICSU Committee on Data for Science and Technology (CODATA), Research Data Alliance (RDA) and European Commission (EC) have been instrumental in promoting the FAIR Data Principles in across the world. The European Union and many other research funders are now promoting FAIR data practices in their funded scientific research projects in Europe and other regions.

Recently in 2018, a European Commission's Expert Group released an action plan and roadmap for early adaptation of FAIR Data titled "Turning FAIR into Reality: Final Report and Action Plan from the European Commission Expert Group on FAIR Data". Thus, Indian research institutions seeking collaborations in EU-funded scientific research and experiments are expected to adopt the FAIR Data practices in their respective institutions. An international network named the GO FAIR Implementation Network has now been launched alongside a network of Data Stewardship Competence Centers (DSCCs). Similarly, In the global South, a Brazilian GO FAIR Implementation Network was established in 2019. The GO FAIR Implementation Networks are also instrumental in the coherent development of the global Internet of FAIR Data & Services (IFDS) and a federated European Open Science Cloud (EOSC).

Table 1 lists some important international initiatives for the promotion of open research data, which have European, African and global focus. The Global Open Data for Agriculture and Nutrition (GODAN) is the earliest initiative, while FAIRsFAIR project is the latest. Table 2 shows existing open research data repositories in the global South and more specifically in the BRICS countries. By December 2019

Table 1 International initiatives for the promotion of open research data

Name	Website	Twitter handle	Year of establishment
Global Open Data for Agriculture and Nutrition (GODAN)	Godan.info	@GodanSec	2013
African Open Science Platform (AOSP)	Africanopenscience.org.za	@aosp_africa	2016
Global Indigenous Data Alliance (GIDA)	Gida-global.org	@GidaGlobal	2018
Global Open (GO) FAIR Initiative (GO FAIR)	Go-fair.org	@GOFAIRofficial	2018
European Open Science Cloud (EOSC)	Eosc-portal.eu	@EOSC_eu	2018
Fostering FAIR Data Practices in Europe (FAIRsFAIR)	Fairsfair.eu	@FAIRsFAIR	2019

Source: Author's Compilation

Table 2 Open research data repositories in BRICS countries

Country	Number of data repositories (as on 25-12-2019)	Number of data repositories (as on 27-02-2017)
Brazil	8	6
Russian	22	19
India	50	30
China	42	32
South Africa	10	5
BRICS total	132	92

Source: Re3Data.org

India had hosted the highest number of data repositories amongst the BRICS countries followed by China and Russia. Further for BRICS countries they research data repositories have risen from 92 in February 2017 to 132 in December 2019. While in the Asian Pacific region, India hosts the third-highest number of data repositories, Australia stands first with 90 repositories and Japan second with 57 data repositories. The United States is the highest contributor globally, hosting 1054 data repositories followed by Germany (394) and the United Kingdom (283). As the inclusion of the data repositories on Re3Data.org is voluntary, based on the submission of nominations by the host institutions, the institutions establishing new research data repositories are expected to take a proactive role to get them indexed with this global registry. This would improve global availability, accessibility and findability of the research datasets produced by the researchers in different countries and institutions. FAIR Data Principles become worthwhile as institutions create data repositories and then make them discoverable through enlisting on Re3Data.org, benefitting the researchers and practitioners.

2 Key Strategy and Policy Documents in India

Delhi Declaration on Open Access (2018): The Open Access India, an advocacy group for open science in India, released this declaration on 14 February 2018 for strengthening a roadmap and action plan for open access (OA) movement in India. This was widely discussed with the members of the community, including the OA advocates, practitioners and researchers for the preparation of this document. It promotes an integrated approach encompassing all open science channels such as open scholarships, OA publishing, OA self-archiving, open research data, open educational resources, open technologies, open innovation and other realms of open science (Das 2018). The Open Access India has also been instrumental in launching IndiArxiv.org, a preprints server for the Indian researchers, professionals and practitioners, which was launched on 15 August 2019. In running another online preprints' server, namely "AgriXiv.org: Preprints for Agriculture and Allied Sciences" Open Access data has been involved.

National Data Sharing and Accessibility Policy (NDSAP) (2012): NDSAP aims at promoting data sharing and enables access to goi-owned data for national planning and development. The objective of the policy is to facilitate access to goi-owned shareable data and information in both human-readable and machine-readable formats in a proactive and periodically updatable manner. NDSAP ensures an ecosystem for open government data, in participation with the various union and state ministries, departments, organizations, agencies and autonomous bodies (Department of Science and Technology, India, 2012). The goi-owned data are shared through Data.gov.in web portal. All datasets and data resources, including metadata published on this open government data (OGD) platform, are licensed under the Government Open Data Licence—India. Few Indian states and urban local bodies also have created their data portals utilizing the OGD platform, e.g., Sikkim.data.gov.in for the Government of Sikkim, Tn.data.gov.in for the Government of Tamil Nadu, Odisha.data.gov.in for the Government of Odisha, Surat.data.gov.in for the Surat Municipal Corporation and Smartcities.data.gov.in for the Smart Cities Mission. Several other data portals of the state and local governments are expected to be created shortly. The stated benefits of this data sharing policy are maximizing use, avoiding duplication, maximized integration, identification of data owners, better decision-making and equity of access.

Biological Data Storage, Access and Sharing Policy of India (2019): The draft version of this policy document was released by the Department of Biotechnology (DBT), under the Ministry of Science & Technology, Government of India (goi) in July 2019 (Department of Biotechnology, India, 2019). This policy addresses issues relating to the storage, access and sharing of all biological data in general and it is specifically applicable to high throughput, high-volume data generated within the country following relevant extant laws, rules, regulations and guidelines of the GOI. The draft policy distinguishes between research data and public resource data. Research data are generated by individuals engaged in research on scientific or social problems and that data are of interest to the individuals. On the other hand, public institutions, such as DBT, Indian Council of Medical Research (ICMR) or Indian Council of Agriculture Research (ICAR), generate public resource data, for example, cancer registry data and genome sequence data on members of various ethnic groups. The draft policy suggests that public resource data should be shared rapidly after generation and curation. Further, the draft policy suggests three kinds of data resource sharing, namely, Open Access, Managed Access and No Access. Open access data are placed in the public domain and are shared without any restrictions imposed by the data provider. In managed access data, the data users are asked as to why they wish to access the data and how the accessed data would be used. If any restriction is placed on the use of data is made known publicly and should be adhered to. In the framework for data sharing and access stated in the draft policy, it is suggested that "Data generated from publicly funded projects should be shared openly for the public good, with few restrictions and on time, safeguarding the ethical issues that may arise out of shared data", triumphing the open data mandates for public-funded research results.

INSA Policy Statement on "Dissemination and Evaluation of Research Output in India" (2018): The San Francisco Declaration on Research Assessment (sfDORA or DORA) was announced during the Annual Meeting of the American Society for Cell Biology (ASCB) in San Francisco, the USA in December 2012. Unlike many other conference recommendations, the DORA has succeeded to convince the science academies, research funding agencies, science communicators and other research establishments to do away with the use of traditional journal-based metrics, such as Journal Impact Factors, as a surrogate measure of the quality of individual research articles to assess an individual researcher's contributions. They recommended the use of alternative methods of impact assessment to reduce biases in citation-based evaluations. In India, a few of the funding agencies, research organizations and individuals are signatories of DORA. The prominent ones are the Department of Biotechnology (DBT), goi and Wellcome Trust-DBT India Alliance (WT-DBT IA). For longer use in India the Declaration recently got translated into Hindi and had a plan to get of translate into other Indian languages. DORA influences the development and deployment of a conceptual framework of Altmetrics or alternative metrics. Altmetrics significantly considers social media platforms for dissemination of findings of scientific research, to get a thriving altimetric score for each scientific publication. Similar to DORA, the Indian National Science Academy (INSA) released a statement titled *A Policy Statement on Dissemination and Evaluation of Research Output in India* in May 2018 (Chaddah and Lakhotia, 2018). The policy statement supplements efforts made by the "Inter-Academy Panel on Ethics in Science," established in 2015 by three leading science academies in India. INSA Policy Statement deals with four sets of principal recommendations, detailed in the following.

(a) ***Promotion of Preprint Repositories and Peer Review After Dissemination***

Although two distinct issues are covered in this principal recommendation, these are interconnected in the present-day context. Preprint repositories, which began with the establishment of arXiv.org in 1991 for the scholars across the world, and recently conceptualized IndiArxiv for the scholars in India (launched in August 2019), facilitate dissemination of preprint articles of the scholar to the scientific communities in their subject areas or based on their geolocations. The preprints servers are OA, and there is no fee for submission or dissemination of a scientific publication. Submission of preprint articles on the preprints servers is practised by millions of scientific researchers across the world. Thus, the promotion of preprints repositories is an important policy recommendation that will help researchers disseminate their articles and will help in establishing proof of prior-data. Here is a glimpse of available online preprints repositories specific to the countries and regions in the global South (Table 3).

Table 3 Different regional and national preprints servers

Name	Website	Tagline	Maintained by	Twitter handle
AfricArxiv	https://africarxiv.org	A free preprint service for African scientists	A consortium of institutions	@AfricArxiv
Arabixiv	https://Arabixiv.org	The Arabic Preprint Server—Arabic Open Science Repository	A consortium of institutions	@Arabixiv
ChinaXiv	https://chinaxiv.org	Preprints Repository of China	National Science Library, Chinese Academy of Sciences	#Chinaxiv
INA-Rxiv	https://inarxiv.id	The Preprint server of Indonesia	Institut Teknologi Bandung	@INArxiv_ID
IndiArxiv	https://indiarxiv.org	A Preprints Repository Service for India	Open Access India	@IndiArxiv

Source: Author's Compilation

(b) ***Promoting Journals Published in India***

Due to the proliferation of information and communication technologies (ICTs), Indian scholarly journals have been converging into electronic journals, embracing the latest e-publishing technologies available for the scholarly journals. Indian scholarly journals, published by the science academies, apex research bodies, scientific societies, and other not-for-profit publishers have earned global recognition since the days of their launching, due to sustained efforts in maintaining the qualitative research contents with the help of dedicated editorial team members. The recently initiated "UGC-CARE List Quality Journals", mentored by the University Grants Commission's Consortium for Academic Research and Ethics (CARE), has been enlisting scholarly journals based on certain qualitative criteria. This UGC List suggests the publishing avenues to the research scholars and academic staff members working in the higher educational institutions (HEIs). For the enlisting process that took place in 2018–19, several scholarly journals were not considered for inclusion as they did not maintain journal websites or were irregular, besides other qualitative factors. The importance of maintaining a journal website is recognised for the wider dissemination to places beyond one's perceived borders. In addition to maintaining a journal website, a journal may plan to keep the contents freely accessible and sharable to a wider audience. This requires publishing research papers with open content licenses, such as Creative Commons licenses. Some journals have migrated to publishing e-journals with OA content. Some others have remained confined to a paywall for accessing the full-text contents. While a few other journals' contents are freely available, without having definite open licensing terms. At the same time, the not-for-profit publishers get into the journal publishing aiming at the advancement of knowledge and serving their respective scientific communities. While for-profit publishers see journal publishing as an avenue for making substantial profits. Thus, we see mixed approaches in journal publishing in India. With e-publishing new e-journals are born, which have no print edition. Gold OA publishing, particularly, publish scholarly articles after charging an Article Processing Charge (APC). Green OA allows self-archiving of research publications on OA institutional repositories, preprints servers and subject-based OA knowledge repositories.

(c) ***'Publish or Perish' Policy, Open Access Charges and Evolution of So-called Predatory Journals***

This set of recommendations aims at minimizing predatory journals and predatory conferences in the country while ensuring the availability of research funds for nominal APCs in reputed gold OA journals. It also discourages publishing OA articles in hybrid journals as that engages in double-dipping practices. Lately, in December 2019, the UGC recommended Indian universities to introduce a compulsory pre-PhD course on the Research and Publication Ethics (RPE) for awareness about the publication ethics and publication misconducts. The course comprises three theories and three practice modules, namely Philosophy and Ethics, Scientific Misconduct, Scientific Conduct, Publication Ethics, Open Access Publishing, Publication Misconduct, and Database and Research Metrics.

(d) ***Criteria for Evaluating Research Output: "What Did You Publish" Rather Than "Where Did You Publish?"***

This set of recommendations aims at assessment of an individual's research contributions primarily to be based on the impact of what is published rather than on where it is published. It also encourages Indian researchers to publish in Indian journals, whenever available, instead of indulging in a rat-race for publishing with the high impact scholarly journals published from abroad. This quartile also suggests each of the 'best five' papers identified by a candidate or a nominator should be categorized as 'Confirmatory', 'Incremental Advance' or 'Path-Breaking Advance'.

Suggestions for a National Framework for the Publication of and Access to Literature in Science and Technology in India (2019): This discussion paper (jointly published by the Indian National Science Academy, New Delhi, Indian Academy of Sciences, Bangaluru and National Academy of Sciences India, Allahabad) proposes a draft national framework for the publication of and access to literature in S&T (Chakraborty et al. 2019). This a follow-up activity after publishing the INSA Policy Statement on Dissemination and Evaluation of Research Output in India. In terms of open science and research data, the discussion paper recommends: "An institutional mechanism for National Science Repository Preprint archive/Published data archive and searchable metadata for India be created… All publications from publicly funded research, except that which is classified, must be deposited in this archive. Any new funding for a PI must be released after the prior published results are deposited in the archive."

