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Adoption of Industry 4.0 Technologies in India's Start-up Ecosystem

Sanjaya Kumar Malik[*]

[***Abstract***: *Industry 4.0 (IR4)—a fusion of old and emerging technologies (e.g., AI, IoT, robotics, 3D printing, blockchain and so on)—is increasingly narrowing down the boundary of physical and digital world. The effective adoption of IR4 technologies can bring about a sea change in productivity growth, facilitate efficient and sustainable utilisation of depletable resources, enable predictive maintenance and can thus bring significant progress to our lives. Analysing the selected IR4 start-ups of India, this paper reveals that IR4 technologies are adopted into several sectors for performing several challenging tasks which cannot be done efficiently and flawlessly by human-beings. It underscores that the steady improvement in the diffusion of ICT—a precondition for successful adoption of IR4 technologies—has indeed facilitated the adoption of IR4 technologies into Indian start-ups. Moreover, of the total selected IR4 start-ups, one-third have effectively adopted the IR4 technologies, around fifty percent are in initial phase of the adoption, and these adoptions of IR4 technologies are mostly located in metro-cities, not expanded into small cities. The present diffusion of ICT is not enough, therefore it must be diffused expediently to ensure the successful adoption of IR4 technologies in India.]*

Keywords: *IR4, IR4 technologies, start-ups, India*

1. Introduction

The first industrial revolution driven by invention of steam engine, mechanisation, and railroad construction, the second by electricity, assembly-line and mass production, and the third by semiconductors, electronics, and information technology (i.e., computer and internet), not only led to a great increase in productivity but also brought about phenomenal changes to lives and livelihoods (Schwab, 2016). Now the fourth industrial revolution (IR4) has come into practice with the emergence of new technologies such as artificial intelligence (AI), advanced robotics, 3D printing, big data analytics, blockchain, cloud computing, internet of things (IoT), gene editing, nanotechnology, 5G, and so on. The IR4, a blend of the old technologies (i.e., IT) and the emerging technologies, has been blurring the boundary of physical and digital world. The IR4 technologies are permeating into all economic activities

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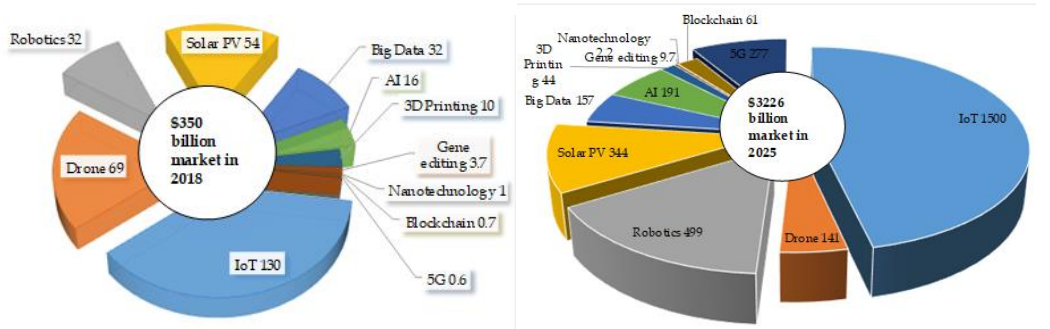
(e.g. mining, construction, agriculture, industry, manufacturing, services, health, finance, and so on). These rapidly advancing technologies rely on two things such as digitization and connectivity (i.e., the third industrial revolution (IR3)), hence the absence of these things is likely to obstruct the adoption of IR4 technologies.

In 2018, IR4 technologies account for $350-billion market that would reach $ 3.2 trillion by 2025 (UNCTAD, 2021). Figure 1 shows that IoT is claiming the largest market share of $ 130 billion and this could reach to $ 1.5 trillion in 2025. Now the continued technological progress and the development of AI-enabled self-programming robots along with the large-scale manufacturing, packaging and automobile industry are likely to drive the market of robotics from $32 billion in 2018 to $499 billion in 2025. Both IoT and Robotics have the largest market shares among IR4 technologies, and IoT alone is expected to occupy a half of the future growth of the IR4 technologies. The market of third important technology, i.e., solar PV, as shown in Figure 1, is expected to grow from $55 billion in 2018 to $334 billion by 2025. The increasing energy demand, favourable government regulations and shift towards sustainable consumption are likely to drive the market share of solar PV (Chaudhary et al., 2019). As indicated in Fig.1, there will be a similar rapid growth in other IR4 technologies by 2025. It is to mention that developed economies are in general the suppliers as well as the users these IR4 technologies, whereas developing economies are mostly users of these technologies (UNCTAD, 2021).

Figure 1. Market size estimates of IR4 technologies between 2018 & 2025, $billions



Source: UNCTAD (2021: Figure 5)

Adoption of IR4 technologies in developing countries can increase productivity tremendously, facilitate efficient and sustainable usage of resources, enable predictive maintenance, enable us detecting diseases and responding to the public health emergencies (e.g., Covid-19 pandemic) and thereby bringing significant positive changes to our lives. These technologies can solve problems more effectively, provide new capabilities and opportunities and allow much more efficient usage of natural and human resources; and they often offer small-scale solutions which can be rapidly scaled up to meet human needs for energy, food, clean water, health care and education (UNCTAD, 2018). If they are adopted successfully, IR4 technologies can help developing countries leapfrog the previous stages of technological revolutions (ibid).

The countries around the world are striving to use and adopt IR4 technologies into their several economic activities to revitalise their economies. India is of no exception in this regard, it has started adopting or using IR4 technologies to rejuvenate the primary, secondary and tertiary sector of its economy. Given the significance of the adoption of IR4 technologies in developing countries, like India, it is imperative to study the adoption of IR4 technologies in India. Hence, this paper intends to explore the adoption of IR4 technologies in India. More particularly, it tries to analyse how and in which context the IR4 technologies are adopted into several sectors of the economy.

This paper is organised into five sections including introduction. The subsequent section discusses the database of this study. Section 3 explores how IR4 technologies are adopted into different sectors of India. How effectively IR4 technologies are adopted into several activities in India is discussed in section 4. The final section summarises and concludes the discussion of the paper.

2. Data

There is a serious data constraint to understand the adoption of IR4 technologies in India. There is no standard source of data to study how these technologies are adopted across different economic activities of the country. Nevertheless, start-up India platform provides information on start-ups that are based on IR4 technologies.[1] Additionally, the National Start-up Awards (NSA), launched in 2020, provides some detail information about the focus of start-ups based on IR4 technologies.[2] There are total 3,818 start-up applications received for NSA during 2020 and 2021, of which around 11% are based on IR4 technologies.[3] Table 1 gives the technology-wise distribution of start-up applications based on IR4 technologies in India. As already reported, globally IoT accounts for majority of total innovations in IR4 technologies (i.e. 37%), we have found similar trend in start-up applications in India for IoT. During both the periods 2020 to 2021, around 50% of start-up applications are based on IoT, followed by Robotics and computer vision who have around 14% of applications each. Though the start-up based on IoT has dominating share of 50%, robotics is seen to have increased its share from 5% to 21% between 2020 and 2021.

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[1] Startup India is a flagship initiative of the Government of India, launched on 16 January 2016, intended to build a strong eco-system for nurturing innovation and Startups in the country that will drive sustainable economic growth and generate large scale employment opportunities.

[2] NSA seeks to recognise outstanding start-ups and ecosystem enablers that are building innovative solutions and scalable enterprises, with a high potential of employment generation or wealth creation, demonstrating measurable social impact (NSA, 2020).

[3] 1,641 and 2,177 start-up applications were received during 2020 and 2021 respectively for NSA. 11% and 10% applications, which were received for NSA during 2020 and 2021 respectively, were based on IR4 technologies.

