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Industry 4.0: A Roadmap for India's Global Leadership

March 2022

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For Transforming India to a Fully Developed Nation by 2047

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Introduction

We are living in the new era of the fourth industrial revolution. This revolution, akin to the previous industrial revolutions, will reroute the development trajectory of nations. India did not participate in the first two industrial revolutions and played a catching-up game in the third industrial revolution. The fourth industrial revolution offers an opportunity for its resurrection to become an advanced and prosperous nation with USD 40 Trillion economy before reaching 2047 (100 years after independence). Today, India is well placed economically, technologically and industrially, with the strong advantage of demographics. This is perhaps for the first time that India has an opportunity to prepare ahead and lead in the fourth industrial revolution. Will India grab this once-in-the-century opportunity to propel the country into a prosperous nation? The answer is "yes" if I listen to the voices of India's industry leaders, entrepreneurs and aspirational youth.

We need to achieve steady growth in the GDP for the next 25 years to realise our aspirations, and the development has to be inclusive and sustainable. For this, we need (bold) ideas and a well-thought roadmap and focused execution to make India globally competitive and a leader in the fourth industrial revolution. I propose a three-step roadmap and a framework to achieve rapid, inclusive and sustainable economic growth of India by applying the principles of Industry 4.0.

Roadmap for India's Leadership in Industry 4.0

	Mission 2025	Mission 2035	Mission 2047
	Initiate to Establish	***Integrate to Grow***	***Multiply to Lead***
Focus	Digital and Data Sensors and Automation (Industry 3.0 and towards Industry 4.0)	Connected and Smart New Products, Services & Platform(s) (Industry 4.0)	Networked and Intelligent "Platform of Platforms" (Industry 4.0 and towards Industry 5.0)
Digital & Physical Infrastructure	Secure Digital Network Infrastructure, 5G Connectivity, and Smart City (100 cities)	Integrated Physical & Digital Smart National Infrastructure, Digital Twin of Cities, Connected Cities, Towns & Villages for a Smart State	Networked and Intelligent National infrastructure to make it a "Smart Nation" with "Country as a "Platform"
Technological Capability	Cutting edge Indigenous Capabilities in Core Technologies: of Industry 4.0 (e.g Data, AI, Cloud, IoT, Simulation & Modelling, Digital Twin)	Technological Platform Solutions integrating Information, Operational and Bio Technologies (e.g. Cognitive and Bio-intelligent Systems)	Intelligent, Sustainable, Self Aware, Autonomous Interconnected Platforms, and Laying Foundation to Industry 5.0
Industry & Enterprises	Digital (Industry 3.0) Enterprises with Demonstration of 25 Industry 4.0 lighthouse enterprises	Connected & Smart Enterprise(s) with Cyber Physical Production Systems with Mass Customisation & New Platform Business Models	Networked, Intelligent and Autonomous Enterprises in the entire industrial value chain with distributed local production using local resources

The proposed framework offers a systematic approach to building a solid foundation and achieving growth and leadership before India reaches its 100th year of independence. There are two key enablers to prepare and empower Indian industry to achieve accelerated growth in the fourth industrial revolution:

1. Building robust physical and digital infrastructure
2. Developing indigenous technology capabilities

India has already taken some steps and launched various initiatives in building infrastructure and developing technology. The proposed framework provides a three-step development roadmap for each of these areas and for the industry:

1. **INITIATE TO ESTABLISH** – is the first step in the journey focused on transforming various government and industry initiatives (existing and new) into established core capabilities required for industrial growth by 2025. During this period, India has to build and develop communication infrastructures (5G), technologies (IoT, Data, Cloud, AI) and skilled talent in these core areas.
2. **INTEGRATE TO GROW** – is the second step focused on integrating and converging core capabilities that lead to smart products, services, platforms, supply chains and enterprises to achieve economic and social growth between 2026 and 2035. The adoption of Industry 4.0 is expected to rapidly grow during this period and become a necessity for the growth of certain industry sectors (e.g. Automobile OEM's want to shift to mass customisation, which requires connecting to their Tier I and II suppliers).
3. MULTIPLY TO LEAD – is the third step focused on multiplying capabilities developed in the last step to build intelligent, networked, self-aware and autonomous enterprises to achieve accelerated growth making India a global leader and an advanced nation by 2047. This is also a time for India to define and build capabilities for the fifth industrial revolution.