Discussion Paper on National Strategy on Artificial Intelligence (2018): The Niti Aayog, goi's premier think tank, released this a discussion paper on 4 June 2018. The theme of the paper is *Artificial Intelligence for All* (AIforAll) emphasizies intervention of AI in five key sectors in India, namely, healthcare, agriculture, education, Smart Cities and infrastructure, and Smart Mobility and Transportation (NITI Aayog, 2018). AI projects in India in such sectors would utilize utilizing the latest techniques and technologies of AI, machine learning and big data analytics. This paper emphasizes that the Data Ecosystem is a key enabler in the *AIforAll* transformation in the country. It also suggests having a better understanding of the key issues such as access to vast quantities of data, the convergence of data and data annotation. For overcoming issues related to data access, the paper proposes to strengthen rule-based principles for the government data sharing, corporate data sharing, consent-based data sharing, and digitized and crowd-sourced collection of data by government.

Open Science India Report (2018): This digital version of the report was launched in September 2018 by the Centre for Innovation, Intellectual Property and Competition (CIIPC) of the National Law University, Delhi. This report attempts to identify the optimal legal and policy interventions required for a sustainable open science movement in India. This draft report summarizes the major findings and recommendations from the open science project conducted at CIIPC. In addition to this report, CIIPC also publishes an e-newsletter titled *Open Signs* since July 2016. Till December 2019, CIIPC published 39 issues of *Open Signs*, which is a crowd-sourced newsletter for sharing the latest developments in the areas of open science, OA, open data, open educational resources and other open movements. The newsletter also covers intellectual property related issues that have significance for the open movements. This report highlights post-NDSAP open government data initiatives in India, and web-based projects, viz., the Open Data Impact Map (Opendataimpactmap.org), OpenCity.in and Datameet.org (Scaria and Ray 2018).

3 Recent Research Data Initiatives in India

National Data Quality Forum (NDQF): Launched in July 2019, NDQF is a joint initiative of the Indian Council of Medical Research (ICMR)'s National Institute for Medical Statistics (NIMS) and the Population Council (PC) to network with producers and users of demographic and health data in the country. It is a step forward to institutionalize a system for assessing the quality of data that drives health policies. The project is aimed at improving the quality of India's demographic, health and nutrition data. NDQF also targets a "goal of improving data quality by sustaining a strong dialogue on data quality issues among all stakeholders and advocating for the strengthening of the systems that produce and manage data." So far, it has launched a website (Ndqf.in), a newsletter, infographics, policy briefs and a blog. The other reports will be generated over time. This project also monitors data related to SDG3 (Sustainable Development Goal 3: Good Health and Well-Being) targets and indicators.

NCAER National Data Innovation Centre (NDIC) (ncaer.org/data.php): Launched in 2018, NDIC is a consortium-based project hosted by the National Council of Applied Economic Research (NCAER), New Delhi, in partnership with the University of Maryland, University of Michigan and Bill & Melinda Gates Foundation, USA. The main objective of NDIC is to serve as a laboratory for experiments in data collection, interfacing with partners in think tanks, Indian and international universities, and government. In 2019, it released a call for proposals on methodological innovations to improve data quality, while in 2020, the Centre had plans to host the first international survey methodology conference in India and a few short-term training programmes. NDIC is envisaged to become a national centre of innovation and excellence in data collection that is expected to build research capacity to strengthen India's data ecosystem to meet the challenges of the knowledge-driven society. NCAER is widely known for its long-standing data collection activities, such as the India Human Development Survey (IHDS), Additional Rural Incomes Survey (ARIS), Rural Economic & Demographic Survey (REDS), National Survey of Household Income and Expenditure (NSHIE) and Market Information Survey of Households (MISH). NDIC enriches NCEAR's research data core.

RBI Data Sciences Lab: The Reserve Bank of India (RBI) had proposed to establish a Data Sciences Lab, to be operational by December 2018 to engage in big data analytics for financial and banking sector in India (Hebbar 2018). The lab would have a role of "forecasting, nowcasting, surveillance, and early-warning detection abilities that aid policy formulation." The growing number of non-performing assets in the Indian banking sector, as well as the weak financial health of the country, are the tipping points to initiate such a project utilizing latest techniques and technologies of the artificial intelligence, machine learning and big data analytics. RBI had already started the process of recruiting Lab's director and experts.

National Data Archive: An Online Microdata Library (Microdata.gov.in/nada43/): This is an online portal of the Ministry of Statistics and Programme Implementation (MoPSI), goi, to disseminate microdata from MoPSI surveys and censuses. The portal presently makes available statistical data from the Annual Survey of Industries, Household Consumer Expenditure, Economic Census, Enterprise Surveys, Employment and Unemployment, Land and Livestock Holding Surveys and Other Surveys conducted by the National Sample Survey Office (NSSO). So far, 145 datasets are currently available on this portal, and accessible to the registered users only through a user login process. The portal also fulfils the Guidelines for Statistical Data Dissemination (GSDD), released by MoPSI in February 2019. In addition to this portal, most of the datasets of NSSO are also available through the ICSSR Data Service (icssrdataservice.in). This data repository is not listed on the global Registry of Research Data Repositories (Re3Data.org).

ICSSR Data Service: Social Science Data Repository (icssrdataservice.in): This is an online portal, jointly maintained by the Indian Council of Social Science

Research (ICSSR) and MoSPI to disseminate the social science and statistical datasets to social science researchers across the country (Arora et al. 2018). Presently, the portal is maintained by the Information and Library Network (INFLIBNET) Centre, Gandhinagar. So far, 140 datasets are available on this portal, and accessible to the registered users only through a user login process. This data repository is listed on the global Registry of Research Data Repositories (Re3Data.org).

Many similar initiatives are documented in a recent special issue on research data management in the DESIDOC *Journal of Library & Information Technology*. In this issue, a paper highlights the global and Indian open data resources for clean energy and water sectors (Francis and Das 2019), while another paper analyzes the contents of Indian research data repositories (Bhardwaj 2019). The publications by Mittal and Mahesh (2008), Ghosh and Das (2007), Das (2008) and Arora et al. (2018) enumerate various open data and institutional repositories operated in South Asia including in India.

4 Select Global Research Data Networks Supporting the Global South

Research Data Alliance (RDA) (rd-alliance.org): RDA is an international network aimed at building the social and technical bridges to enable open sharing and reuse of data. RDA was founded in 2013 by the European Commission, United States National Science Foundation, United States National Institute of Standards and Technology and Australia Department of Innovation. RDA maintains a close collaboration with the ICSU Committee on Data for Science and Technology (CODATA). They jointly celebrate the International Data Week (IDW) and organize CODATA-RDA Schools of Research Data Science—a series of capacity building events in different parts of the world. In the CODATA-RDA Schools, participants are selected from across the world, including the researchers from the global South. The activities of RDA are operated through a network of working groups and interest groups, which directly and logically tackles numerous data infrastructure challenges. As of May 2019, RDA had 34 working groups and 66 special interest groups. Several groups are there to address the data infrastructure challenges in implementing the FAIR Data Principles in different countries, funding agencies, and institutions.

Global Open Data for Agriculture and Nutrition (godan.info): GODAN is another global initiative for promoting food and nutrition security across the world. It was launched in October 2013 in active participation of the Food and Agriculture Organization of the United Nations (FAO) and other intergovernmental and international organizations. GODAN (2015) released a theory of change narrative in April 2015 and which was revised several times. This document emphasizes the GODAN's collective vision for the world and identified high-level and intermediate-level impacts for reducing information asymmetries in the world, and setting exemplary best practices and communities of practice. In August 2016, GODAN released the first issue of the Success Stories brochure, which contains 15 success stories mostly from the developing nations, such as Rwanda, Sentinel, Ethiopia, South Africa, Thailand and Indonesia (GODAN, 2016). In May 2017, GODAN released the second issue of the Success Stories brochure, which contains 11 success stories mostly from the developing nations and regions from the global south, such as Africa, Asia, Caribbean & Pacific and Yemen (GODAN, 2017). Many of the global initiatives, including the ones which are operated in India, are also highlighted in these two brochures.

Global Indigenous Data Alliance (GIDA) (gida-global.org): Founded in 2018, GIDA is a global network for advancing indigenous data sovereignty and governance and asserting indigenous peoples' rights and interests in data. GIDA produces *the CARE Principles for Indigenous Data Governance* in 2019 is a product of a global consultation process, and it was drafted at the International Data Week (IDW) and RDA Plenary event "Indigenous Data Sovereignty Principles for the Governance of Indigenous Data Workshop" at Gaborone in Botswana on 8 November 2018. The CARE Principles further supplement the cause of FAIR Data Principles and became online on 13 September 2019 for promoting good data governance practices (Global Indigenous Data Alliance, 2019). The CARE Principles for Indigenous Data Governance include four quadrants, namely, Collective Benefit (C), Authority to Control (A), Responsibility (R) and Ethics (E), as depicted in Fig. 1. Each quadrant of the CARE Principles is further divided into three parts. For examples, Collective Benefit further divides into C1: For inclusive development and innovation, C2: For improved governance and citizen engagement and C3: For equitable outcomes; Authority to Control divides into A1: Recognizing rights and interests, A2: Data for governance

Fig. 1 Be FAIR and CARE—the FAIR Data Principles Meet the CARE Principles. Source: Gida-global.org/care, accessed on 19 April 2020

and A3: Governance of data; Responsibility divides into R1: For positive relationships, R2: For expanding, capability and capacity and R3: For indigenous languages and worldviews; and Ethics divides into E1: For minimizing harm and maximizing benefit, E2: For justice and E3: For future use. So, twelve data governance subprinciples are added to the CARE Principles model aiding to promoting indigenous control of indigenous data by advancing sovereignty and governance.

5 Conclusion

India has emerged as a forerunner in the global open science movement, including in the open research data spectrum. Slowly, but steadily, Indian researchers' community has been gradually understanding, accepting, as well as adopting the FAIR Data Principles, which would be directly beneficial while engaging with the global research collaborators and researchers' communities. The national policy frameworks have been evolving in the present decade, while Indian researchers attempt to collaborate with the actors of global science. The public policymakers in India in the realm of S&T and higher education have felt the importance of building the open science and open research data capabilities, the scientific communities, and the best practices as seen with the emergence of relevant national policies, strategies and action plans. The national institutions, such as the office of the Principal Scientific Adviser to goi, the NITI Aayog, the Ministry of Science and Technology and other ministries have taken initiatives in rolling out research data capabilities in different subject domains. The findable, accessible, interoperable and reusable research data should not be a distant dream to Indian researchers and S&T practitioners. They should be educated to become the data steward and help others to create smart data management plans for FAIR open science utilizing the Data Stewardship Wizard (Ds-wizard.org) or similar other tools. Since the planning of a research project until the winding up of the same Indian researchers should be sensitized to and educated in creating a smart data management plan to deal with raw, processed and analyzed research data for the downstream researchers and research projects. Similar to IndiArxiv.org, a national-level multi-disciplinary open research data repository should also be created by an organization, for self-archiving of processed research data by researchers and practitioners working in India and the Indian subcontinent. This initiative will help the Indian researchers in contributing to open research data for the advancement of science. The research institutions and funding agencies need to create proactive and suitable research strategies, protocols, as well as sustainable infrastructure for the proliferation of open research data at the institutional, national and funders' level.

For combating the COVID19, a range of global networks of biomedical researchers and practitioners have been collaborating and sharing their research findings on OA platforms. They are also utilizing open research data platforms for sharing research data and objects for data-driven decision-making and innovating new products and solutions. For example, the European Union has launched the "EU COVID19 Data Platform" (Covid19dataportal.org), where researchers can store, share and analyze a wide variety of findings on COVID19. Similarly, researchers in many other countries in the global South are utilizing open research data for the advancement of scientific and social science research. In April 2020, The OECD released a policy brief titled "Why Open Science is Critical to Combatting COVID-19" which strongly advocates open research data and open science for overcoming public health challenges. Similarly, the RDA has set up the RDA COVID19 Working Group to define guidelines on data sharing and reuse to help the global researchers maximize the efficiency of their work to support the urgency of the coronavirus pandemic. We expect that researchers and research funding agencies in the global South will be more frequent in research data sharing and reuse soon for the advancement of science, technology and innovation (STI) benefiting the humanity.

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Chapter 15
Crisis in Technical Education in India: Evolving Contours of the Computer and Information Sciences Discipline

Hastimal Sagara and Keshab Das

1 Introduction

Engineering education is among the key enablers in human resource development, technological advancement and socio-economic progress of any nation. It creates skilled human power that helps improve productivity and efficiency (mainly, in terms of resource use) across sectors. Globalization of economic activities and mobility of professionals across national borders and the emergence of a knowledge society are putting new insights on the competency requirements of engineers, their role in the emerging international scenario and their ability to work harmonious and effectively in multidisciplinary and multicultural teams (Jha 2010: 40).

Processes of industrialization, urbanization, modernization and technological advancement can potentially lead to a surge in demand for engineers which in turn fuel the pace of expansion of engineering education across the globe. India too had a similar experience. In fact, a number of developing countries including Thailand, Malaysia, South Korea and China had designed integrated national policies to build local/indigenous technological capability in those industrial sectors which they deemed critical to their progress—for instance, steel, aviation, petrochemicals, electronics and energy (Ramesh and Weiss 1979). Soon after Independence, political leaders and planners in India realized the imminent significance of fast-tracking engineering education in the country that was so essential to building its industry, roads, dams, communication systems, power and drinking water facilities and other infrastructure in general (Bhargava 2001). India saw a massive expansion of engineering education during last seven decades. From 1990 onwards, with the development of computer technology in USA, India started with the introduction of computer technology graduate level courses in Indian institutes, regional colleges and graduate level courses in others, set up by industrial houses (Bhargava 2001: 78).

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K. Das et al. (eds.), *The Digitalization Conundrum in India*, India Studies in Business and Economics, https://doi.org/10.1007/978-981-15-6907-4_15

Most of the engineering activities have become multidisciplinary and new advances in nanoelectronics, molecular computing, bioinformatics, genetic engineering and information and communication technology have transformed engineering education (Jha 2010: 45). One of the areas of study which has, especially, taken off in the recent three decades or so, arguably, concerns what has now come to be termed broadly as the Computer and Information Sciences (CIS)[1] discipline. India produces more computer science and IT engineers than other disciplines (Banerjee and Muley 2008: 47). India has the advantage of being the third largest reservoir of scientific and engineering personnel in the world. Therefore, it is important to know if the CIS education rightly equips its students with skills that enhance their employability and efficiency.