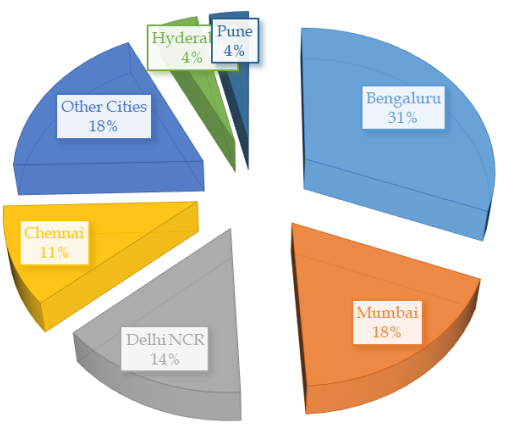
Table 1. IR4 start-up applications for NSA

Types of technology	*NSA 2020 Applications (%)*	*NSA 2021 Applications (%)*	*Total Applications (%)*
IoT	89 (49.17)	118 (52.44)	207 (50.99)
Robotics	10 (5.52)	47 (20.89)	57 (14.04)
CV	24 (13.26)	35 (15.56)	59 (14.53)
AR	14 (7.73)	19 (8.44)	33 (8.13)
3D printing	12 (6.63)	6 (2.67)	18 (4.43)
Big Data	22 (12.15)	-	22 (5.42)
CC	10 (5.52)	-	10 (2.46)
Total	181 (100.00)	225 (100.00)	406 (100.00)

Note: CV stands for computer vision, AR for augmented reality, CC for cloud computing
Source: Author's calculation using NSA data

The aim of this paper is to explore the adoption of IR4 technologies in India. The paper employs an exploratory approach to understand this. Given the data constraints, we have selected 55 start-ups from the start-up India platform—26 from winner list of NSA (2020 and 2021) and 29 from the start-up Indian showcase platform—to understand adoption of IR4 technologies in Indian start-ups.[4] These selected start-ups are mostly located in the metro cities. As shown in Figure 2, the majority of the start-ups are located in Bengaluru followed by Mumbai, Delhi NCR and Chennai. Further, the selected data indicates that IR4 start-ups are not much spread into the small cities or villages in India (Figure 2).

Figure 2. Locational distribution of IR4 start-ups in India



Source: Start-up India database

[4] The start-ups, which are showcased on Start-up India platform, are the most promising start-ups of the country. They have been selected by the experts and have gone through multiple rounds of screening and evaluation before they are showcased in the platform. They have distinctly been emerged as the best in their field.

3. Adoption of IR4 technologies in Indian start-ups

Here, we have attempted to capture the adoption of IR4 technologies in start-ups located in different sectors of the economy. As reported in Table 2, IR4 technologies are adopted across several sectors of the economy such as agriculture, animal husbandry, energy, manufacturing, marine, education, healthcare, IT services, business services and so on. It is to note that AI and IoT are seen to have been adopted into most of sectors of the economy, as reported in Table 2. Having discussed the sectoral diffusion of IR4 technologies, in what follows we have analysed how the IR4 technologies are adopted into different activities of the sectors in the economy.

Table 2. Diffusion of IR4 technologies among different sectors of the country

IR4 Technologies	***Agriculture***	***Animal husbandry***	***Energy***	***Manufacturing***	***Marine***	***Education***	***Healthcare***	***IT services***	***Business services***	***Misc. activities***
AI	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3D printing				✓						✓
AR				✓		✓			✓	
Big data			✓					✓	✓	
Blockchain	✓	✓		✓						
CC			✓							
CV	✓					✓			✓	✓
DL	✓		✓							
Drone					✓				✓	
IoT	✓	✓	✓	✓			✓		✓	✓
ML		✓	✓	✓	✓			✓		
Robotics		✓			✓					✓
VR			✓			✓				

Notes: DL for Deep Learning; ML for Machine Learning; and VR for Virtual Reality
Source: Table prepared using data from Start-up India Database

3.1. IR4 start-ups in agriculture

Agriculture is one of the mainstays of the economy, and the highest number of labour force is found to have employed in agriculture, but its contribution to national GDP is around 15%. With the advent of IR4 technologies, there is an optimism that the adoption of these technologies is likely to revamp the agriculture of this country. In the subsequent paragraphs, we discuss how IR4 technologies are adopted into the agriculture.

IR4 technologies such as AI, blockchain, CV, DL, and IoT are employed in agriculture to perform a number of activities as reported in Table 3. In agricultural value chain or supply chain—generally consisting of farmers, middlemen or intermediaries and final customer—the farmers tend to get exploited invariably by series of middlemen as they have little knowledge about their produce once it leaves the dairy/field (these farmers have asymmetric information about waste or pricing of their products). Similarly, the customers

also have no way to gain information about their purchase, regarding quality, safety, and hygiene; and they hardly have any knowledge about how much of their paid money is going to the farmers. In this situation, the IR4 start-ups are digitizing different players (i.e., farmers, farmer collectives, and customers) across the agricultural supply chain. The digitization of the supply chain can track the real or near-real time information (e.g. prices and quality) pertaining to the agriculture and thereby doing away with the problem of information asymmetry akin to agriculture. *EmerTech*, a start-up, takes the advantage of blockchain technology to digitize and connect farmer collectives with each other and directly with their customers, and thereby ensures food quality, price transparency, and end-to-end traceability of agricultural products (see Table 3).

Table 3. IR4 start-ups in Agriculture

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
EmerTech	Mumbai, Maharashtra	Blockchain	Digital supply chain, e-commerce	Ensure food quality, price transparency and end-to-end traceability of agriculture products
AI-Genix	Mumbai, Maharashtra	AI	Crop protection & management, sustainable farming	Enabled millions of farmers to produce high-quality, toxic pesticide residue-free food and increase the yield
Klevermind	Delhi	AI	Supply chain management with logistic support	End to food wastage, improves farms' income
Shapos	Bagalkot, Karnataka	AI, IoT	Silk supply chain management (farm to consumer)	Fair pricing, reduces wastages, and better income to silk farmers
Intello Labs	Gurugram, Haryana	AI, DL, CV	Digitize food quality assessments	Ensures quality and fair-pricing of the commodity
Nelbac	Bengaluru, Karnataka	IoT	Irrigation & fertigation controlling (horticulture)	Automation of irrigation/fertigation of small farms & gardens
Nibiaa	Imphal, Manipur	IoT	Remotely monitoring or managing agricultural farms	Reduction in labour cost, improvement in agricultural productivity

Source: Start-up India database

In these days, farmers and agricultural scientists are struggling to protect their crops from insect-pests. It is seen that overtime these insect-pests develop resistance against the

pesticides or insecticides, and the price of pesticides is spiralling day-by-day and at the same time, there are governmental restrictions on the usage of toxic pesticides in crop production. All these changes are making the farmers (e.g., horticulture crop farmers, plantation crop growers, floriculture crop growers, cash crop growers, and tea/coffees farmers and so on) helpless and hopeless for their crop protection. In this situation, AI-Genix's '*BraveHawk'—an* environment-friendly, non-toxic and next-generation technology for agricultural insect-pest management and sustainable farming—is designed to phase out highly hazardous toxic pesticides (see Table 3) . The BraveHawk induces a change in the behaviour of insects and exploiting the same to aggregate and exterminate the herbivorous and omnivorous insect pest, and safeguards the farmer and crop prospective beneficial insects such as carnivorous insects, parasitoids and nectar and pollen feeding bees (honey bee, bumbel bee, carpenter bees, etc.).

The agricultural start-up, for instance *Intello Labs*, who employs AI, DL and CV to digitise food quality assessments across fresh product supply chains to ensure quality and fair pricing to food items. The *Intello Labs'* smartphone application allows the users to take a picture of the commodity they are buying and check its freshness details stored online. This start-up can help people to stay healthier as it ensures food quality and it can help storehouses to pinpoint and cycle out old stock.

There is another important problem that the IR4 start-up is dealing with is as follows. Scarcity of land and labour in urban areas are driving farmers away from agriculture. Many urban dwellers because of their busy-life style do not choose the agriculture as a viable option as they cannot afford time to look after their plants. In this context, *Nelbac*, a start-up, is developing farm/landscape automation devices using microcontrollers, sensors and IoT to help small farmers and gardeners customise their farms with minimum supervision and thus propagating a self-reliant lifestyle. It offers automation devices for irrigation and fertigation of small and marginal farmers. The device is designed in such a way to integrate it to any modern methods like hydroponic, aquaponics, microgreen units, etc.