The efforts to achieve the vision to lead in the fourth industrial revolution have to be holistic and coordinated - it is not a journey of taking discrete actions and building some pockets of excellence. Indian talent is powering research, innovation and technology entrepreneurship globally. By creating the right ecosystem, the same talent can propel India to become an advanced and prosperous nation before reaching 100 years of independence.

This paper introduces the concept, evolution and impact of the fourth industrial revolution, followed by a discussion on how different nations are preparing to succeed. It then offers ideas for short-, mid- and long-term strategies to realise the dream of a self-reliant, sustainable and prosperous India by 2047.

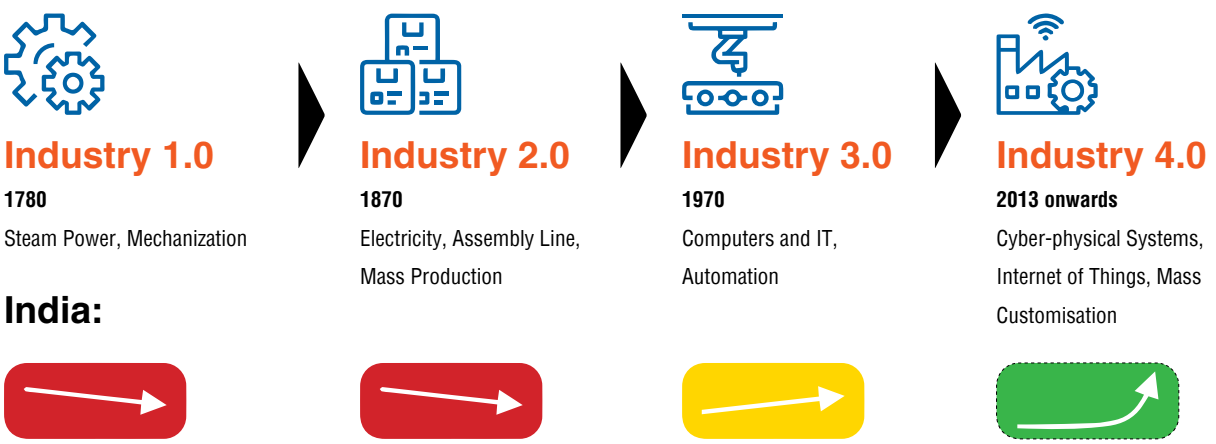
PART 1

INDUSTRY 4.0 AND ITS IMPLEMENTATION IN SOME LEADING COUNTRIES

The Fourth Industrial Revolution (Industry 4.0)

Each industrial revolution propelled an exponential growth in human evolution. Now, the Fourth Industrial Revolution (Industry 4.0) is well underway. The industry is undergoing a major technological revolution in the way products are designed, manufactured and distributed. Industry 4.0 involves rapid, end-to-end digitisation of all physical assets and their integration into digital ecosystems. Industry 4.0 can enable smart factories, connect supply-chain network and logistics capabilities and inform planning and inventory processes, along with a host of other capabilities, enabling organisations to know things they did not know before. Cyber-physical systems form the basis of Industry 4.0 using modern control systems, embedded software systems and IoT (the Internet of Things). Artificial intelligence and IoT are blurring the boundary between the physical world and the virtual one, where the efforts of humans and machines are combined to create a formidable force. This way, products and production systems get networked and become smart and intelligent, enabling new forms of value creation. Industry 4.0 promises a new frontier in manufacturing and other sectors, with enhanced value creation through higher productivity and efficiency throughout the value chain. Industry 4.0 is a vision that evolved from an initiative to make the German manufacturing industry more competitive ('Industrie 4.0') to a globally adopted term. The technologies that enable Industry 4.0 include smart sensors, automation devices, advanced robots, Internet of Things (IoT), cloud computing, location detection technologies, human-machine interfaces, augmented reality, 3D printing, artificial intelligence (AI), big data analytics, and mobile devices, among others.

Industrial Revolutions and their Economic Impact on India



Industry 4.0 is a new paradigm where devices and machines communicate with each other and take control of production on the shop floor. Machines and their software make effective decisions on production planning as well as on actual production, based on triggers in the demand of the product, thus efficiently managing manufacturing and distribution.