This paper is an attempt to examine the status of India's engineering education in general and computer science and engineering education, or the CIS discipline, in particular. It is important to note here that this study focuses on engineering education courses in engineering and technology, information and technology, computer engineering, electronics and telecommunication engineering, networking, cybersecurity, animation, multimedia and MCA. However, this study excludes architecture, management, design, town planning, pharmacy, hotel management and catering, applied arts and crafts. The reason behind this exclusion is an apt need for a separate study of the CIS education that experienced a spurt in demand ascending from the fast-expanding IT sector in India during the post-reform period. In the process, enquiries have been made as to what kind of challenges confront technical education and if there are possibilities for responding to those. Discussions and arguments presented here are based on secondary data sourced primarily from the All India Council for Technical Education (AICTE).

This paper is divided into six sections. Section 2 exposits the antecedents and progress of engineering education in India since the early years of Planning. In Sect. 3, an attempt has been made to map new developments that are shaping the CIS education in India. Section 4 identifies factors responsible for recent developments in the industry that are impacting the technical education and, especially, the CIS discipline in India. Section 5 provides a critique of state initiatives to address the concerns of the sector. The end section proffers concluding observations and policy recommendations.

[1]Computer and Information Sciences is a group of subjects including communication engineering, computer science, IT, electronics, high-performance engineering, computer networking, animation, multimedia, cybersecurity, BCA, MCA, digital electronics, VLSI, CAD, CAM, embedded systems design, software engineering, telematics, automation and machine learning, big data analytics and cloud computing, etc. This grouping of subjects is done exclusively for this paper, as suggested by the co-editor Madhabananda Das, Senior Professor, School of Computer Engineering, KIIT University, Bhubaneswar, India.

2 Engineering (Including IT) Education Promotion in India: Antecedents

This section broadly describes how the Government's conducive policies helped evolution of the engineering education in India in general and CIS education in particular. Discussion is divided into two parts. First part includes listing down setting up of engineering institutes at different points of time and pointing out important recommendations of some of the notable committees on technical education in India. The succeeding part maps as to how the CIS has evolved particularly during the post-reforms period.

2.1 Engineering Education

During the colonial era, engineering education was launched in India with a clear focus on civil engineering which was essential towards building physical infrastructure then. Some of the earliest engineering institutions established since then include Thomason College of Engineering, Roorkee (1847), Poona Engineering and Mechanical School, Pune (1854), Indian Institute of Engineering Science and Technology, Shibpur (1856), Banaras Hindu University, Banaras (1916) and Harcourt Butler Technological Institute, Kanpur (1920) which all eventually emerged as institutions of high repute in their respective fields (Singh 2010: 3–4). This initial strong foundation acted as a major catalyst for the Government of India to move ahead with establishing several high-end engineering institutions as also fully/partially supporting technical education in India.

The first science policy in India, namely, the Scientific Policy Resolution, 1958 largely emphasized promoting basic research in almost every field of science and developing and making available basic infrastructure to buttress domestic scientific research. During the first three decades of independence, demand for engineers had soared due to the commencement of state-funded key infrastructural projects. Several committees on engineering education in India had put forth significant recommendations including setting up of the Indian Institutes of Technology (IITs) (Sarkar Committee 1948), promoting postgraduate engineering education and research (Thacker Committee 1959–61), reshaping postgraduate education in engineering and technology (Rama Rao Committee 1995), setting up of regional engineering colleges (Mashelkar Committee 1998), revitalization of engineering education (Rao Committee 2003) and setting up of *new* IITs (Rama Rao Committee 2004). Most importantly, the Sarkar Committee (1948) had recommended the establishment of higher technical institutes based on the lines of the Massachusetts Institute of Technology (MIT) in the four regions of India, that eventually led to setting up of the five Indian Institutes of Technology at Kharagpur (1950), Bombay (1958), Kanpur (1959), Madras (1960) and Delhi (1961) (Banerjee and Muley 2008: 16).[2] In 1970, India had a total of 139 engineering institutions, and only four of them were in the private sector (Sing and Singh 2014). In the early 1980s, there were about a hundred engineering colleges admitting around 25,000 students each year. The Private Universities (Establishment and Regulation) Bill, 1995 gave boost to opening of many private engineering colleges, and by the end of 2000, number of engineering institutions rose to nearly 1400, of which 85% were in the private sector (Sing and Singh 2014).

2.2 Computer Sciences and Related Engineering Education

In the late 1990s, a rush to update existing computer systems due to the dot-com bubble in the midst of a shortage of IT professionals in the West-led companies to search for new sources of IT competence. This created an upsurge in demand in India for computer coders, testers and software programmers to analyse and correct legacy software that was not available in the United States at competitive cost. Heeks (1996 and 2004) observed that low to medium level entry barriers for software firms in developing countries like India led to smoother trade in IT-enabled services (ITES). Compared to other sectors, demand for professionals in computer occupations widened and deepened and their wages grew faster in the USA during 2006–14 (Nager and Atkinson 2016). With the change in demand in favour of computer software and hardware engineers, electronics and communication engineering particularly in the US and European markets by the end of the previous century, the focus of engineering education relocated to the IT and computer sciences. The government set up or promoted a number of professional and specialized institutions of repute in different states across the country that helped lay a strong foundation for the growth of the IT industry, particularly, in *computer science and engineering* during the post-reforms period, as stated in the following paragraph.

In an analysis of the nature of state intervention in the Indian IT sector, Parthasarathy (2004a, b) has identified three phases—rigid policy restrictions (prior to 1984), eased restrictions (1984–90) and proactive promotion of the IT industry (post-1990). Kallummal (2012) observed that concerted efforts on the part of the Government of India, particularly since the 1980s and a host of other factors like government–diaspora relationships, private initiatives, emergence of software technology parks, clustering and public–private partnerships facilitated this positive development for the IT sector. Changes in state policies during the 1980s which rejected a highly regulated and autarchic policy approach were essential for the rise of a software industry in India (Parthasarathy 2004a, b). With the economic reforms

[2]Importantly, there have been major reviews of the functioning and upgradation of IITs as may be gleaned from the following reports: Nayudamma Committee Report (1986), Rama Rao Committee Report (2004) and Kakodkar Committee Report (2011). Details at https://www.iitsystem.ac.in/?q=iitsystemreview/view (Accessed April 7, 2020).

formally in place by 1991, the IT sector received a major boost during the 1990s through a series of state policies—the dismantling of Foreign Exchange Regulation Act (FERA) and other restrictive regulations; setting up of STPIs and Electronic Hardware Technology Parks; introduction of single-window clearance and, importantly, removal of physical controls on imports of most electronic equipments and components (Joseph 2007). Heeks (2004) observed that the state policy of protection and promotional intervention had helped build technological capabilities including those in the IT sector. While, during the pre-reforms period, it was only the central government that provided all kinds of fiscal incentives and infrastructure facilities to promote the IT industry in the country; the post-reforms period witnessed provincial governments too offering additional incentives on competitive basis (Das and Sagara 2017).

For increasing the number of graduates in the field of computer science and electronics and communication, the Government of India established 16 Indian Institutes of Information Technology (IIITs) opting for a Public–Private Partnership (PPP) mode between 2011–12 and 2019–20.[3] For high-quality undergraduate and postgraduate level education in the field of engineering and technology, the Government of India rechristened Regional Engineering Colleges (RECs) as National Institutes of Technology (NITs) during the first decade of the present century.[4] Numerous academic programmes in this field have been initiated in the private sector as well. Some of the reputed ones include BITS (Pilani), Thapar Institute of Engineering and Technology (Patiala), Dhirubhai Ambani Institute of Information and Communication Technology (Gandhinagar), Manipal Institute of Technology (Manipal), R. V. College of Engineering (Bangalore), Vellore Institute of Technology (Vellore), Nirma Institute of Technology (Ahmedabad) and Amity School of Engineering and Technology (New Delhi) (Bansal et al. 2019: 1307). As on March 28, 2020, under the discretion of the AICTE, there have been 10,987 institutes offering different technical courses with around 587,494 members of faculty and an intake of 3,284,417 students for the AY 2019–20. Further, in the category of 'Engineering and Technology and Master of Computer Application (MCA)', there have been 6716 institutes with 468,521 members of faculty and the total intake of 2,604,900 students.[5]

3 Engineering Education in India: Recent Trends

Favourable socio-economic developments coupled with conducive state policy encouraged private sector to contribute towards engineering education in India during the post-reform period. Since then, there has been mushrooming of engineering institutions in the country largely in the southern states. There is a dearth of publicly available data on India's engineering education system. This paper attempts to document

[3] https://pib.gov.in/newsite/mbErel.aspx?relid=106785 (Accessed on March 20, 2020).

[4] https://mhrd.gov.in/technical-education-5 (Accessed on March 22, 2020).

[5] https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 12, 2020).

the trends in the engineering students' intake, pass out and placement at different levels including undergraduation, postgraduation and Ph.D. This section attempts to map primarily those trends in engineering education in India in the recent times.

3.1 Expansion and Contraction of Engineering Education

As discussed earlier, the engineering education expanded at varying pace in terms of total number of institutes, intake capacity and number of courses during last seven decades. For instance, about 2.3 lakh engineering degrees, 20,000 engineering masters degrees and about 1000 engineering PhDs were awarded in India in 2006 (Banerjee and Muley 2008: 2). Table 1 shows that the total number of AICTE-approved institutes increased marginally from 7031 in 2012–13 to 7180 in 2015–16; however, the number decreased thereafter to 6716 in 2019–20. It is important to note that around 80 per cent of these institutes were in the private sector. However, this share reduced to 70.41 per cent for the reason that every year several private engineering institutes have been closed during last eight years. The AICTE permits to set up new institutes across the country every year. Around 1260 new institutes (both UG and PG) were opened between 2012–13 and 2019–20, of which 763 were in the private sector. Earlier, more number of permissions was given under the privately owned or non-aided institutes category compared to the government-owned or government-aided one. But, the share of the former has declined from 91.02 per cent in 2012–13 to 28.66 per cent in 2019–20. With falling demand of engineering education in India, as is discussed in the coming sections of this paper, 449 engineering institutes were closed and of which 443 institutes were in the private sector. It indicates that in a span of eight years, 98.66 per cent of the closed institutes were non-aided and privately managed engineering institutes. The intake capacity of engineering institutes increased by around 16.51 per cent between 2012–13 and 2015–16, but it has only decreased thereafter. It should be noted that the privately owned or managed institutes dominate the total number of engineering seats by around 80 per cent in India. In addition to this, private sector also leads the public sector by about three fourths in total number of enrolments. However, vacant seats are a common problem for all types of engineering institutes. Every year, they end up with about half of their seats having no takers.

Soon after Independence, the engineering graduates were more in the traditional disciplines of engineering education in India, but as stated earlier, fast developments in the IT sector during last three decades led to more and more engineers graduating in the CIS disciplines. The number of computer science and IT engineers produced has been greater than those in other disciplines (Banerjee and Muley 2008: 44). The trends in enrolment, pass out and placement were observed quite different in all disciplines of engineering. For instance, mechanical, electronics and communication, computer science, civil and electrical engineering are still the leading branches in terms of students' priority. From Table 2, it may be stated that compared to other AICTE approved disciplines, chemical engineering, mechanical engineering,

Table 1 AICTE-approved engineering and technology and MCA Institutes in India, 2012–20

Particulars		Academic Years							
		2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Numbers of institutes	*T#*	7031	7073	7175	7180	7172	7101	6866	6716
	*G**	1347	1433	1497	1588	1730	1814	1895	1987
	*P**	5684	5640	5678	5592	5442	5287	4971	4729
	*S***	80.84	79.74	79.14	77.88	75.88	74.45	72.40	70.41
New institutes	*T#*	245	129	153	93	178	143	162	157
	*G**	22	22	23	37	119	86	76	112
	*P**	223	107	130	56	59	57	86	45
	*S***	91.02	82.95	84.97	60.22	33.15	39.86	53.09	28.66
Closed institutes	*T#*	37	56	34	72	89	78	34	49
	*G**	0	0	0	0	2	2	0	2
	*P**	37	56	34	72	87	76	34	47
	*S***	100	100	100	100	97.75	97.44	100	95.92
Intake	*T#*	2,831,765	3,074,734	3,299,291	3,202,107	3,093,297	2,956,152	2,785,735	2,604,900
	*G**	423,820	459,061	483,656	492,805	510,297	523,743	546,600	557,538
	*P**	2,407,945	2,615,673	2,815,635	2,709,302	2,583,000	2,432,409	2,239,135	2,047,362
	*S***	85.03	85.07	85.34	84.61	83.50	82.28	80.38	78.60
Enrolment	*T#*	1,808,400	1,841,796	1,775,466	1,713,665	1,593,366	1,518,108	1,079,649	NA
	*G**	353,795	367,587	376,077	383,934	391,312	391,062	NA	NA
	*P**	1,454,605	1,474,209	1,399,389	1,329,731	1,202,054	1,127,046	NA	NA
	*S***	80.44	80.04	78.82	77.60	75.44	74.24	NA	NA

(continued)

Table 1 (continued)

Particulars		Academic Years							
		2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Seats filled (%)	*T*#	63.86	59.90	53.81	53.52	51.51	51.35	38.76	NA
	*P**	60.41	56.36	49.70	49.08	46.54	46.33	NA	NA
	*P**	5.12	3.73	2.70	2.47	2.26	2.12	NA	NA

Source Drawn upon the data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed April 21, 2020)
Notes *T*#—Total, *G**—Government, *P**—Unaided Private, University Managed-Private and Deemed University-Private, *S***—Share of Private in Total

Table 2 Intake and Enrolment in select engineering disciplines India, 2018–19

Particulars	TE	ME	MCA	ECE	EE	CSE	CE	CE*
Intake	12,445	802,484	94,159	556,236	442,296	587,244	507,664	36,190
Enrolment	6358	422,992	31,334	233,825	215,083	320,081	261,589	20,883
Seats filled (%)	51.1	52.71	33.28	42.04	48.63	54.51	51.53	57.7

Source Drawn on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php
Notes TE—Textile Engineering, ME—Mechanical Engineering, ECE—Electronics and Communication Engineering, EE—Electrical Engineering, CSE—Computer Science Engineering, CE—Civil Engineering, CE*—Chemical Engineering

computer science engineering and civil engineering had higher enrolment in 2018–19. The enrolment in the CIS in Electronics and Communication Engineering and Computer Science Engineering was recorded as 42.04 per cent and 54.53 per cent, respectively, in 2018–19. However, despite almost half of the total seats remaining vacant, the intake proportion for the computer science engineering was higher than all other branches individually excepting chemical engineering. The electronics and communication engineering and electrical engineering still could manage to fill seats by 42.04 per cent and 48.63 per cent, respectively. Though, MCA programme had its own attraction in the past, in 2018–19, it could fill only about one third of total seats. The enrolment in absolute numbers in MCA was still reported higher than the textile engineering and chemical engineering disciplines. From the above discussion, it can be concluded that demand for engineering education including CIS has fallen in India that has eventually led to closure of courses and/or institutes.