Finally, IR4 start-ups are dealing with monitoring and managing agricultural farms (i.e. monitoring soil, water, and localised weather of farms). The organised farmers and corporate farmers who focus on farming like tea, coffee, wine-making, high-return crops like horticulture and fruits farming, nuts and cereals which requires strict regulations on overall quality of the product and who have to maintain standing crop throughout the year. It is difficult to get more insight about what is happening to the soil quality, water quality, localised weather of their farms on near real time basis, which was not possible before and without sending samples to the lab, which is an expensive exercise. Moreover, the physical managing and monitoring of these huge farms tend to make the farming expensive as a huge part of expenses goes to meet labour costs. In this situation, *Nibiaa*, an IR4 start-up, with the help of web, IoT, and mobile-based platform, monitor and manage these farms on a near real time and thus improves agricultural productivity and reduces the labour cost of farming.

3.2. IR4 start-ups in animal husbandry

India is the world's leading producer and consumer of milk, the dairy farmers, the majority of them are small- and medium-scale farmers, are struggling to earn a sustainable earning. Along with the traditional practice of dairy farming, low market prices, low extension services, and thereby low milk production are the feature of animal husbandry in India. The milk production of the country is considerably low compared to developed country which is a cause of great concern.[5] Furthermore, there is a considerable gap in training and knowledge with respect to cattle nutrition, clean milk production, cattle health management along with the limited availability of qualified veterinarians and artificial insemination workers in rural areas, which are severely affecting the quality of milk production, productivity, and profitability of the animal husbandry in India.

Table 4. IR4 start-ups in Animal Husbandry

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
MoooFarm	Gurugram, Haryana	AI, ML	Dairy farm management	Boosts dairy productivity
Adis	Belgaum, Karnataka	AI, ML, CNN	Cattle management tool via animal biometric	Accelerate farming productivity
Stellapps	Bengaluru, Karnataka	IoT	Digitising dairy supply chain	Increases productivity & reduces costs and wastage
Qboid	Gurugram, Haryana	IoT, Blockchain	Detecting adulteration of milk	Improves the quality of milk production
White Gold	Mumbai, Maharashtra	Robotics	Detecting milk adulteration	Ensures milk quality

Source: Start-up India database

However, there are start-ups which employs the IR4 technologies to deal with the problems of low productivity issues of animal husbandry. As it is apparent from Table 4 that start-ups such as Mooofarm, Adis, and Stellaaps are addressing the several issues pertaining to meagre milk production and thereby improving the productivity of dairy farming in India. Mooofarm, for instance, has been a great help to dairy farmers as it helps them connecting to extension services, helps them purchasing high quality dairy farming inputs, enables instant access to credit and affordable cattle insurance services, digitally manages livestock and so on, and thereby boosting the milk productivity and income of dairy farmers in Haryana and Punjab. In addition, this start-up helps the farmers learn how to manage cattle health, nutrition, breeding cycles, dairy farm, through e-learning created by experts and thus help them make a transition from the conventional mode of dairy farming to the advanced mode of dairy farming.

[5] For instance, in the Netherlands milk production on average is 30 lbs – 40 lbs per cow/day, in India it is on average about 4 lbs per cow/ day.

India has the largest dairy industry in the world, with the production of 176 million tonnes (OECD-FAO Agricultural Outlook 2013-22). Nonetheless, a significant portion of Indian milk is adulterated. Not only does this keeps the dairy farmers in survival mode as they are paid less for their adulterated milk, but also keeps the consumers fearful. Milk aggregators are seeking effective ways to eliminate adulteration. In the conventional mode, only FAT/SNF testing is done at the collection centre since adulteration testing machines are expensive to be installed at smaller collection centres. Hence, the sources of adulteration do not get pinpointed. Even though the rudimentary testing is undertaken at the collection centres, that is not shared across the dairy supply chain. This practice in dairy industry does not benefit the honest farmers and the aggregators, but it benefits the adulterant farmers and the dishonest middlemen. These issues in dairy industry keep the primary stakeholders in survival mode in lieu of growth mode; and the aggregator invariably fears losing the allegiance of the farmers and thereby choses to pay for the adulterated milk. The highlighted problems of dairy farming not only impact the health of consumers but also causes significant loss to dairy industry.

In this context, the start-ups such as *Qboid* and *White Gold, which use IR4 technologies such as IoT, Blockchain and Robotics, can be used to test every drop of milk at the point of supply without disrupting the current ecosystem.* Within no time, the industry can identify and eliminate sources of adulteration and delays, thereby paving the way for a healthier nation and the prosperity of millions of dairy farmers in every corner of the country. For instance, Qboid's IoT-enabled machine that can detect adulteration and check milk composition parameters at point of source of milk collection for each farmer; and the data is then transferred to the cloud server and enables multiple actors within the supply chain to view the data in real-time. This start-up also facilitates speedy payment to farmers of their produce by the dairy.

3.3. IR4 start-ups in energy

Electricity plays an inevitable role in our everyday lives. Nonetheless, the electricity sector is confronted with several challenges, viz., increasing energy demand, Transmission and Distribution (T&D) losses, peak load management, reliability issues, issues of asset management, providing affordable electricity, the problem of integrating renewable energy sources to deal with the issue of energy shortage and so on. With a conventional electric grid, the ever-increasing demand for energy or electricity puts enormous pressures on the usage of fossil fuels and thereby adding huge amount of carbon footprints.[6] The conventional process of energy generation causes approximately 25% of global greenhouse gas emissions (Selvam et al 2016).

[6] The conventional grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centres, and has distribution lines that connect individual customers.

Table 5. IR4 start-ups in Energy

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Esyasoft	Bengaluru, Karnataka	IoT, ML, DL	Digitalising electric grid system	Smart grid solutions
Minionlabs	Chennai, Tamil Nadu	IoT, ML, AI	Managing & monitoring energy usage	Enabling energy transparency & energy savings
Zunroof	Gurugram, Haryana	VR, IoT, Data Analytics	Harnessing, storing & monitoring solar energy	Solution to electricity problem through solar rooftop system
Repos IoT	Pune, Maharashtra	IoT, Cloud	Fuel e-commerce & energy distribution infrastructure	Doorstep delivery of fuel & avoiding wastage of fuel & manpower

Source: Start-up India database

Table 5 shows that the IR4 technologies can digitise the supply-chain of electricity (i.e., generation, transmission, distribution, and consumers) and thus turn the conventional electric grid to smart grid, as shown in the case of Esyasoft[7]. Esyasoft offers some key solutions such as a meter data management, meter data analytics, energy efficiency consumption monitoring system, peak load management, renewable energy integration, usage and theft analytics, forecasting, billing, prepayment, consumer mobile app and so on. It is currently offering services to one million consumers in India. The Esyasoft has been deployed in India's largest successful smart metering project in Indore, Madhya Pradesh, and this smart metering project has increased the billing efficiency by 22%.

In these days, energy managing and energy monitoring, along with reducing carbon footprints, should reduce operating costs, provide insights on energy consumption and manage load distribution. Generally, energy monitoring involves capturing overall energy consumption of a facility or consumption of defined areas or recording the individual energy consumption of each device. All these require installation of multiple energy meters with complex wiring and instructions. In order to cut-short the complexities of energy monitoring, *Manionlabs,* a start-up, which leverages ML and AI to offer a single device called '*Manion*' that seamlessly collect individual energy signatures of various assets and devices inside the building. Minion a hand-sized energy auditing device with much easier installations has the ability to analyse this data for valuable actionable insights with a non-intrusive energy management solution. It senses each and every appliance, device and tool turning ON and OFF inside the building and gives a comprehensive report

[7] A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

on predictive analytics and maintenance without burning a hole in user's pocket.[8] The energy management solution of Manionlabs enables energy transparency, energy efficiency up to 30% savings, predictive maintenance and asset health monitoring and ensures safety through the recognition of any anomalies such as high and low voltages and power fluctuations. The solution that *Manionlabs* provides is suitable for all kinds of retail facilities & Entertainment Malls, hotels& restaurants, small and medium enterprises SMEs, hospitals, IT/BPO's, Government Buildings, banks, Automobile and Logistics, Energy Utilities, individual homes and housing communities or any other industry for the monitoring of machinery.