As discussed above, the total number of technical institutes increased through out faster, particularly during post-reforms period. For instance, according to the AICTE-Approved Process Handbook (for different years, 1997–2012), number of technical institutes was a meagre 562 in 1997–98, but it increased to 2388 in 2008–09, that further increased to 3393 in 2011–12. While the number of institutes offering courses in CIS education increased from 6099 in 2012–13 to 6474 in 2016–17, it declined to 6151 in 2019–20 (Table 3). Since 2016–17, this has led to a progressive shutting down of hundreds of related courses in this field. It is important to note that MCA is not an engineering programme but is related to computer sciences; therefore, this discussion includes MCA as well. With a rise in demand for computer-related skills, the number of MCA institutes rose significantly. However, the trends in the MCA programme appeared similar to other programmes, as discussed earlier. The number of MCA institutes in India fell by 716 from 1739 in 2012–13 to 1023 in 2019–20. With a fall in the number of institutes offering MCA course, both approved intake and enrolment have moved southward. The intake capacity of MCA institutes has fallen from 132,148 in 2012–13 by 51.48 per cent to 64,114 in 2019–20. It is evident from the Table 3 that only one third of seats got filled in the MCA programme in India. Since 2012-13, there has been a decline in the total number of students, faculties and student–teacher ratio per MCA institute. In a span of eight years between 2012–13 and 2019–20, the number of enrolled students declined by 45.7 per cent from 55,105 to

Table 3 Computer science and related engineering education institutes and MCA education in India

AY year	Number of CIS institutes	MCA education in India							
		Number of institutes	Intake	Number of students enrolled	Seats filled in (%)	Number of enrolled students per institute	Number of faculties	Student–Teacher Ratio	Number of faculty per institute
2012–13	6099	1739	132,148	55,105	41.7	31.69	19,016	2.9	10.94
2013–14	6218	1568	122,884	41,690	33.93	26.59	21,980	1.9	14.02
2014–15	6385	1461	116,276	35,979	30.94	24.63	22,872	1.57	15.66
2015–16	6431	1345	107,061	35,053	32.74	26.06	20,404	1.72	15.17
2016–17	6474	1233	94,159	32,753	34.79	26.56	18,793	1.74	15.24
2017–18	6446	1159	85,164	31,382	36.85	27.08	17,652	1.78	15.23
2018–19	6276	1065	73,713	28,458	38.61	26.72	13,190	2.16	12.39
2019–20	6151	1023	64,114	29,920	46.67	29.25	11,972	2.5	11.70

Source Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

Table 4 Enrolment in B.Tech/B.E. and M.Tech on regular mode in India, 2014–19

Year	Number of students enrolled for M.Tech	Number of students enrolled for B.Tech/B.E
2014–15	289,311	4,254,919
2015–16	257,361	4,203,933
2016–17	160,888	4,085,321
2017–18	142,081	3,940,080
2018–19	135,500	3,770,949

Source Drawn on by the author based on data obtained from https://mhrd.gov.in/sites/upload_files/mhrd/files/statistics-new/AISHE%20Final%20Report%202018-19.pdf

29,920. The total number of students per MCA institute, number of total faculties and student–teacher ratio have fallen since 2012–13. This clearly indicates a continuous decline in the demand for the MCA course in India. Moreover, this reduces supply of computer software developers and innovators in the field of computers as well as probable aspirants in the field of teaching of such programmes.

An increasing number of vacant seats and a poor placement record of engineering graduates in recent years are indications of a sluggish demand for engineering education and a subsequent closure of courses as well as institutes. The number of students enrolling in the regular Master of Technology (M.Tech) and the Bachelor of Technology (B.Tech)/Bachelor of Engineering (B.E.) programmes in engineering education continuously declined in India since 2014–15 (Table 4). There was a fall in the enrolment by 11 per cent in the B.Tech/ B.E. programme and 55 per cent in the M.Tech programme observed between 2014–15 and 2018–19. This clearly suggests that engineering courses at both UG and PG levels are experiencing a continuous fall in demand. Less intake of students reduce the supply of technical and scientific manpower in the country which may eventually result into fall in number of innovations. Further, the M.Tech programmes are in real trouble. And, this is likely to have an adverse impact on the supply of future teachers for the engineering courses.

3.2 Performance of Students of Engineering Education

Evaluation of a higher educational institute and its overall grading in addition to other important parameters also depend on pass out ratio of students and their placement record in the recent AYs. Many of the reputed engineering colleges including IITs and NITs are highly selective in their admission process (Karkare et al. 2013); therefore, they succeed in enrolling some of the academically most brilliant students in their courses. Hence, performance of students in various examinations as well as campus interviews is likely to be outstanding. However, it may not be true in case of other engineering institutes.

High pass out ratio and good placement of students indicate better academic ranking of engineering institutes. A host of students performing better in their 10 +2 board examinations opt for engineering education in India. But, in their graduation, 40 per cent of engineering students fail to clear examinations as per their academic schedule (Table 5). Grade inflation, grace marks and liberal evaluation of students push results upward and overall result has neared 90 per cent in the recent years. The situation of placement is not quite different from pass out one. Around two thirds of the students of the private engineering institutes failed to get any placement between 2012–13 and 2018–19. The overall situation was gloomier during the same period. Engineering students end up paying hefty fees to their institutes during their five year or seven years academic programmes. If their degree fails them to get a fair job and they end up accepting an ordinary employment, then it conveys a strong message for the future generation suggesting them not to opt for a career in engineering for their bright future. This leads to fall in enrolment of engineering institutes and eventually closure of several courses and/or institutes.

Almost all IIT graduates and postgraduates get jobs before they graduate (Karkare et al. 2013). But campus recruitment in the most favourite traditional engineering courses was not even 50 per cent of the number of students enrolled in recent times. For instance, Chemical Engineering, Civil Engineering, Mechanical Engineering, Textile Engineering and Electrical Engineering had placement as a share of total enrolment as 30.05 per cent, 20.68 per cent, 34.13 per cent, 32.14 per cent and 34.62 per cent, respectively; it implies that around two third of the total students enrolled

Table 5 AICTE-approved engineering and technology and MCA institutes in India, 2012–19

Particulars		Academic years						
		2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
Enrolment	*T#*	1,808,400	1,841,796	1,775,466	1,713,665	1,593,366	1,518,108	1,079,649
	*P**	1,454,605	1,474,209	1,399,389	1,329,731	1,202,054	1,127,046	NA
	*S***	80.44	80.04	78.82	77.60	75.44	74.24	NA
Passed	*T#*	1,125,129	1,241,905	1,321,169	1,370,753	1,438,360	1,269,626	NA
	T##	62.22	67.43	74.41	79.99	90.27	83.63	NA
	*P**	885,766	981,517	1,051,850	1,094,013	1,154,572	984,464	NA
	PI#*	60.89	66.58	75.17	82.27	96.05	87.35	NA
Placement	*T#*	434,457	477,510	536,903	567,228	579,029	569,215	617,035
	T#*	31.78	31.66	33.64	34.48	33.68	36.83	NA
	*P**	357,573	393,162	444,500	472,629	484,420	467,637	508,016
	*P***	40.37	40.06	42.26	43.20	41.96	47.50	NA

Source Drawn upon the data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed April 21, 2020)

Notes *T#*—Total, *P**—Unaided Private, University Managed-Private and Deemed University-Private, *S***—Share of Private in Total, *T##*—Passing Percentage of Total Intake, PI #*—Passing Percentage of Intake of Private Institutes, *T#**—Placement Percentage of Total Passed, *P***—Placement Percentage of Passed in Private Institutes, NA—Not available

Table 6 Enrolment and placement of students in select engineering disciplines, 2018–19

Field of engineering	Enrolment	Placement	Enrolment to placement (%)
Chemical engineering	20,883	6275	30.05
Civil engineering	261,589	54,104	20.68
Computer science engineering	320,081	112,712	35.21
Electrical engineering	215,083	69,120	32.14
Electronics and communication engineering	233,825	100,383	42.93
MCA	31,324	14,625	46.69
Mechanical engineering	422,992	144,363	34.13
Textile engineering	6358	2201	34.62

Source Drawn on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php

failed to get a job in the campus recruitment drive (Table 6). The developments were not quite different in the engineering disciplines included in the CIS. Further, the placement as a share of enrolment for MCA, Electronics and Communication Engineering, and Computer Science Engineering for AY 2018–19 was recorded at 46.69 per cent, 42.93 per cent and 35.21 per cent, respectively. It may be surmised that not even half of the graduates in the said disciplines could manage campus recruitment and the other half were just not employable for various reasons at least at that moment.

The US sub-prime crisis in 2008 temporarily reduced demand for the IT engineers from India (Das and Sagara 2017). In recent times, the digital disruptions are also impacting their demand in a big way (Sagara and Das 2019). Trends in enrolment may help understand it. The intake capacity and total enrolment of students in computer science and related engineering education had not changed much. The total number of approved intake of students in the CIS education institutes though increased from 2,699,617 in 2012–13 to 3,094,596 in 2015–16, it has continuously declined since then and reached 2,539,063 in 2019–20 (Table 7). The reason for this falling trend was low enrolment of students in these courses. There existed more than 50% gap between intake capacity and actual enrolment of students in the CIS courses in India. The gap between the number of available seats and number of filled seats has ranged between around 10,00,000 and 12,50,000 seats. The passing percentage of students with respect to enrolment has reasonably improved and stood between 90 and 95 for the last five years, i.e. the passing percentage of the total enrolled students increased from 61.25 per cent in 2012–13 to 83.03 per cent in 2017–18. The passing percentage of enrolled number of students, though improved since 2012, ranged between 61 per cent and 85 per cent during 2012–13 to 2019–20. Though placement as a percentage of enrolled number of students increased from 23.55 per cent in 2012–13 to 42.77 per cent in 2018–19, no companies/firms offered a job to almost two thirds of enrolled students on their campus at that point of time. Further, placement data drew a gloomier picture when taken as a percentage of approved intake of students. It was as low as

Table 7 No. of computer science and related engineering education institutes

AY	Approved intake Capacity	Number of enrolled students	Number of students passed	Number of students got placement	Enrolment to approved intake (%)	Passed to enrolment (per cent)	Placement to enrolment (%)	Placement to approved intake (%)
2012–13	2,699,617	1,753,369	1,073,846	412,845	64.95	61.25	23.55	15.29
2013–14	2,951,825	1,800,132	1,190,317	455,585	60.98	66.12	25.31	15.43
2014–15	3,182,775	1,739,507	1,269,132	513,674	54.65	72.96	29.53	16.14
2015–16	3,094,596	1,678,612	1,325,436	546,692	54.24	78.96	32.57	17.67
2016–17	2,999,138	1,560,559	1,400,722	561,465	52.03	89.76	35.98	18.72
2017–18	2,870,988	1,486,752	1,234,950	553,152	51.79	83.06	37.21	19.27
2018–19	2,712,022	1,400,027	NA	598,816	51.62	NA	42.77	22.08

Source Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and from All India Survey on Higher Education (AISHE) 2018–19

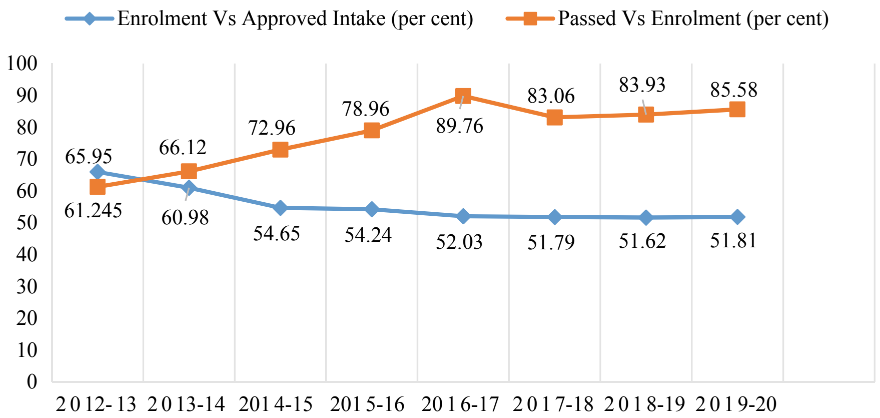

Fig. 1 Students of computer science and related to engineering education Institutes. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

15.29 per cent in 2012–13 and increased to 22.8 per cent in 2018–19. All these data indicate a very dismal performance of the students.

According to the National Employability Report (2011: 45) based on the survey of 120,000 engineers across India, 'States with more government colleges as compared to private colleges fare better on employability in the IT services sector'. From Fig. 1, it may be observed that the ratio of enrolment to total intake of students of computer science and related to engineering education institutes has been around 50 per cent between 2012–13 and 2019–20. Further, out of the total enrolled students, the passing ratio has not been cent per cent. Over a period, the passing ratio has improved from 65.95 per cent in 2012–13 to 85.58 per cent in 2019–20. Moreover, the ratio of placement to approved intake ranged from 15 per cent to 20 per cent. The enrolment to placement ratio, though it was quite low, has significantly improved from 23.55 per cent in 2012–13 to 38.66 per cent in 2019–20 (Fig. 2). It is a positive indicator. After paying exorbitant fees in private engineering institutes, if engineering graduates see poor placements may potentially discourage the future aspirants to take up engineering as their career.

As discussed earlier, with a decline in the number of MCA institutes, the number of students enrolled as well as their passing out had steadily fallen between 2012–13 and 2019–20 (Fig. 3). The enrolment and pass out numbers in MCA declined by 45.70 per cent and 32.57 per cent, respectively, during the same period. MCA was also a priority for students interested in computer science during the first decade of the present century. The enrolment was recorded as high as 55105 in 2012–13 in the AICTE-approved MCA institutes. However, the enrolment has almost got reduced to half to 29,920 in 2019–20. Placement of MCA students has been only at 50 per cent. Since there is a declining trend in MCA course, such institutes are also closing down progressively.

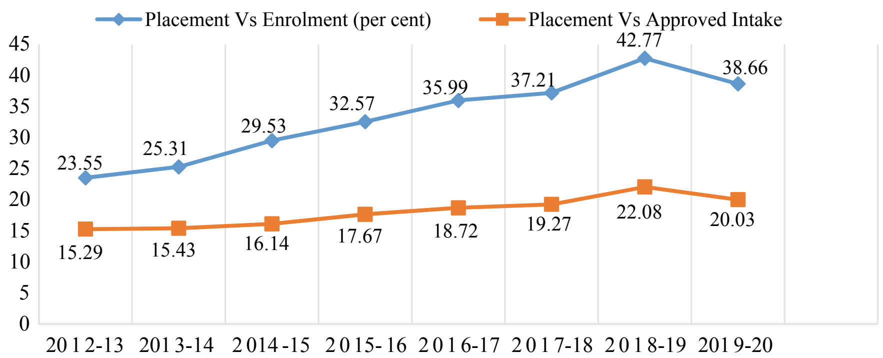

Fig. 2 Students of computer science and related to engineering education Institutes. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

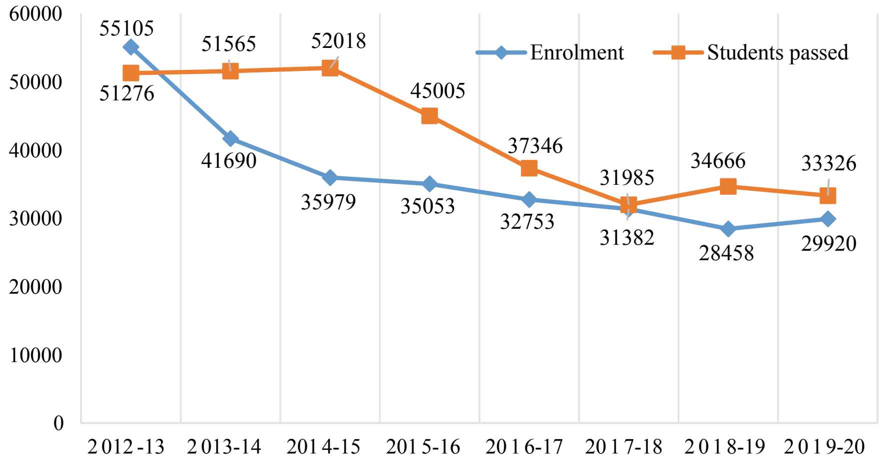

Fig. 3 Enrolment and passing of students of MCA institutes in India. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

The situation at undergraduate engineering institutes in the CIS disciplines is equally dismal. From Table 8, it is evident that pass out ratio to enrolment of students in the undergraduate level engineering institutes in major disciplines for the AY 2018–19 was reported below 25 per cent. For instance, for computer engineering, electronics engineering, electrical engineering and information technology, the proportions were 18 per cent, 22 per cent, 23 per cent and 20 per cent, respectively. It indicates that either drop out ratio at the undergraduate level is higher or students are unable to cope up with the course for various reasons.

Table 8 UG level enrolment and Turnout/Pass out in major disciplines at engineering institutes, 2018–19

Name of the discipline/Subject	Enrolment	Turnout/Pass out (%)
Computer engineering	880,349	156,570 (17.78)
Electronics engineering	631,365	141,114 (22.35)
Electrical engineering	394,154	89,745 (22.77)
Information technology	187,962	37,204 (19.79)
Other engineering and technology	3,852,188	49,820 (1.29)
Total	2,323,272	474,453 (20.42)

Source All India Survey on Higher Education (AISHE) 2018–19, Department of Higher Education, Ministry of Human Resource Development, GoI, New Delhi, p. 107 for enrolment and p. 167 for pass out

It is important to know about the enrolment and pass out at the postgraduate, M.Phil and Ph.D. levels in various disciplines of the CIS discipline. The number of PhDs in the area of Engineering and Technology increased from 2081 in 2011–12 to 4907 in 2017–18 (Ravi et al. 2019: 57). According to the All India Survey on Higher Education, enrolment was recorded the highest in IT and computer, computer science and IT in postgraduate, M.Phil and doctoral programmes in the AY 2018–19 (Table 9). However, no students were enrolling for M.Phil and Ph.D in animation and multimedia, and the enrolment was highest in computer science for the said programmes. Interestingly, computer engineering and electronics engineering are equally in demand, particularly, at the postgraduate and Ph.D. levels. Computer engineering, electronics engineering and computer science had Ph.D. enrolment in a decreasing order in that sequence. Students' enrolment and pass out figures were recorded relatively higher in computer engineering and electronics engineering. However, the passing out ratio to enrolment even for the IT and computer, computer and IT disciplines were observed as 34.4, 41.13 and 45.14, respectively, only. These trends are not quite different from computer engineering, electronics engineering and information technology courses as pass out ratio was recorded as 46.28, 45.58 and 56.85, respectively.

3.3 Closure of Engineering Courses and Institutes

For engineering aspirant's decision to opt for a particular discipline depends on number of factors including good placement, faculty, research and quality of college in the recent years.[6] For admission in UG programmes in engineering, many competitive examinations both at state level and all India level are held every year. But for admission in a PG programme, students get through the Graduate Aptitude Test

[6] View of Anup Singh, Director General, Nirma University (ToI, November 14, 2018: 2).

Table 9 Enrolment and Turnout/Pass out in Ph.D., M.Phil and PG disciplines of IT, computer science and engineering disciplines in India

Discipline/Subject	Ph.D. Enrolment	Ph.D. Turnout/Pass out	M.Phil enrolment	M.Phil Turnout/Pass out	PG enrolment	PG Turnout/Pass out	Passing rate (%)
IT and computer	763	117	176	419	152,237	52,307	34.40
Computer science	1892	348	973	1552	33,422	13,747	41.13
IT	210	34	25	4	11,253	5079	45.14
Animation	0	0	0	0	87	16	18.39
Multimedia	0	0	0	0	50	8	16.00
Computer engineering	5846	833	0	0	29,714	13,751	46.28
Electronics engineering	4774	856	0	0	27,019	12,315	45.58
Information technology	378	64	6	7	3031	1723	56.85

Source All India Survey on Higher Education (AISHE) 2018–19, Department of Higher Education, Ministry of Human Resource Development, GoI, New Delhi, pp 110 and 109 for enrolment and p 170 for pass out

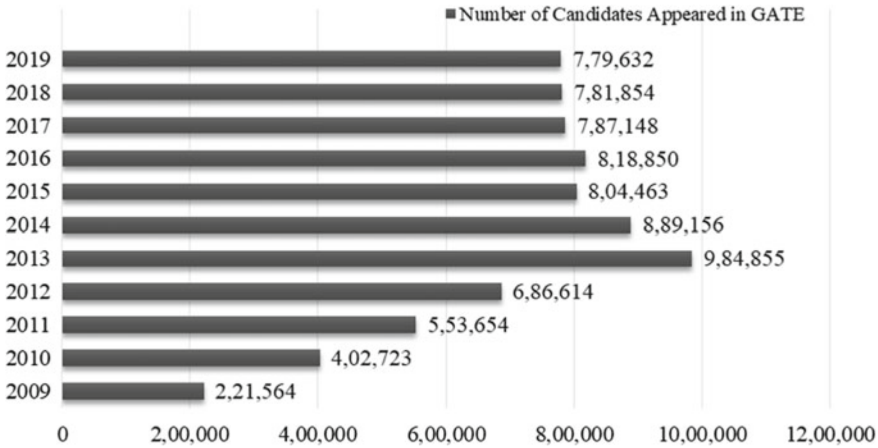

Fig. 4 Number of candidates appeared in GATE. *Source* Drawn on by authors based on data obtained from https://www.ignitedengineers.com/gate/number-of-candidates-appeared-in-gate/

in Engineering[7] (GATE). The number of students appearing for the GATE and their priorities for select engineering branches are two vital indicators of demand for engineering education in India. From 2009 to 2013, the number of students appearing for GATE increased from 221,564 to 984,855 (Fig. 4). However, from 2013 onwards, this number has steadily fallen every year. Interestingly, looking at the subject-wise composition of the students appearing for GATE, it indicates that it had only increased for subjects including electronics and communication engineering, mechanical engineering, electrical engineering and civil engineering (Table 10). These are core subjects in engineering which are still a priority among the students. In case of electronics and communication engineering, there was a small increase compared to other subjects as stated above. However, there was not any significant change in the GATE applications for computer science and IT as a subject.

In recent years, as discussed earlier, boththe intake capacity and enrolment of students in engineering institutes have fallen considerably. According to the AICTE, out of the approved intake of about 37 lakh, only ten lakh students were enrolled for different engineering courses with vacancy of around 27 lakh seats in 2018.[8] It is important to note here that all seats in 23 IITs have been filed in the current academic session 2019–20, and in 2018, 118 seats had found no takers, while 110 seats remained vacant in 2017, 96 seats in 2016, 32 seats in 2015, three seats in

[7]The Graduate Aptitude Test in Engineering (GATE) is an examination that primarily tests the comprehensive understanding of various undergraduate subjects in engineering and science. The score is used for admissions to various postgraduate education programs (e.g. Master of Engineering, Master of Technology, Master of Architecture, Doctor of Philosophy) in Indian higher education institutes.

[8]https://www.sundayguardianlive.com/news/12525-1-lakh-drop-number-iit-jee-applicants.

Table 10 Subject-wise composition of candidates appeared in GATE

Year	ECE	CS and IT	ME	EE	CE
2010	1,04,291	1,07,086	59,338	52,246	19,406
2011	1,37,853	1,36,027	81,175	72,680	29,347
2012	1,76,944	1,56,780	1,12,320	1,10,125	36,156
2013	2,56,135	2,24,160	1,65,814	1,52,381	67,472
2014	2,16,367	1,55,190	1,85,578	1,41,799	90,872
2015	1,72,714	1,15,425	1,85,758	1,25,851	1,01,429
2016	1,83,152	1,31,803	2,34,727	1,46,293	1,18,147
2017	1,52,318	1,08,495	1,97,789	1,25,859	1,19,873
2018	1,25,870	1,07,893	1,94,496	1,21,383	153,078

Source Drawn on by authors based on data obtained from https://en.wikipedia.org/wiki/Graduate_Aptitude_Test_in_Engineering
Notes ECE—Electronics and Communication Engineering, CS and IT—Computer Science and Information Technology, ME—Mechanical Engineering, EE—Electrical Engineering, CE—Civil Engineering

2014 and 149 seats in 2013 remained vacant.[9] Almost all seats in the 23 IITs were filled during the recent years. However, over 50 per cent of seats remained vacant in engineering institutes of major states in India including Odisha (80 per cent), West Bengal (60 per cent), Andhra Pradesh (55 per cent), Tamil Nadu (52 per cent), Maharashtra (50 per cent) and Kerala (50 per cent).[10] Moreover, with at least 30 per cent of the total available seats lying vacant, around 800 engineering colleges are likely to be closed down, progressively sooner than later. Poor placement of students has reduced demand for engineering education in India over a period. With less or no students enrolled with them, several engineering institutes are finding it difficult to cope with high operational costs to continue with a course or the institute itself. Therefore, the only practical option available with them is discontinuation of an academic course or closure of an institute.

Between 2012–13 and 2019–20, on an average, every year about 34 institutes in computer science and related engineering education were progressively closed and about 152 new institutes in the same discipline were opened. (Fig. 5). It implies that certain engineering courses may not find takers; however, some new disciplines in engineering education are emerging and are in demand. Between 2012 and 2020, an average of about 102 institutes got closed progressively every year. Further, in a span of eight years, 98 new MCA institutes were opened (Fig. 6).

If privatization of technical education and increase in demand for engineers had led to setting up of numerous engineering institutes all over the country, then the poor placement and vacant seats in engineering institutes have led to their closure.

[9] https://indianexpress.com/article/education/engineering-day-over-50-seats-in-engineering-colleges-across-states-went-vacant-know-why-aicte-india-org-wbjeeb-nic-in-5993630/.

[10] https://indianexpress.com/article/education/engineering-day-over-50-seats-in-engineering-colleges-across-states-went-vacant-know-why-aicte-india-org-wbjeeb-nic-in-5993630/.