Sun is the source of all life on our planet and our fixed sources that supply energy are in depleting stage and at the same time these sources generate tons of CO_2. In this situation, *Zunroof* start-up leverages the IoT, VR and data analytics to provide rooftop solar solution to households to harness, store, maintain, and manage consumption of electricity. The Zunroof offers three different services to the users—(i) on-grid solutions, which is enabled by machine learning[9]; (ii) off-grid solar solutions for those who need to store energy and harnessed from the sun to use it when there is no electricity available[10] and (iii) innovative IoT technology which helps the customers to track and save energy as they use it with innovative home technologies. Zunroof has significantly impacted the households as it helps the householders save 100% electricity bills and also make money by selling excess solar units back to the grid. The Zunroof's solar rooftop installations also produces completely green energy as, for instance, IKW solar saves more than 154 trees and prevents more than 20 tonnes of CO2 emission. Zunroof has more than 4,500 solar rooftop installations in 75 cities across several states in India (viz., Delhi-NCR, Haryana, Uttar Pradesh, Punjab, Karnataka, Telangana and Gujarat), ranging from 1KW to 100KW.

3.4. IR4 start-ups in manufacturing

As reported in Table 6, the IR4 technologies are adopted into start-ups to deal with several issues pertaining to manufacturing sector in India. In manufacturing sector, there are pressing demand for customizability, reduction in errors, zero material waste, low

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[8] Minion is based on a machine learning approach that uses automation to train its state-of-the-art algorithm which captures voltage and energy signatures at microsecond speed to identify the individual assets used and study patterns of their consumption. And, going a step further Manionlabs' algorithm can even identify the power source of the device whether it is a power grid, diesel generator or a green energy source.

[9] On-grid system is the one in which solar power system is connected to the utility's power grid. The excess power generated is sent to the utility grid and the consumer gets compensated for it. On-grid solar power systems use a solar power system to generate electricity and are directly linked to the utility power grid. These systems feed surplus solar electricity to the utility grid, and users are reimbursed for the extra power supplied back.

[10] Off-grid solar systems operate independently of the grid but include batteries that can store the solar power generated and supply electricity after the power goes off or during the night.

development cost and time. In recent years, 3D printing technology has drawn major attention as it can meet these increasing demand of manufacturing sector. In addition, there are increasing demand for 3D printed high-performance polymers and light-weight aviation components. In this context, as reported in Table 6, *Fabheads*, designed and manufactured a new series of 3D printers, "FibrBot" that uses carbon fibre as a printing materials instead of plastic or metal.[11] These carbon fibre printers of Fabheads are meant for increased customizability, reduction in errors, zero material waste, low development cost and time. These printers are targeted to equip Indian carbon fibre industry with economic and more precise fabrication. Fabheads is also a leader in Carbon Fibre Drone Airframes manufacturing, and in other high-performance sectors like Defence and Aerospace part manufacturing. In a relatively short span of time, they have developed several drones for defence and civil purposes, both multi-rotor and fixed wing. Fabheads is catering to OEMs, MSMEs, academic organisations, aerospace, aviation and defence in the country.

Table 6. IR4 start-ups in Manufacturing

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Fabheads	Chennai, Tamil Nadu	AM	Composite manufacturing & manufacturing carbon fibre 3D printers	Customizability, reduction in errors, zero material waste, low development cost and time
BlinkIn	Bengaluru, Karnataka	AR, AI	Customer support & after-sale services	Cost-efficiency
UdyogYantra	New Delhi, Delhi	AI, ML, IoT	Real-time monitoring of quality, quantity and traceability of food	Ensuring right quality and quantity of food
RDL	Mangalore, Karnataka	IoT	Shop floor & operations management, & predictive maintenance	Optimised resource utilisation and higher productivity
Gordian	Bengaluru, Karnataka	IoT	Supply chain & logistics management	Fast, secure and affordable delivery
TagBox	Bengaluru, Karnataka	IoT, ML, AI	Supply chain and logistics management	Ensuring product quality and compliance, end-to-end traceability and operational efficiency
Skyislimit	Mumbai, Maharashtra	AI, ML, Blockchain, IoT	Sales and operation management	Increased operational efficiency

Source: Start-up India database

As apparent from Table 6, apart from the composite manufacturing, IR4 technologies are seen adopted by start-ups to do and support several activities of manufacturing such as

[11] Carbon fibre raw material allows the manufacturer to print parts that are as strong as steel but as light as plastic.

customer management (e.g., consumer support, after-sale services, installations etc.), digitising food experiences (i.e., real-time monitoring of quality, quantity and traceability of food), shop floor and operation management, supply chain and logistics management, sales and operation management and so on. In what follows, we discuss some of these start-ups.

BlinkIn's product (i.e., Scotty)—an expert-driven visual communication tool—employs AR and AI to convert the conventional audio tech support call into more intuitive and efficient visual support. It helps connect experts to customers or local technicians using an SMS link where installation is needed. The agent can see through customers' cameras, allowing them to visually inspect equipment or error messages and help them solve problems using augmented instructions and screen annotation tools. By doing so, BlinkIn helps customers who are dealing with installation issues or after-sale issues or complaints and thereby making the entire business cost-efficiency or cost efficient (e.g., in Wuhan, China, ventilators, which were sourced from Germany, were installed with the help of BlinkIn during Covid-19 pandemic). BlinkIn helps reduce the direct involvement of technicians by empowering the end-customers in visual-guided complaint registration or self-installation of devices.

Population growth, increasing urbanisation and the rising incomes have generated a need and demand for trade of ready-to-eat—cooked food and it is a broader dietary transition which is becoming a new practice, especially in urban areas. There is also an urgency for safe, predictable and sustainable food supply chain and the future food brand will be relied upon trust built through proactive communication and transparency around safe and healthy food sourcing, handling and preparation. In this situation, *UdyogYantra* adopts AI, IoT and ML to empower food and agri-businesses with real-time monitoring and control of their supply-chain and operations to help achieve quality, quantity and traceability. It has become a solution to unaddressed problems such as the child nutrition and health at Mid-Day Meals, authenticating food quality and quantity in food delivery industry, real time authentication platform to enable agriculture-trading and so on.

In order to manage shop floor and multiple input-output operations efficiently without incurring any error is not plausible by the human managers or supervisors. This entails the adoption of IR4 technologies (e.g., IoT), as seen in Table 6. RDL uses IoT technology to manage shop floors and multiple operations and predictive maintenance which in fact helped the manufacturing units optimise resources utilisation and brings about higher productivity.

Further, in what follows, we discuss some supply-chain issues of manufacturing that are addressed by the IR4 start-ups. In case of delivery of luxury brands and retailer of high value goods, security, safety and privacy have always been the great concern. Therefore, businesses or consumers who need secure deliveries are resorted to alternative means in the form of utilising their own delivery staff or premium courier services. In this context, *Gordian* is focussed on providing businesses and consumers a premium secure delivery at

affordable prices using IoT. The IoT-enabled devices of Gordian manage manufacturing supply chain to ensure secure, safe, and fast deliveries to customers with end-to-end accountability and traceability. The Gordian device uses OTPs to unlock, provide real-time alert, live tracking and internal cushioning. This device enables business to secure all high value and confidential items during transit and protect them from damage while assuring accountability and tamper-free delivery. This process indeed ensures fast, secure, and affordable delivery of luxury brand and retailers of high-value goods, parcels which requires high privacy (e.g., confidential documents, hard disk, sex toys and so on).

Similarly, relying on AI, ML & IoT, *TagBox* tags a product, shipment or an asset and predict and prevent supply-chain quality failures, and thus ensures end-to-end traceability and improves operational efficiency. Tagbox is helping organisations control supply chain outcomes by solving problems like product quality and compliance, end-to-end traceability and operational efficiency. It combines IoT-based real-time sensing, ML-driven predictive insights and AI-driven actions to resolve supply chain problems. It is seen to have provided solutions to pharma companies like Dr Reddy laboratories for real time temperature and location monitoring and traceability of sputnik V Covid-19 vaccine in India.