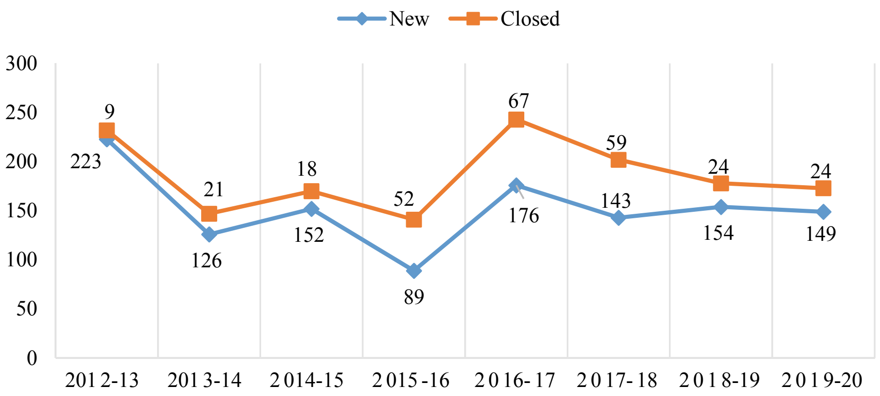

Fig. 5 Number of computer science and related engineering education Institutes. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and from All India Survey on Higher Education (AISHE) 2018–19

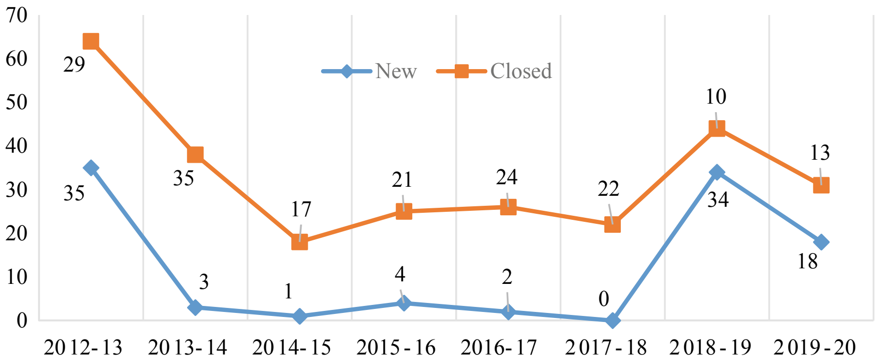

Fig. 6 Number of closed and new MCA institutes in India. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

The total number of computer science and IT course related institutes went through a progressive closure of courses between 2012–13 and 2018–19 (Table 11). Between 2012 and 2018, a total of 917, 1622 and 1408 institutes progressively closed down courses in electronics and IT application, computer science and IT and communication engineering, respectively. The most notable courses that experienced closure included Computer Science and IT (54 per cent), electronics and IT application (24 per cent) and communication engineering (17 per cent). The new-age courses including high-performance computing, networking, machine learning and artificial intelligence and IT management also experienced closure, though these numbers were relatively much small. But it is important to note here that total number of institutes offering such courses are also much less in number. It is important to note

Table 11 Number of progressively closed courses in computer science and IT fields in India, 2012–19

AY	Diploma	UG	PG	Post Diploma	PG Diploma	UG second year direct	MCA Second Year Direct	Total
2012–13	67	162	79	5	5	0	0	318
2013–14	125	356	170	2	2	4	0	659
2014–15	113	198	75	0	1	1	0	388
2015–16	128	245	310	0	0	0	4	687
2016–17	112	153	131	0	1	2	8	407
2017–18	234	409	336	0	1	5	9	994
2018–19	134	199	312	1	0	1	2	649
Total	913	1722	1413	8	10	13	23	4102
Share in Total (per cent)	22	42	35	0.2	0.23	0.30	0.55	100*

Source Calculated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)
Note * Approximated

that the number of institutes progressively closing their courses was recorded the highest at the undergraduate level (42 per cent) followed by the postgraduate level (35 per cent) related to computer science and IT field between 2012–13 and 2018–19. Of all courses closed down, 22 per cent of the institutes had diploma courses during the same period. However, from 2015–16 onwards, the closure of courses was observed higher at the postgraduate level (Fig. 7). The reduced demand for engineering education including computer science and IT-related courses has led

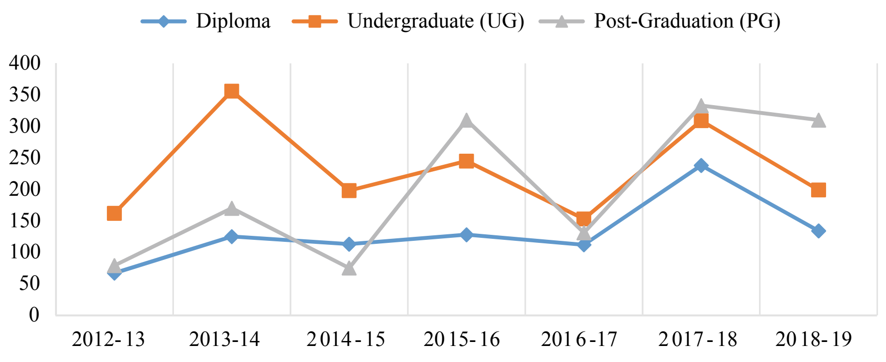

Fig. 7 Progressive closure of courses at Diploma, UG and PG in India. *Source* Calculated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)

Table 12 Number of progressively closed courses in select engineering disciplines, 2012–19

Academic year	*E**	*C**	*C***	*H**	*N**	*M**	IT*	Total
2012–13	45	233	27	6	2	1	3	317
2013–14	97	550	40	10	0	0	5	702
2014–15	61	278	39	6	2	1	1	388
2015–16	195	343	101	39	6	1	2	687
2016–17	108	191	93	8	6	1	1	408
2017–18	270	361	213	28	18	2	2	894
2018–19	205	215	170	44	11	3	1	649
Total	981	2171	683	141	45	9	15	4045
Share in Total (%)	24.25	53.67	16.89	3.49	1.11	0.22	0.37	100

Source Calculated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)
Notes *E**—Electronics and IT Application, *C**—Computer Science and IT, *C***—Communication Engineering, *H**—High-Performance Computing, *N**—Networking, *M**—Machine Learning and Artificial Intelligence, IT*—IT Management

the AICTE's decision not to permit setting up of any new engineering college from 2020–21 onwards,[11] needless to say that the regulatory body finds no scope in further expansion of engineering education in the country.

The IT revolution in India during the post-reform period led to starting of new courses in the CIS by existing engineering institutes or opening up of new colleges/universities in this field. However, with the decline in demand for such courses, this trend completely got reversed. As shown in Table 12, around 4045 institutes closed courses progressively including Electronics and IT Application (981), Computer Science and IT (2171), Communication Engineering (683), High-Performance Computing (141), Networking (45), Machine Learning and Artificial Intelligence (9) and IT Management (15). However, three major disciplines, namely, Electronics and IT Application (24.25 per cent), Computer Science and IT (53.67 per cent) and Communication Engineering (16.89 per cent) overwhelmingly formed 94.81 per cent of the total closure of courses during 2012–19. It indicates that either there is an overcapacity of the institutes compared to number of engineering aspirants or these courses are increasingly losing their demand in the market.

In recent times, not only engineering courses but institutes/colleges are also closing down for lack of demand. It is important to remember that the southern India leads others in total number of engineering institutes as well as intake capacity. The number of institutes in computer science and IT-related courses had been closing down due to their lack of demand between 2012–13 and 2019–20. Amongst the states, Telangana (83), Andhra Pradesh (64), Maharashtra (50), Haryana (44) and Tamil Nadu had the highest number of closure of such institutes (Table 13). However, it is important to note that these states happen to have more engineering colleges than

[11] https://www.business-standard.com/article/education/no-new-engineering-colleges-from-2020-says-aicte-all-you-need-to-know-119011900276_1.html (Accessed March 15, 2020).

Table 13 Number of computer science and IT-related institutes closed down in select states, 2012–19

State	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	Cumulative Total (per cent)*
Andhra Pradesh	18	18	9	7	4	7	0	1	64 (14)
Gujarat	0	0	0	4	5	1	2	3	15 (3)
Haryana	1	3	2	11	14	6	4	3	44 (10)
Karnataka	0	0	1	2	9	0	3	1	16 (4)
Madhya Pradesh	0	0	1	3	7	4	5	3	23 (5)
Maharashtra	1	4	3	8	14	14	5	1	50 (11)
Punjab	0	0	2	1	3	6	3	2	17 (4)
Rajasthan	5	2	1	1	10	7	3	2	31 (7)
Tamil Nadu	0	3	5	10	4	10	6	3	41 (9)
Telangana	18	12	7	12	8	22	2	2	83 (19)
Uttar Pradesh	0	3	3	11	11	0	3	0	31 (7)

Source Calculated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)
Note * Figures in parentheses are percentages of cumulative closed institutes to all technical institutes in the respective states as in 2019–20

their counterparts in the country. Some of the most notable states that experienced closing down of the computer science and IT-related institutes in the country included Telangana (19 per cent), Andhra Pradesh (14 per cent), Maharashtra (11 per cent) and Haryana (10 per cent) during the same period.

During the last over half a decade, an increasing number of engineering colleges are closing down courses all across India. As shown in Table 14, the number of institutes that had closed down courses related to computer science and IT was observed high in select states including Telangana (705), Maharashtra (687), Tamil Nadu (614) and Andhra Pradesh (391). Their relative share in the total number of

Table 14 Number of computer science and IT-related institutes with progressive closed courses

State	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	Cumulative Total (per cent)#
Andhra Pradesh	40	141	55	55	13	44	43	391 (10)
Arunachal Pradesh	0	0	1	0	0	0	1	2*
Assam	0	2	0	0	1	1	7	11*
Bihar	0	1	2	0	0	0	0	3*
Chhattisgarh	3	5	1	8	7	14	13	51 (1)
Delhi	0	14	0	1	1	6	0	22*
Gujarat	1	35	6	26	14	17	17	116 (3)
Haryana	33	0	13	52	22	39	32	191 (5)
Himachal Pradesh	0	0	0	2	2	0	0	4*
Jammu and Kashmir	0	1	0	0	0	1	0	2*
Jharkhand	0	0	0	0	3	8	0	11*
Karnataka	11	14	14	18	19	46	56	178 (4)
Kerala	1	10	5	7	26	20	27	96 (2)
Madhya Pradesh	27	14	31	31	19	50	16	188 (5)
Maharashtra	26	78	69	42	138	258	76	687 (17)
Odisha	4	22	2	11	12	23	27	101 (3)
Puducherry	2	0	1	0	0	0	2	5*
Punjab	17	25	22	17	23	32	18	154 (4)
Rajasthan	23	26	19	42	22	56	33	221 (5)
Sikkim	0	0	0	0	1	1	0	2*
Tamil Nadu	26	67	101	110	43	132	135	614 (15)
Telangana	90	156	24	236	32	90	77	705 (18)

(continued)

Table 14 (continued)

State	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	Cumulative Total (per cent)#
Uttar Pradesh	11	39	17	24	16	35	45	187 (5)
Uttarakhand	1	3	1	0	2	5	8	20*
West Bengal	1	4	4	5	10	17	16	57*
Total	317	657	388	687	426	895	649	4019

Source Tabulated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)
Notes # Figures in parentheses are percentages of statewise cumulative closed courses to closed technical courses in all the states mentioned in the Table as in 2018–19
*Percentages being negligible are not reported here

institutes closing down courses was as follows: Telangana (18 per cent), Maharashtra (17 per cent), Tamil Nadu (15 per cent) and Andhra Pradesh (10 per cent).

About 75 per cent of the engineering graduates are taught at the private engineering colleges (Banerjee and Muley 2008: 4); therefore, it is likely that an overwhelmingly large number of engineering institutes that closed courses in recent times should be in the private sector. For instance, out of a total of 3996 institutes that closed their courses, 3830 institutes were either unaided or deemed universities in the private domain or universities managed by private entities (Table 15). The share

Table 15 Number of engineering institutes that closed courses, 2012–19 (Ownership wise)

Kind of ownership	Academic year							
	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	Total
Government	2	7	9	41	18	38	14	129
Government aided	6	0	1	4	4	12	6	33
Unaided private	309	647	378	638	385	835	624	3816
Deemed university (private)	0	1	0	0	0	0	0	1
University managed (Private)	0	2	0	0	0	1	10	13
University managed (Government)	0	0	0	4	0	0	0	4
Total	317	657	388	687	407	886	654	3996

Source Tabulated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)

Table 16 Number of privately owned institutes that closed courses, 2012–19 (Discipline wise)

AY	*E**	*C**	*C***	*H**	*N**	*M**	IT*	*N***	*N#*	*S**
2012–13	40	230	29	6	2	1	3	311	317	98.11
2013–14	92	501	40	10	0	0	5	648	657	98.63
2014–15	58	273	38	5	2	1	1	378	388	97.42
2015–16	177	329	90	33	6	1	2	638	687	92.87
2016–17	100	183	87	8	6	1	0	385	407	94.60
2017–18	246	345	207	26	18	2	1	845	886	95.37
2018–19	194	209	168	44	11	3	0	629	654	96.18
N##	907	2070	659	132	45	9	12	3834	3996	95.95

Source Tabulated by the authors based on data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed March 25, 2020)
*Notes E**—Electronics and IT Application, *C**—Computer Science and IT, *C***—Communication Engineering, *H**—High-Performance Computing, *N**—Networking, *M**—Machine Learning and Artificial Intelligence, IT*—IT Management, *N***—Number of Institutes that Closed Courses under Private Ownership, *N#*—Number of both Public and Private Institutes that Closed Courses, *S**—Share of Privately Owned Institutes to Total Institutes that Closed Courses (per cent), N##—Number of Institutes that Closed Courses under Private Ownership

of government-owned, government-aided and government-managed institutes that closed down their courses was a meagre 4.15 per cent of the total. It is crucial to know whether the courses closed down by engineering institutes had similar trend across IT and computer-related disciplines or not. Of the total number of institutes that closed down courses, more than 96 per cent were originally operating in the private sector in different branches including Electronics and IT Application, Computer Science and IT, Communication Engineering, High-Performance Computing, Networking, Machine Learning and Artificial Intelligence and IT Management (Table 16).

4 Reasons Behind Crisis in Engineering Education

The quality of an engineering institute may be judged on a host of parameters including adequacy of infrastructure, scholarship of teachers and their publications, internship, soft skills and placement of graduates. The employability percentage decreases with an increase in the number of engineering colleges in a particular state, clearly establishing that opening more engineering colleges shall not solve the problem of quality of engineers in the country (National Employability Report 2011: 4). Mushrooming engineering and management colleges, with some notable exceptions, have largely been functioning as *commercial* entities dispensing very poor quality education (Yashpal Committee Report 2008: 78). The premier institutes like IITs, NITs and a few other institutes of repute are producing a very small number of talented engineering students at all degree levels (Sharma 2014). However, other engineering institutes have not been able to thrive equivalently. The spawning private engineering colleges has resulted in the rise of low-quality output in the form of engineering graduates enhancing the apprehension that such a trend would stifle growth of the domestic economy (Singh and Singh 2014). The poor employability of engineering graduates is reflecting poorly on the faculty shortage and quality and pedagogy (Reddy undated: 23). Factors responsible for the deteriorating situation in the sphere of technical education in India have been discussed extensively in the media as also by scholars (for instance, see, Subbarao (2013) and Karkare et al. (2013)). The reasons attributed vary across inadequate physical infrastructure to a fall in quality of the scholastic content per se. Some of the major such issues have been discussed in the following.

4.1 Faculty Shortage

Quality teaching has been the IIT system's forte: although emphasis is placed on basic sciences, IIT courses cover cutting-edge fields in technology and engineering (Jayaram 2011: 187). Academics as a career is on a steady decline among the suitably qualified people, possibly as a result of lack of incentives here and lucrative opportunities elsewhere (Pitroda: 2006–09: 186). The engineering education system in India has been unable to attract the best engineering students towards postgraduate studies (Banerjee and Muley 2008: 3); therefore, they may not attract quality teachers both in required number and quality. Subbarao (2013) observed that the shortage of faculty both in number and in quality and the minimal academia–industry interaction are the most serious problem facing higher engineering education system in India. Inadequate number of quality teachers is one of the most important factors impacting the quality of teaching in higher educational institutes. About 2813 faculty positions in IITs and 3211 positions in NITs are lying vacant.[12] Planning Commission of India (2011: 26) noted that state institutions and central institutions suffer from 40 per cent and 35 per cent shortage of faculty, respectively. There were nearly 33 per cent of teacher posts lying vacant in central universities in March 2018 (Kumar 2018:118). It should be noted here that despite shortage of faculties in the engineering institutes in the public sector, vacancies of seats for students were much less compared to private sector. The student–teacher ratio of engineering institutes was observed above five per cent in 2012–13, but it slipped down to around two per cent in 2018–19 (Table 17). It signifies that the growth in number of teachers has not kept pace with the increase in enrolments. A fall in student–teacher ratio—due to reduced amount of time of interaction between the students and their teachers—is likely to have an adverse impact on learning. However, teacher shortage is not a problem unique to only the engineering institutes but also to the IITs and the IIMs that report teacher shortages as high as 30 per cent (Ravi et al. 2019: 23).

There was a dramatic increase in the number of teachers—largely as contract hires with limited scope for advancement or stable employment—in Higher Education

[12]https://timesofindia.indiatimes.com/home/education/news/why-iits-nits-are-facing-faculty-shortage-in-specialised-streams/articleshow/70359096.cms.

Table 17 AICTE-approved Engineering and technology and MCA institutes in India, 2012–20

Particulars		Academic years							
		2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Faculties	*P**	60.41	56.36	49.70	49.08	46.54	46.33	NA	NA
	T#	325,994	447,774	580,803	598,610	594,415	599,353	496,895	468,521
	*G**	41,621	52,377	62,614	60,928	62,270	67,933	69,362	77,247
	*P**	284,373	395,397	518,189	537,682	532,145	531,420	427,533	391,274
	*S***	87.23	88.30	89.22	89.82	89.52	88.67	86.04	83.51
Faculty teacher ratio	*T#*	5.55	4.11	3.06	2.86	2.68	2.53	2.17	NA
	*P**	5.12	3.73	2.70	2.47	2.26	2.12	NA	NA

Source Drawn upon the data obtained from https://facilities.aicte-india.org/dashboard/pages/dashboardaicte.php (Accessed April 21, 2020)
Notes T#—Total, *G**—Government, *P**—Unaided Private, University Managed-Private and Deemed University-Private, *S***—Share of Private in Total

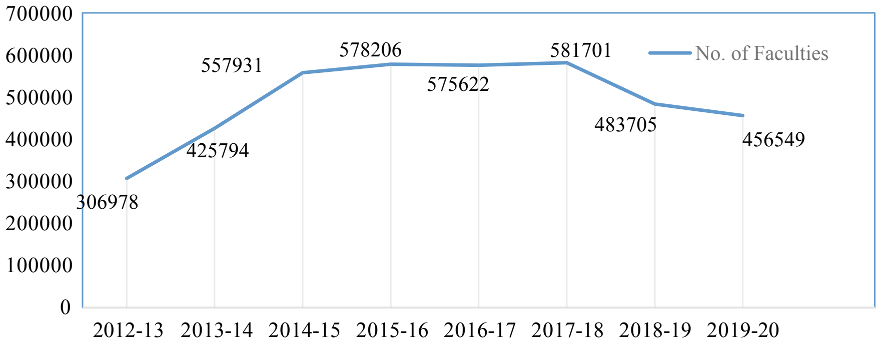

Fig. 8 Number of faculties at computer science and related engineering education institutes. India Survey on Higher Education (AISHE) 2018–19. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and were obtained from All India Survey on Higher Education (AISHE) 2018–19

Institutes (HEIs) in India post-2000; however, this growth was driven primarily by the private colleges and universities. (Ravi et al. 2019: 23). The number of members of faculty working with the computer science and related engineering institutes increased from 306,978 in 2012–13 to 581,701 in 2017–18, albeit, subsequently, the number fell to 456,549 in 2019–20 (Fig. 8). The number of faculty members of MCA institutes reduced from 19,016 to 11,972 during 2012–13 to 2019–20 (Fig. 9). The fall in the number of teachers at CIS institutes by 125,152, surely, would have significant impact on student–teacher ratio, competition of teaching assignments on time, fair and timely assessment of examination papers, redesigning of new syllabi and aggregate research work by the members of the faculty.

4.2 Research Publications and Innovation

Research publications and innovation is an important parameter determining ranking of an engineering institute. Globally, Indian engineering institutions have been ranking among the poor performers in the area of research and development. State funding of research and innovation can potentially help improve its grade and ranking of an academic institute. India had spent on research and development around 0.62 per cent of its GDP in 2015 which was comparatively much lower than South Korea (4.23 per cent), Japan (3.14), the USA (2.74) and China (2.11) in 2016 (Ravi et al. 2019: 54). Total contribution of India in terms of papers published during the last 40 years has been 134,771 papers in engineering (Global Ranking-7) and 50,325 papers in computer science (Global Ranking-3), and since 2004, India has increased its scientific output 3.8 times in the SCOPUS database and 3.4 times in the Web of

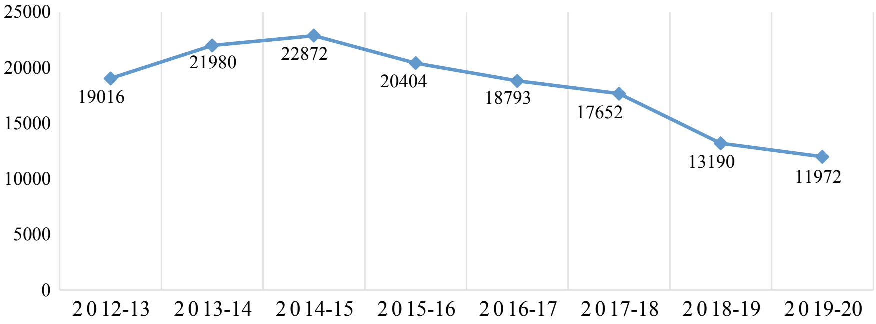

Fig. 9 Number of faculties at MCA Institutes in India. *Source* Drawn by authors based on data obtained from https://www.facilities.aicte-india.org/dashboard/pages/dashboardaicte.php and data were obtained from All India Survey on Higher Education (AISHE) 2018–19

Science.[13] Kumar et al. (2009) observed that scientific output of 15 major disciplines from India in 2006 spread over 445 Indian journals indicated that engineering and computer science and technology published 1084 (5.9 per cent of national total) and 85 (0.5 per cent of national total) papers in 2006. Rajan et al. (2018) estimated that in engineering and computer science, a total of 147,449 (4.63 per cent globally) and 107,052 (5.73 per cent globally) papers were published, respectively, during 2011–16. It is important to note here that India hosts 62 per cent of low-quality fake journals published globally (Ravi et al. 2019: 58). It suggests the presence of a culture that promotes unscholarly and unscientific research culture in the country.

Looking at the number of engineeringand computer science institutes in India, the number of quality publications and its relative share in the global total is quite low. Quality research publications at Indian engineering institutes have been quite limited in number (Subbarao 2013), and globally recognized publications have remained confined to the top technical institutes. Among the top 100 highly publishing engineering institutes, the IITs (35 per cent), deemed universities (20 per cent), NITs (17 per cent) and state public universities (12 per cent) far exceeded colleges (8 per cent), the state private universities (3 per cent), Centrally Funded Technical Institutes (CFTIs) and central universities (2 per cent).[14] Bansal et al. (2019: 1312) in their study titled 'Comparing Research Performance of Private Universities in India with IITs, Central Universities and NITs' observed that the top 25 private universities were almost equivalent to the IITs, NITs and central universities in their research output, citation and international collaboration in India. Therefore, the share of state private universities, other CFTIs and central universities is insignificant in the total number of top publications. It would be interesting to identify determinants of multi-dimensional research and collaboration undertaken by the top 25 private universities in the context of development of private engineering and CIS education in India.

[13] https://economictimes.indiatimes.com/news/science/will-india-be-among-the-top-3-nations-in-science-output-by-2030/articleshow/56429161.cms?from=mdr.

[14] https://www.nirfindia.org/2019/EngineeringRanking.html (Accessed March 2, 2020).

Table 18 Applications for patent, trademark filing activity, industrial design count and utility model, 2017

Name of country	No. of patent applications	No. of application of trademark filing activity	No. of application of industrial design counts	No. of application of utility model
China	1,381,594	5,739,823	628,658	1,687,593
USA	606,956	613,921	45,881	NA
Japan	318,479	560,269	32,457	6,105
Republic of Korea	204,775	230,466	67,357	6,811
European patent office	166,585	371,508 (European Union Intellectual Property Office)	111,021 (European Union Intellectual Property Office)	NA
Germany	67,712	225,768	45,803	13,301
India	46,582	283,575	11,117	NA
Russian Federation	36,883	291,732	7,390	10,643

Source Drawn on data obtained from WIPO IP Facts and Figures 2018, pp 13, 23, 31, 42

India has not been ranking quite high in scientific innovations as well. Table 18 shows that a reasonable number of applications were filed by India with the World Intellectual Property Organization (WIPO)/European Union Intellectual Property Office in 2017 under the categories including patent (46,582), trademark filing activity (283,575) and industrial design count (11,117). However, India trailed behind China, the USA, Japan, the Republic of Korea and Germany by a notable margin in the said categories.

Government expenditure, almost entirely the Central Government, is the driving forceof Research and Development in India which is in contrast to the advanced countries where private sector is the dominant and driving force of Research and Development spend.[15] According to Watal (2019: 3 and 47) in the report titled ‘Research and Development Expenditure Ecosystem: Current Status and Way Forward’, ‘Public expenditure on R and D in India has remained stagnant around 0.6–0.7 per cent of its GDP during last two decades compared to the US (2.8 per cent), China (2.1 per cent), Israel (4.3 per cent) and Korea (4.2 per cent). The expenditure on R and D increased from Rs. 24,117 crore in 2004–05 to Rs. 104,664 crore in 2016–17. Between 2017 and 2018, 93 per cent of the R and D expenditure was incurred by central government sources.[16] This minimizes the scope of research funding for the private engineering institutes in the country. The current situation is expected to improve due to the government’s decision allowing corporate India to use their

[15] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1580049 (Accessed May 30, 2020).

[16] https://www.newindianexpress.com/nation/2020/may/02/research-and-development-expenditure-icmr-among-bottom-5-2138133.html (Accessed May 30, 2020).

mandatory corporate social responsibility (CSR) spending for investments in publicly funded incubators and contribute to research efforts in science, technology, medicine and engineering at major institutions and bodies.[17] Recently, the Government of India initiated 'Inclusive Innovation Fund' to encourage research and innovation in the country.[18]

4.3 Lack of Internship and Industry Linkage

Engineers deal with machines and tools; therefore, practical exposure helps more than theoretical teachings in classroom. Subbarao (2013) pointed out that poor laboratory and library, poor linkage with industry, poor visibility in terms of publications, patents, new products and low or no international collaboration in teaching and research have emerged as the bane of technical education in India. The Indian engineering firms increasingly require more analytical, adaptive and creative engineers to upgrade the country's infrastructure, to respond to climate change and compete for higher value-added IT-orders in the global market (Blom and Saeki 2010: 29). Sixty per cent of faculty do not discuss how engineering concepts apply to industry and 'Only 40% of engineering students in India perform internships and only 36% undertake projects outside their assigned coursework, as a consequence, the engineering discipline in India is very theoretical' (National Employability Report: Engineers 2019: 8). As observed by (Yashpal Committee Report 2008: 41) only those institutions which had actively and on a continuous basis reached out to the alumni and the society had benefitted. However, those established private engineering institutions which have an advantage of industry patronage have been making extra efforts to enrich their curriculum with both intensive and extensive industry exposure and internship facilities for their students.