Furthermore, IR4 technologies are into several other operations or activities of manufacturing organisation, which is apparent from the start-up called *'Skyislimit'*. Skyislimit leverages AI, ML, blockchain and IoT to bring about 'Salesfokuz', a comprehensive SaaS service that helps organisations run more efficiently by automating their sales and operational functions. It also developed HrMNxt, Storeware, Alpha Billing, and PROMA that are meant for HR management, store management, billing software, and project management respectively. Skyislimit is seen to have served 10,000 users around the world.

3.5. IR4 start-ups in marine services

There are millions of structures such as bridges, dams, oil rigs, submerged pipelines, submarine data and power cables; and these structures, which are beneath the water surface and beyond the sight, play a great strategic importance. Owing to the hostile environment and human limitation, the inspections of these assets or infrastructures are very tough. However, the start-ups (e.g., EyeROV and Planys) are started using IR4 technologies such as robotics, AI, and ML to deal with the aforementioned difficulty in inspecting the underwater assets (such as identifying cracks, defects and possible anomalies in a variety of assets located underwater) (See Table 7).

As it is reported in Table 7, EyeROV technologies, for example, a marine robotic start-up, designs and manufactures industrial-grade underwater drones that can help the asset-owners to do inspects their under-water assets safely and efficiently. The products offered by this start-up is suitable for Oil, Gas, maritime, defence (navy), nuclear plants, marine research, fisheries, Dams, Bridges, search and rescue. The start-ups which are inspecting

underwater assets are not only making the underwater-inspections safer and cost effective, but also increases efficiency and help the asset owners forecast maintenance and repair better.

Table 7. IR4 start-ups in Marine

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
EyeROV	Ernakulum, Kerala	Drone, Robotics, AI, ML	Inspection of underwater assets	Safer and efficient solutions to underwater inspections
Planys	Chennai, Tamil Nadu	Robotics	Inspection of underwater assets	Safer and efficient solutions to underwater inspections
SDE	Mumbai, Maharashtra	Robotics	Collection of maritime & oceanic data in real time	Cost efficient and autonomous unmanned marine surface vehicle

Source: Start-up India database

Furthermore, collection of maritime and oceanic data in real time is really unsafe and challenging activity. Even the simplest problem in a maritime environment becomes complex and hazardous to solve. The solutions to these problems are usually very expensive, and they cannot provide real-time data, as the risk of human life and the weather conditions restrict the collection of data. Now, we have started deploying IR4 technologies such as AI and Robotics, as reported in Table 7, to perform these risky tasks safe and efficient manner. SDE, for instance, is providing an efficient autonomous solution (i.e., a marine unmanned vehicle system) for the collection of maritime data in real time. This solution puts no human life at risks and reduces operating expenses and capital expenses by more than 60% and 45% respectively. SDE's technologies help save life at sea along with providing actionable insights to make informed decisions in mission-critical scenarios. Its services are beneficial for applications such as intelligence surveillance and reconnaissance, mine counter measures, anti-submarine warfare, search and rescue, data gathering and integration with Satcom and weapon systems.

3.6. IR4 start-ups in education

Education sector faces several challenges and obstacles which can be solved through the adoption of IR4 technologies (see Table 8). There is absence of awareness about the right career choices, as evident from the fact that around 45% of students make wrong career choice, as reported by India Today. There is also paucity of counsellors and mentors in India.[12] Owing to the absence of awareness on personalised learning needs, 94% of engineers are unemployable (NASSCOMM) and 70% of people are not happy with their current jobs (Times Survey). To deal with the above stated issues, Bodhami, an online

[12] 95% of schools in the country do not have counsellors – Times; India needs 1.5 million counsellors, but 1 lakh counsellors are available currently (Times of India).

personalised learning platform, uses AI for persona analysis and career recommendations to students and job-seekers (see Table 8). Bodhami through aptitude test assesses the state and potential of users (students and job-seekers) and through career counselling suggests the target career and jobs.

IR4 technologies apart from providing career counselling are providing training to GE healthcare workers who are located remotely in Tier 2 and Tier 3 cities of the country. *NexRea* using AR and VR developed augmented reality application to impart and upgrade skill among the users (basically GE healthcare workers) located in Tier 2 and 3 cities of India. Using this app, these healthcare workers can use medical devices, maintain them and troubleshoot them without the assistance of any expert.

Table 8. IR4 start-ups in Education

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Bodhami	Goa	AI	Personalised counselling & learning platform	Skill development (Rural Impact)
Nexrea	Hyderabad, Telangana	AR, VR	Training solutions	Skill development
GingerMind	Bengaluru, Karnataka	CV, AI, AR	Empowering visually-impaired	Inclusive innovation
RobotGuru	Mysore, Karnataka	HoloSuit, VR	Virtual 3D classroom for robotics/AI/VR/STEAM learning	Skill development

Note: STEAM: Science, Technology, Engineering, Arts, Mathematics.
Source: Indian Start-up data

According to the estimates of the World Health Organization 90% of the approximately 285 million affected by visual impairment live in the poorest countries of the world and their socio-economic condition is often miserable. Either because of the lack of awareness and knowledge or because of financial constraints, most of visually impaired people do not have access to the required technologies which could make them self-reliant and thereby helping them lead a path of progress. To enable these visually impaired people to become a part of development, *GingerMind* has built 'Eye-D'—an AI-power smartphone apps and wearable like smart glasses—to help the blind and visually impaired people function as independently as possible. Using AI and AR, Eye-D makes the campuses and workplaces accessible for visually impaired. It offers blind users' location-based features and more, using only a camera and internet connection. The GingerMind has partnered with leading non-profit organisations across India, Nepal and Bangladesh to impact and uplift the visually impaired community at large. Through these organisations it benefits individuals who live below the poverty line. The Eye-D now acts as a true companion,

helping the visually impaired achieve independence in 3 major areas – Learning, Identification and Navigation.[13]

As reported in Table 8, the IR4 technologies are being deployed to provide a virtual 3D classroom to facilitate (practical) learning of advanced technologies. *RobotGuru* leverages VR and Holosuit to creates a virtual 3D classroom for robotics, AI, VR and STEAM learning. Unlike the conventional learning mechanism, RobotGuru offers an innovative method of training which helps to discover, develop and nurture skills using extended reality. It can virtualise the entire skill training modules into 3D interactive virtually reality and augmented reality modules. It allows students to explore, interact, experience and be involved.

3.7. IR4 start-ups in healthcare

Not only in education, IR4 technologies are also into healthcare and diagnostic services, as apparent from Table 9. IR4 start-ups, for instance Niramai and Sunfox have started offering early diagnostic services to cancer and heart disease respectively. *Niramai,* for example, has developed an accurate, affordable solution for detecting early-stage breast cancer using AI. This is better than the conventional diagnostic method as it works for all women above 18 years; whereas the current screening method do not work in women under 45-years. And, it is also portable, radiation-free and privacy conscious. The Niramai's screening test can be conducted by health workers or nursing staffs, and thereby making it ten times less expensive than current mammography methods. Its portability and price also make it much more accessible in rural areas. Niramai has screened over 25,000 women in 12 states, many of them from underprivileged sections who were offered free screenings.[14]

The IR4 technologies are also into other digital health services such as digital therapeutics (DTx). DTx is defined as "evidence-based behavioural treatments delivered online which can increase accessibility and effectiveness of healthcare" (Sepah et al., 2015). In India, chronic heart failure patients rely heavily on their cardiologists for even their basic queries. Besides, travelling to the hospital for follow ups could be tedious, particularly for patients in the Tier II and Tier III towns as the access to healthcare and specialists is limited. In this situation, Wellthy Therapeutics, which relies on AI, IoT along with the ICT technologies, offers digital health services, e.g. DTx which acts as a gateway between the patient and the doctor in accompaniment to traditional healthcare (Table 9). The DTx of this start-up routinely collects information on patient's health that helps doctors better monitor their patient's health to make better, data-driven decisions regarding treatment plans,

[13] GingerMind has had a positive impact on the lives of over 40,000 people in India and 70,000 people around the world spread over 160 countries. A simple application (Eye-D) is helping the visually impaired to go about their life independently—from reading names of medicines to telling them where they are and which is the nearest bank. This app is now operational in 12 languages and is looking expanding to regional Indian language.

[14] Niramai has 70% female workforce, many of them are the only breadwinners in their families.

essentially enhancing the delivery of healthcare for every individual. An important advantage of Wellthy therapeutics is remote monitoring through its DTx platform which has been validated clinically for chronic health conditions, viz., diabetes, hypertensions and heart failures. Further, this remote monitoring of patient is seen to have provided greater access to quality healthcare, which have reduced hospital visits, and thereby saving additional cost for patients.[15]

Table 9. IR4 start-ups in Health Care

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Niramai	Bengaluru, Karnataka	AI	Diagnostic services (detecting early stage of breast cancer)	Portable, affordable, and efficient
SunFox	Dehradun, Uttarakhand	AI	Heart monitoring machine, early diagnosis service	Smallest & affordable, efficient
Wellthy Therapeutics	Mumbai, Maharashtra	AI, IoT	Access to healthcare services, remote monitoring of patients, and blood pressure & sugar monitoring.	Improving quality of life for patients (Cementing the gap in seamless access to healthcare)
Dipitr	Bengaluru, Karnataka	IoT	Health services, posture corrector	Physical wellness & productive
Anvayaa	Hyderabad, Telangana	AI, IoT	Elder care platform, emergency care management for senior citizen	Real time pro-active elder care platform

Source: Indian Start-up data

With extensive growth of the corporate world, the number of people attending full-time desk Jobs has also been increasing enormously. Today, millions of people are engaged in desk jobs, which involve eight to 10 hours long sitting posture. If the posture is incorrect, it can affect an employee's productivity as bad sitting posture for hours can lead to back pain and neck pain. Therefore, good posture is really important in terms of keeping physical fitness and productivity at the workplace. In this case, *Dipitr* has adopted IoT technology to come up with an innovative wearable device called 'Stark'. Stark is Asia's first 360-degree posture care solution. While there are many posture belts and braces available in the market for improving sitting posture, they are often inconvenient to use and unable to track any improvement. Stark of Dipitr takes care of posture correction,

[15] DTx platform of Wellthy Therapeutics, by increasing disease awareness among patients, encouraging compliance to treatment plans, and allowing remote monitoring and progress tracking by doctor, can exponentially decreases the overall burden on the healthcare infrastructures.

posture training, posture tracking and posture management functions to make employees' back happy and healthy.

IR4 technologies are also spreading into elderly healthcare, as apparent from ***Anvayaa***, a start-up based on AI and IoT (see Table 9). Elders in India who do not have their kin nearby, struggle to navigate the environment for routine and emergency needs.[16] They seek someone to talk to, and reach out for needs; and their kids feel guilty about not being able to be there physically for them. In this situation, Anvayaa provides high tech touch personalised services to elders that can provide a sense of empowerment and dignity. Currently, there is no solution which is comprehensive healthcare backed with real-time in person care provision. Using AI and IoT, *Anvayaa* is offering a pro-active personalised senior care platform to provide pro-active care to elderly people living independently in India. This platform is a one-stop solution to all elderly needs (e.g., emergency assistance, health needs, daily needs, social needs and so on) which is surely giving peace of mind to families and kin. Anvayaa is also offering solution to dementia patients and any other patients with chronic diseases related to cardio and pulmonary disorders. Now Anvayaa's senior care platform is operational in more than 25 cities of India.

3.8. IR4 start-ups in IT services

As shown in Table 10, IR4 technologies are getting adopted by start-ups to offer several IT services such as customer relations management, HR management and so on.

Digital marketing revolution and huge rise in online media for all communications has put business on their toes. Handling manually such flow of information is either not possible or requires humongous cost in human. In this situation, start-ups such as Yugasa and Locobuzz are helping organisations or enterprises automate their customer relation management. *Yugasa*, for instance, provides Yobo—an AI-enabled and NLP-based chatbot—that can manage and automate customer relations with enterprises.[17] Yobo helps customers in establishing the strong on-line presence. No human can work 24×7 and attend multiple queries at one time, while Yobo chatbot can. Yugasa's Yobo supports more than 70 languages including Indian languages. It can be integrated into any website, e-commerce, WhatsApp, Facebook and mobile app to receive your customers or prospects 24×7 and do intelligent talks with them.

IR4 technologies are also into recruitment and HR management in business enterprises. For any organisation, searching, finding and recruiting a right candidate for any job is increasingly becoming a huge problem. To deal with the problem of HR management, *TalentRecruit* is among the fastest HR tech start-up in India that provides advanced

[16] There are around 75% of elderly live independently without their kids; 80% elderly need support; 85% feel lack of safety and security; and 90% of elderly feel isolated and neglected.

[17] NLP chatbot is an AI-powered chatbot that enables humans to have natural conversations with a machine and get the results they are looking for in as few steps as possible. This type of chatbot uses natural language processing (NLP) techniques to make conversations human-like.

recruitment automation technology to automate the entire recruitment and on-boarding process for business enterprise, MSME, and government organisations. Its recruitment platform driven by AI and ML and it helps organisation easily find the right candidates at the right time and cost for each job offered.

There is a broad issue pertaining to HRM (human resource management) operations. HRM operations comprise multiple responsibilities viz., staffing processes, managing employees' data, managing payrolls, performance analysis and much more; and performing these operations manually is not a sustainable practice. Moreover, these operations sometimes become difficult to perform when more data are piled up; and there is less likely that the manually processed tasks are free from errors. To address the above issues, *Bizex,* which *is* a complete cloud-based HRM suite, based on AI technology, can help streamline and automate the HRM operation and manage all the above task with zero error. It is developed to assist a multitude of teams, big, small, across various industries in India. Assisting organisations from hiring resources to reducing attrition rates are few of the USPs of Bizex.[18] In addition, it can perform host of other tasks such as increasing company profits by optimising HR related expenses and payrolls, reducing wastage of human resources, simplifying and automating every day's routine or repeated jobs or tasks, maintaining a contact-less attendance management system and so on.

Table 10. IR4 start-ups in IT services

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Yugasa	Gurugram, Haryana	AI	Customer relation management	Increased customer engagement & business relationships
Locobuzz	Mumbai, Maharashtra	AI, ML, Big data	Digital customer experiences	Establish and strengthen an enterprise's digital foothold among customers
TalentRecruit	Bengaluru, Karnataka	AI, ML	Automating talent recruitment & on-boarding processing of enterprises	Effortless, efficient and just system
Bizex	Bengaluru, Karnataka	AI	HRM operations	Streamlining & managing HRM operations with zero error

Source: Start-up India database

[18] A unique selling point (USP), also called a unique selling proposition, is a marketing statement that differentiates a product or brand from its competitors.

3.9. IR4 start-ups in business services

As reported in Table 11, IR4 technologies are being adopted by start-ups to offer several business services. In what follows, we present some these cases.

Because of the high-dependence of web and online systems, security has become an essential part of in everyday and professional lives. Start-ups are seen adopting IR4 technologies to deal with the security issues and cyber security issue in particular. *Pivotchain*, for example, provides Raven-AI, a customizable deep learning software platform integrated into vision-based networks typically deployed for industrial surveillance, asset security, or process monitoring applications. It is a video analytics company catering to a wide range of global customers. Ever since its inception, it has grown in size and capability and currently have presence in India & middle east. It serves smart city, airports, logistics and homeland security verticals.