4.4 Unsatisfactory Soft Skills

Engineers do deal with people; hence, merely a technical degree is not enough for a consistent advancement in their career. As new technologies emerge, market requirements for human skill sets dynamically change for the engineers. Therefore, educating engineers with a comprehensive and deep set of skills are of tremendous importance for the employability of individual engineer and for the country's development (Singh and Singh 2010: 28). Eventually, both technical and soft skills to students need to be taught to enhance their employability (Meshram and Dubey

[17] https://www.thehindu.com/business/firms-can-use-csr-funds-for-rd/article29471805.ece (Accessed May 30, 2020).

[18] https://www.business-standard.com/article/news-ians/government-to-form-india-inclusive-innovation-fund-113121800788_1.html.

2015: 681). According to Nguyen (1998: 73), 'The desirable skills and attributes for engineers include the ability to communicate effectively, both verbally and in writing, to peers, the employers, client and the community; engineers should be bilingual'. Engineers who are in high demand possess three skill sets: core employability skills, communication skills and professional skills (Blom and Saeki 2010: 28). According to the India Skills Report (2019: 32), 'About 60% of the recruiters reported lack of right quality and updated skill sets in graduating engineering students in India'. Hence, the lack of required skills in the engineering graduates in India makes them less employable. However, generalizations would be grossly misleading as there have been institutes of high standards—both in the private and public domain—where in addition to advanced course soft skills are also emphasized.

4.5 Employability and Placement

Engineering courses which are linked with industries or corporates through internship or training are scoring high on employability compared to others (India Skills Report 2019: 26). Trends in macro employability and employability among engineers show no change over the past nine years, and about 80% of engineers are not employable for any job in the knowledge economy (National Employability Report: Engineers 2019: 7). Aring (2012: 7) in her *Report on Skills Gaps* noted that 'Although India graduates 450,000 engineers each year, only a fraction—25%—possess the skills to be employable'. Currently, just about three per cent Indian engineering students are equipped with new-age skills like artificial intelligence, which is sweeping the industry.[19] Except the IITs, a few NITs and some private engineering colleges, these new institutes failed to make their students job-ready; for instance, in 2017–18, less than 50%students got jobs from AICTE-approved engineering colleges.[20] The AICTE-CII Survey Report (2012: 12) observed that even among the high-ranking institutes in 80 per cent of institutes, 50 per cent or more final year students were offered jobs at campus interview during 2007–12 and 65% of the institutes were able to place only 40 per cent or more students in the companies directly aligning to the core disciplines taught. However, between 2007 and 2012, among the low ranking institutes, less than 40 per cent of students were offered job from campus in more than 90 per cent of the institutes and only 30 per cent of the institutes were able to place successful students in the companies directly aligning to the core disciplines taught. From Table 18, it can be stated that employability of engineers for their different roles was found less than 50 per cent in India. It varied from one discipline to the other. The employability for the role of associates in ITES Operations (Hardware and Networking) and ITES/BPO recorded 36.2 per cent and 39.35 per cent, respectively,

[19] https://www.newindianexpress.com/opinions/editorials/2020/feb/17/revamp-technical-education-in-india-2104411.html.

[20] https://indianexpress.com/article/education/how-the-indian-engineering-degree-lost-its-sheen-this-decade-6182675/.

Table 19 Employability in different branches of engineering in India, 2019

Roles	Employability (%)
IT roles	
Software engineer—IT product	3.4
Software engineer—IT services	16.25
Start-up ready—IT services	3.74
Associate—ITES Operations (Hardware and Networking)	36.2
Engineering roles	
Design engineer—Non-IT	6.62
Sales engineer—Non-IT	19.85
Non-technical roles	
Business analyst—KPO	9.39
Associate—ITES/BPO	39.35
Technical content developer	12.15
Creative content developer	17.03

Source https://www.aspiringminds.com/sites/default/files/National_Employbility_Report_Engineer_2019.pdf

(Table 18). As per the *India Skill Report* (2019: 26), 'Electronics and communication engineering and information technology courses in 2018 had highest employability rates with 60.63% and 60.18% respectively. Moreover, Electronics and Communication had reported 12% rise in employability during 2017–18'. The key job areas that would dominate the future job market include artificial intelligence, design, analytics and research and development (India Skill Report 2019: 32). For software engineer for IT services, sales engineer in non-IT roles and creative content developer, employability was reported as 16.25 per cent, 19.85 per cent and 17.03 per cent, respectively (Table 19). It would, then, be reasonable to hold that not all engineering graduates are likely to get placed. Moreover, software engineers in IT product, designer engineers in non-IT and business analysts in KPO having the least employability, they would have little chances of getting suitable jobs. As several low-end private engineering institutions aim at preparing the student to be merely 'job-ready', there have been constraints in securing jobs in a changing technological context. In fact, quite a few top engineering institutions both in the private and public domain have been focusing on devising course work that enables students with such soft skills and other emerging knowledge in the profession; there are enhanced chances for their employability for they remain prepared to adapt to new technological changes or reskilling as and when required by the industry.

4.6 Digital Disruptions

The Fourth Industrial Revolution largely based on digital technologies and innovations heralds a series of social, political, cultural, and economic upheavals that will unfold over the twenty-first century.[21] This revolution would have an everlasting impact on engineering education in the world including India. The World Economic Forum's report *The Future of Jobs* (WEF 2018: 9) states that as the Fourth Industrial Revolution unfolds, companies are seeking to harness new and emerging technologies to reach higher levels of efficiency of production and consumption, expand into new markets and compete on new products for a global consumer base composed increasingly of digital natives. The technical skill sets in future would be dominated by computer hardware and software design, analytics, artificial intelligence and robotics (India Skills Report 2019: 33). Sagara and Das (2019) observed that digital disruptions are likely to have an adverse impact on engineering jobs that require relatively low skills and can be easily replaced by automatic machines or robots; however, tremendous job opportunities lie ahead for engineers in Internet of Things, automation, cloud computing, big data and analytics and blockchain, etc. It is difficult to estimate at least at this stage as to how much impact would the disruptive technologies have on the engineering education; however, one may readily accept that these technologies have already started influencing it.

Escobari et al. (2019: 4 and 15) are of the view that the workers in the lowest wage quintile would be affected the most in the USA and likely to have the highest likelihood to switch into another low paying job; however, they cautioned that reskilling will never be enough without broader structural changes as per the emerging industry demand. With automation, the demand for work and workers could increase as economies grow, partly fuelled by productivity growth enabled by technological progress (Manyika et al. 2017: 8). Therefore, in order to remain relevant in the field of academics, the engineering institutes need to continuously update their syllabus and retrain and reskill their teachers from time to time. Moreover, in addition to their regular degree, diploma and other formal programmes, these institutions could collaborate with the industry towards starting pertinent reskilling programmes for their existing employees.

5 Recent Policy Initiatives and Need of the Hour

A Working Group's report of the erstwhile Planning Commission (2011: 29) on Higher Education for the Twelfth Five-Year Plan suggested an assessment of critical infrastructure requirements and additional infrastructure for capacity creation (including branch campuses) in State universities, government and government-aided colleges, as also engineering and technical institutions. Owing to the sustained efforts and proactive support provided (mainly, in terms of budgetary provisions) during the

[21] https://www.britannica.com/topic/The-Fourth-Industrial-Revolution-2119734.

successive Five-Year Plans, numerous engineering institutes were set up, however, with the implementation of the policy of liberalization and globalization, the number of students passing out of government institutions became insufficient to cater to the demands of the industry (Sharma 2014). The National Knowledge Commission recommended an expansion of the number of universities to 1500 in the country (Tilak 2007). During the last couple of decades, the Government of India has come up with major policy initiatives in order to promote science, technology and innovation in the country. These are a. the National Innovation Foundation (2000) to fund grassroots innovations; b. the Technology Policy (2003) and Science, Technology and Innovation Policy (2013) to promote science and technology and c. Atal Innovation Mission (2016) to create products from technologies and prototypes in areas of national importance (Kumar 2018: 16). A dedicated Ministry of Skill Development and Entrepreneurship (MSDE) was set up in 2014 to implement the National Skill Development Mission, which envisions skilling at scale with speed and standards. The government, like in Singapore and China, has identified 20 universities—ten each from the public and private sectors—as 'Institutions of Eminence' to attain world-class standards of teaching and research with an investment of Rs. 1000 crore to be spent over a five-year period to each institution (Kumar 2018: 119).

The Indian higher education system has not been helped by the small ad hoc changes to which it is accustomed, and is rather in need of fundamental transformation (National Employability Report: Engineers 2019: 7). Chaubey et al. (2018) opined that engineering education must meet the ultimate goal of creating such an environment which helps students to become better engineers and smart global citizens who can use their acquired knowledge of engineering to solve the problem of ordinary citizens and promote inclusive growth, equality and human development. Blom and Saeki (2011: 2) are of the view that engineering education institutions should refocus the assessments, teaching–learning process and curricula away from lower-order thinking skills, such as remembering and understanding, towards higher-order skills, such as analysing and solving engineering problems, as well as creativity.

In order to elevate India's top institutions to rank among the world-class academia, Subbarao (2013) recommended the following: total autonomy, independent and empowered Board of Governors, an outstanding academic as head, liberal funding by the government supplemented by private donations, good faculty with some stars, high-quality students and good infrastructure. India needs to have a mechanism to identify important areas/disciplines that should grow and develop policies and institutions that facilitate this (Banerjee and Muley 2007: 123). In order to improve the quality of engineering education, the Indian institutions should introduce new programmes and resources, with a major focus on faculty development and they should develop scalable web-based mechanisms to connect students with national and international companies and institutions (National Employability Report: Engineers 2019: 9).

Subbarao (2013) suggested re-hiring of retired faculty and inducting qualified engineers from the industry and R and D institutions as adjunct faculty and offering financial and other incentives to induce qualified persons to enter the teaching profession. Banerjee and Muley (2007: 121) have suggested that the existing Quality Improvement Programmes (QIPs) need to be scaled up significantly to at least 1000 QIP seats per year in order to have a direct impact on the quality of engineering teachers. Institutions should customize programme outcomes to meet the specific demand through internships and their involvement with community and should help students deepen their understanding of skills in demand and respond accordingly (Blom and Saeki 2010: 30). Banerjee and Muley (2007: 121) are of the view that flexible continuing education modules drawn up in consultation with industry can build bridges for enhanced academic-industry interactions. For the ailing engineering education, Subbarao (2013) and Hussain and Kumar (2014) suggested collaboration between Indian academia and universities abroad through exchange of research students and promotion of joint research.

6 Concluding Observations

For a modern, industrial and urbanizing nation, engineering education holds paramount value as it creates an enabling environment for nurturing human resource development, technological advancement and socio-economic progress. In India, even since the turn of the nineteenth century, there has been a massive growth of engineering education which surged during the post-Independence decades. India has witnessed fast and multifarious evolvement of engineering education, quality of teaching, placement of graduates, research and publications in the field and some of the finest national-level engineering institutions emerging, especially in the state sector. With economic reforms, the private sector has also made major forays into engineering education by establishing numerous institutions across the country and offering diverse courses. This study has made an attempt to examine the state of India's engineering education in general and computer science and engineering education (or the CIS discipline), in particular. The effort has been to delineate the process and enquire into the performance of engineering education in India, with special reference to the CIS discipline.

Despite a notable rise in the number of engineering institutions during the post-reforms period, a sharp decline is discernible especially since 2012–13 a majority though privately managed ones which account for about 80% of all enrolments. The drop was also noticed in the student–teacher ratio. A disturbing development during the recent years has been an increasing number of vacant seats coupled with a poor placement record of engineering graduates; this has led to closure of several courses and/or institutes overwhelmingly in the private sector. However, it has implications on the supply of technical and scientific manpower, scope for innovation and number of teachers in engineering education. So far as the CIS discipline is concerned (which typically accounted for almost half of all enrolments in recent years), the classic example is that of the once-popular MCA course which has definitely fallen out of favour leaving huge vacancies for this course. Moreover, at the undergraduate level, the pass out ratio was very low either due to high drop out ratio or students' inability to cope up with the course for various reasons. However, for higher degrees (postgraduate, M. Phil. or PhD.) in computer engineering, electronics engineering and computer science, there existed good demand. These observations are quite in contrast to those concerning IITs and NITs where the demand for these courses including those relating to CIS, student–teacher ratios and placement records have been commendable all through. Regionally, the closure has been most pronounced in states such as Telangana, Andhra Pradesh, Maharashtra, Haryana and Tamil Nadu; these are also the states anyway had the largest share of engineering institutions compared to other states.

As of the factors responsible for closure of courses and/or institutions in recent years, course content, academia–industry collaboration, scholastic output, digital disruptions and employability issues emerged as dominant ones. Nevertheless, one could discern a positive development alongside this dismal performance of engineering education in India. There have been a number of new subject areas, especially, within the CIS discipline, where demand has been on the rise and institutions have been responding to these new developments proactively. It may be premature to relate these changes to the grand technological disruptions—better known as the Fourth Industrial Revolution—but the course of engineering education has always been steered by the technological progress taking place within a certain discipline. The study, implicitly, suggests that adherence to high quality in teaching, research and adaptability towards emerging technologies would determine the future of engineering education in India. Any remiss in that focus would spell disaster for the students and the disciplines and, more importantly, enhance dependence on globally proactive players.

Acknowledgements Sincere thanks are due to Dr. Pradeep Choudhury and Professor Dinesh Abrol for incisive and constructive comments on an earlier draft of this article.

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Index

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