Table 11. IR4 start-ups in several business activities

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Pivotchain	Pune, Maharashtra	AI, CV	Securing physical infrastructures (e.g. government & military premises, airports, and logistic centres)	Cost efficient and GDPR compliant
Scapic	Bengaluru, Karnataka	AR	Adding AR& 3D experience to e-commerce platform;	Increases average cart values & reduces product returns
ADQVest	Chennai, Tamil Nadu	Big Data	Providing operational insights/ predictive analysis to businesses	-
Shipsy	Mumbai, Maharashtra	AI	Shipment management (digitizing the entire export-import operation, and distribution process)	Making export-import operation efficient, transparent, and profitable
DiyCam	Mumbai, Maharashtra	AI, CV, IoT	Monitoring operations & compliance for business continuity	-
TechEagle	Gurgaon, Haryana	Drone	On-demand drone delivery solution for health care/essentials & Drone manufacturing	Solution to last mile logistic problem for healthcare and package delivery
Uptimeai	Bengaluru, Karnataka	AI, Big Data	Predictive maintenance (Oil, Gas, Power, Steel, etc.)	Highly accurate, efficient & reduced maintenance

Note: GDPR stands for General Data Protection Regulation.
Source: Indian Start-up data

The start-ups are also seen adopting IR4 technologies to revolutionize e-commerce of auto products, electronics products (e.g., laptop, smartphones), smart glasses, and so on. *Scapic*, for example, is adopting AR technology to build platform which allows brands to create 3D and augmented reality experiences for their products. The Scapic's platform also allows the brands to distribute these experiences online which does not require any app to install. It is beneficial for industries like automobile, in which products require extensive visuals. Scapic has worked with companies like Royal Enfield, Flipkart, Myntra, Walmart, Unilever, Sony, Viacom18, Wipro, Accenture and many others to bring their 3D, AR and VR solutions to life.[19]

In addition to the above, IR4 technologies, as provided in Table 11, are adopted by start-ups to offer operational insights and predictive analysis to businesses, logistic and shipment management, on-demand drone delivery solution to healthcare, monitoring operations and compliance for businesses, predictive maintenance (to oil, gas, power, steel, etc.) and so on.

3.10. IR4 start-ups in miscellaneous activities

IR4 technologies are into several miscellaneous, but important activities of the economy. As apparent from Table 12, IR4 technologies are into real-world visual monitoring to curtail traffic menace, smart parking management to ensure smart and hassle-free parking experience, construction automation for optimal usage of resources (including human and material inputs) and to counteract the regular shortage of skill-labour, water management to address water crisis and to reduce regular wastage of water, public toilet management to ensure smart restroom service at affordable rate, and real-time air-quality monitoring to enable access to affordable and accurate way to monitor air quality. In what follows, we discuss some of the above adoption of IR4 technologies.

It is said that the loss due to a traffic accident amounts to 3% of the world's gross domestic product (GDP), and the negative impact is enormous. As reported by each country, India accounts for 11% of the world's fatalities and is disgracefully the largest in the world. One of the reasons is that the population is large, but it is also because the maintenance level of cars, road conditions, traffic rule compliance level, etc. are all low. The Indian government has taken some steps, such as significantly increasing the penalty for traffic violations in 2019, but it is still far from recovering its disgraceful position.

However, Nayan, start-up located in Delhi, has developed a product to address the big challenge of traffic menace in India. It uses AI and CV technologies for informatics and video analytics for roadways, searching for hazards, violations, and city-wide road and highway monitoring. The product uses mobile phones, CCTV cameras, and other video

[19] Scapic platform helps increase average cart values of the brand and boosts customer confidence on brand's website with eye-catching images and interactive product experiences and thereby bringing about reduction in product returns.

cameras to capture traffic movement and hazardous conditions.[20] Nayan is supporting cities to solve their traffic menace and bring down accidents, dangerous driving and traffic violations. It is offering high precision services for traffic monitoring and road safety such as capturing traffic violations, capturing road defects and capturing vehicle defects and so on. The Nayan's system is being experimentally adopted in several cities in India. It has been adopted by the Dubai policy since 2020.

Table 12. IR4 start-ups in miscellaneous activities

Start-up	*Location*	*Technologies*	*Activities*	*Impact*
Nayan	South Delhi, Delhi	AI, CV	Real world visual monitoring	Solution to traffic menace, reduction in accidents, dangerous driving & traffic violation
Elvicto	Trivandrum, Kerala	IoT	Smart parking management	Smart and hassle-free parking experience
Primerail	Bengaluru, Karnataka	Robotics	Transportation engineering design consultancy (Robotic Vehicle)	most affordable and economical mode of transport for public
Tvasta	Chennai, Tamil Nadu	3D printing	Construction automation	Cost reduction and optimal usage of raw material, & counteracts regular shortage of skilled labour
Wegot	Chennai, Tamil Nadu	IoT	Water management solution	Relief to water shortage & prevention of regular water wastage
Lootel	Indore, MP	IoT	Public toilet management & quality monitoring system	Smart restroom service at affordable price of Rs. 10
Respirer	Mumbai, Maharashtra	IoT	Real time Air quality monitoring	Affordable & accurate way to monitor air quality

Source: Indian Start-up data

An important IR4 technology is the 3D printing or additive manufacturing, which has seen to have been adopted by start-ups for construction automation, as is reported in Table 12. Tvasta has developed 'Nirmaan', a 3D printer, which is India's first attempt at integrating technology into construction automation. India's first 3D printed house using Nirmaan, located at IIT Madras, Chennai, was completed in 2020; and in 2018 Tvasta completed India's first 3D printed structure which is also located in IIT Madras, Chennai. The deployment of Tvasta's Nirmaan in construction is seen to have not only reduced cost of

[20] Nayan extracts traffic violation data such as signal ignoring, sudden lane changes, no seatbelts, and illegal parking in real time.

production by 40%, but also optimised the usage of resources (human and material). Moreover, Tvasta is seen to have addressed the regular shortage of skilled labour by 80%.

As reported in Table 12 and also discussed previously, IoT technology is seen to have been adopted into several activities in India. For instance, IoT has been adopted to address water crisis in India. Access to clean drinking water is a critical issue in India. With a population of 1.38 billion people, India is the second most populated country in the world and around 6% of the population lack access to safe water. India is gradually beginning to realise the importance of water and how to use it smartly. Traditional water meters detect air passing through pipes that causes errors in reading. In addition, leakages, abnormal usage, and open taps are not detected by traditional water meters. IR4 technologies, say IoT, are into this direction to meet this water shortage. In 2015, five individuals came together to solve one prominent issue in their home turf, Chennai, i.e., acute water shortage. To address this problem, they have brought about a product called 'Wegot', which offers an IoT-based water management solution that enables real-time, data-driven and automated decision to reduce the water usage and increase the efficiency of water infrastructure in buildings. WeGot's water-management solution is seen to have cut down water demand by 50% by detecting drop spills and water theft in real-time. It tracks the usage at all consumption points and generates bills as per water usage. It also detects and notifies leakages, broken pipes, abnormal use in real-time via mobile app and web dashboards and these facilities helps users shut water leakages, thus save water from getting wasted or leakages. WeGot solution has been adopted by several building or apartments in Chennai.

Another example of IoT adoption in India is the Lootel, which is a start-up of public toilet management and quality monitoring system. Public toilets cleanliness, hygiene, and quality are one the biggest problem in India. In India, there are enough infrastructure for public restrooms but most of them dirty and abandoned due to the unavailability of the perfect ecosystem of maintenance and cleaning management. Still, we do not use any technology for the operation and management of public toilets. Public toilet infrastructure management and operation still handling in the conventional mode where it does not have control and monitoring system through any technology. Lootel is an IOT based smart restroom concept that is a complete self-sustainable solution for public toilets. It provides a higher-level user usage pattern analysis and operation quality control. Lootel through IoT technology collects data like restroom health, maintenance, per user water consumption, user feedback, café inventory, cleaning record, users' usage and critical emergency data for management. It has been working on a premium-quality public restroom since 2017. Lootel has spread across several cities of India such as Lootel AICTSL Indore, MP, Lootel Rajwara, MP, Lootel Bilaspur, Chhattisgarh, and Lootel Rameswaram, Tamil Nadu.

4. Effective adoption of IR4 technologies into start-ups in India

It is to note that IR4 technologies are seen to have adopted into several activities of several sectors of the economy. Having discussed the diffusion of IR4 technologies, it is important to see how successfully we have adopted these technologies into activities of several sectors of the economy. In order to understand the effective adoption of IR4 technologies, in what follows, we discuss different stages of start-ups—i.e., ideation, validation, early traction and scaling—which a start-up need to go through.[21]

Table 13. Different stages of IR4 start-ups

Startup stage	*Number*	*Percentage*
Validation	10	18
Early traction	26	47
Scaling	19	35
Total startups	55	100

Source: Author's calculation using NSA winners and start-ups showcased on Startup India platform

Table 13 shows that most of the IR4 start-ups are seen to have adopted IR4 technologies as 82% of the total selected IR4 start-ups are already into early traction and scaling stage and these start-ups have successfully crossed the ideation and validation stage. This diffusion of IR4 technologies can be linked to the improved input-based innovation index of India, which increased from 35.5 in 2015 to 44 in 2022 and this improvement also shifted India's global rank in input-oriented innovation index (from 100th position to 42nd position) during the same period (see Table 14).[22] There is another factor—i.e., ICT, an important pillar of input-oriented innovation index of India—whose index value jumped to 72 in 2022 from 38.6 in 2015 (see Table 15). This huge jump of ICT performance of India is in fact contributed to the above-mentioned diffusion of IR4 technologies in Indian start-ups.

To note that IR4 technologies are effectively adopted into 35% of the selected IR4 start-ups since 35% are into the scaling stage of the business. The scaling stage is crucial because the start-ups sometimes do not move beyond the early traction if the first phase of customers are not satisfied with their products or services.[23] Nevertheless, given the steady improvement of ICT performance of India, the start-ups which are in the early-phase of customers will soon be established and earn sustainable profit. Furthermore, the diffusion

[21] Ideation stage comes when there is an idea for a product or service the start-up will deal in. Validation stage comes when a minimum value product (MVP) is developed for the market. Early traction comes when the start-up acquires customers and starts generating revenue. And finally, the scaling stages arrives when the start-up is stabilised and is generating sustainable profit.

[22] Input-oriented innovation index is computed based on a simple average of the scores in five pillars—institutions, human capital and research, infrastructure, market sophistication, and business sophistication.

[23] The scaling stage is therefore very critical for the sustenance of a start-ups. and it is not wise to celebrate the early traction stage.

of technologies takes time to take place successfully, therefore the start-ups in early traction state are likely to reach at the scaling stage of their businesses.

Table 14. Global innovation index of India

Year	*Output-oriented Innovation index*	*Input-oriented Innovation index*	*Global innovation index*
2015	28.0 (69)	35.5 (100)	31.7 (81)
2016	26.7 (59)	40.5 (72)	33.6 (66)
2017	28.1 (58)	42.8 (66)	35.5 (60)
2018	27.9 (57)	42.5 (63)	35.5 (57)
2019	28.5 (51)	44.7 (61)	36.6 (52)
2020	27.7 (45)	43.5 (57)	35.6 (48)
2021	28.8 (45)	44.0 (57)	36.4 (46)
2022	29.1 (39)	44.1 (42)	36.6 (40)

Note: Values in parentheses are India's position in the world
Source: Dutta *et al.* (2015, 2016, 2017, 2018, 2019, 2020, 2021 & 2022)

Table 15. Infrastructure index of India

Year	*Infrastructure (1)*	*ICTs (1.1)*	*General infrastructure (1.2)*	*Ecological sustainability (1.3)*
2015	34.6 (87)	38.6 (86)	38.9 (43)	26.3 (117)
2016	37.0 (87)	39.2 (86)	39.3 (52)	32.6 (109)
2017	44.1 (73)	49.2 (80)	48.5 (32)	34.6 (103)
2018	40.4 (77)	50.8 (83)	46.9 (38)	23.7 (119)
2019	43.0 (79)	62.5 (75)	41.9 (42)	24.7 (117)
2020	38.1 (75)	63.3 (74)	30.9 (46)	20.2 (98)
2021	36.8 (81)	58.1 (86)	32.1 (52)	20.3 (98)
2022	40.7 (78)	71.6 (72)	33.9 (50)	16.7 (115)

Note: Values in parenthesis is India's position in the world
Source: Dutta *et al.* (2015, 2016, 2017, 2018, 2019, 2020, 2021 & 2022)

5. Discussion and conclusion

This paper has explored the adoption of IR4 technologies in India. Particularly, it explores how and in what context the IR4 technologies are adopted into Indian start-ups akin to different sectors of the economy. Besides, the effective adoption of IR4 technologies has also been analysed in this paper. Total 55 start-ups—based on IR4 technologies—have been selected to analyse the adoption of IR4 technologies in Indian ecosystem.

Analysing the selected IR4 start-ups it is seen that the IR4 technologies are adopted into several sectors such as agriculture, animal husbandry, energy, manufacturing, marine, education, healthcare, IT services, business activities and so on. These sectors have been grappling with several challenges which are now seen to have addressed through the adoption of IR4 technologies. In what follow we summarise how some of these challenges are addressed through the application of IR4 technologies.

In agriculture supply-chain, because of asymmetric information farmers are invariably exploited by the middlemen. The adoption of IR4 technologies to digitize the supply chain is however seen to have done away with this problem of agriculture efficiently. Other issues pertaining to agriculture (e.g., crop protection issue, monitoring agricultural farms, and small land-holding problem and so on) are started getting addressed through the adoption of IR4 technologies.

In animal husbandry, traditional practice of dairy farming, poor extension services, lack of access to qualified veterinarians and artificial insemination workers are the causes of low productivity and low profitability of animal husbandry sector which are now seen to have solved through the application of IR4 technologies in dairy farming. In addition, start-ups are started adopting IR4 technologies to address the issue of milk adulteration and other supply chain issues of animal husbandry.

The conventional grid system in energy sector in fact fails to deal with the issues of increasing energy demand, T&D losses, peak load management, providing affordable electricity, and the problem of integrating renewable energy sources. The IR4 technologies, as seen the analysis, can digitise the supply chain of electricity and thus turn the conventional grid to smart grid to solve these problems. There are some other issues—energy management, energy monitoring, reducing carbon footprints, harnessing, storing, maintaining and managing the consumption of electricity—which are also seen to have sorted out through the adoption of IR4 technologies.

In marine sector, the inspection of submerged assets has been tough because of hostile environment and human limitation. However, the IR4 technologies are getting employed in start-ups to deal with this issue of marine sector. Further, collection of maritime and oceanic data in real time is really unsafe and challenging activities. But then again, the IR4 technologies are being used to perform this risky task safely and efficiently.

In manufacturing sector, there are some tasks, namely shop floor management and multiple input-output operations, which cannot be undertaken efficiently without incurring any error. In this situation, the adoption of IR4 technologies, as highlighted in this study, can perform these tasks efficiently and perfectly. In addition, there are many other tasks in manufacturing sector—viz., customer management, composite manufacturing, real-time monitoring of quality, quantity and traceability of food, supply chain and logistics management and so on wherein the IR4 technologies are being adopted to perform these tasks efficiently with zero-error.

There are several other tasks in sectors such as education, healthcare, IT services, business activities, and so on where IR4 technologies are found to have adopted. It is important to note that the tasks which entails the adoption of IR4 technologies are often, as observed from our analysis, very challenging for human beings to undertake.

As understood from the above, not only are the IR4 technologies adopted to address the challenges or difficulties of sectors, but they are also seen to have introduced new or

additional facilities or services to sectors in India. In healthcare sector, for example detecting early-stage breast cancer is not available for women below 45-years, however, as observed from the selected IR4 start-ups, through the IR4 technologies, it is possible to diagnose early-stage cancer for women above 18 years old.

The adoption of IR4 technologies can be linked to the improvement in ICT. Our analysis however reveals that one-third of the total adoptions of IR4 technologies are effectively adopted, as they have established and are earning sustainable profit. It also shows that around half of the total adoption of IR4 technologies are in early phase of their successes and they have not reached the scaling stage of business. It is further noticed that the IR4 technologies are mostly concentred in metro cities, they are not spread into small cities and village-level. The current status of the diffusion of ICT is not sufficient to ensure effective adoption of IR4 technologies in India. More efforts are therefore required to spread ICT technology expediently to facilitate successful adoption of IR4 technologies in the country.

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