The implementation of Industry 4.0 enables companies to increase productivity (by shortening the period between the development of a new product and its delivery to customers in the market by 50%), efficiency (automation allows for greater flexibility, the better quality of products and more efficient production) and energy savings (for example, while waiting for materials processing, robots can be switched off, which saves up to 15% electricity) to ensure competitiveness in the global market. Industry 4.0 offers flexibility, efficient use of resources and integration of customers and business partners in the business process. The ultimate aim is to increase business outcomes and reduce risks by process automation and optimisation, integration, and faster time-to-market, resulting in higher revenues, new products, and new value-added services.

Undoubtedly, Industry 4.0 implementation will lead to economic growth by increasing the GDP. However, it will have other implications as well. The Industry 4.0 technologies can be used for social and sustainable development, and these technologies could provide solutions for all the 17 UN Sustainable Development Goals (SDGs). We can utilise emerging technologies (and principles of Industry 4.0) to deal with the challenges of health and hunger, including early detection of disease and optimising food distribution. As the emerging technologies reduce waste and increase quality and efficiency, they positively impact the environment. Every country is trying to achieve the SDGs, and the new age technologies can address issues like sustaining biodiversity, climate change, mitigating depletion of natural resources and combating pollution.

Implementation of Industry 4.0 Around the World

Given the evolving nature of Industry 4.0, every country is developing its version of the implementation strategy to compete in the future. This section summarises how nations with different economic and industrial development plan to adapt and capitalise on Industry 4.0.

Germany

Germany is the birthplace of Industry 4.0. It adopted this concept in 2010 to become a global leader in advanced manufacturing solutions. One of the major drivers for Germany which led to the formation of this concept was the decreasing unskilled labour and increasing rate of senior citizens (aged more than 60). Germany sought advanced manufacturing to

bring automation to the industry to reduce manual work for achieving more productivity, efficiency, and cost-saving. Germany benefits from its skilled workforce, with more than 80% having formal vocational training or academic degree. Other advantages of Germany include high standards of production technologies, innovative suppliers and advanced capabilities in embedded systems, software and IT security technologies. Also, German companies face competition from Chinese, South American and Korean companies on their ability to develop engineering and IT products at very competitive prices. Germany went ahead with implementing Industry 4.0 to increase its global competitiveness. According to its Vision 2030, Germany wants to achieve three things: autonomy, interoperability and sustainability.

Germany implemented the following policies to achieve Industry 4.0:

- Germany introduced the Hightech Strategy (HTS) in 2006, which focused on boosting innovation within the country. It was launched by the German Ministry of Education and Research (BMBF) as a cross-ministerial strategy to strengthen and secure a leading position in research and innovation and as a global production hub.
- Federal Ministry for Economic Affairs and Energy (BMWi) introduced its first holistic strategy for Germany's digital future in November 2010: Deutschland Digital as the framework for all ICT-related government interventions intended to strengthen its position as an ICT hub.
- In addition, in 2010, the Hightech Strategy was updated to Hightech Strategy 2020, focusing less on specific technologies and more on concrete solutions to global challenges.
- Together with the Forschungsunion (German Research Union), the German government developed ten strategic initiatives linked to the five priority areas of the 2010 HTS. The Forschungsunion adopted the Promotorengruppen ("Promotions Groups") for each key area of the HTS 2010. The Groups were chaired by research and industry representatives. In early 2011, the "Promotion Group Communication" proposed the term "Industry 4.0" to the German government to identify it as a project of the future.
- In 2011, the "Platform Industry 4.0" (PI4.0) set up marked the continuation of the working group I4.0's work. The Platform was an initiative of the three industry associations BITKOM, VDMA and ZVEI, consulted by Acatech. It later became a defining feature of Germany's Industry 4.0 strategy.
- Germany also introduced the Digital Agenda 2014-2017 to restructure value chains and transform the business models of leading industry sectors, including electronics and automobiles.
- The Hightech Strategy was again updated to improve framework conditions, encourage SMEs, and increase collaboration with all stakeholders.

Platform Industry 4.0 played a significant role in creating a platform to bring all the stakeholders to collaborate and become the face of Industry 4.0 in Germany.

USA

The U.S. aims to expand its strengths in information, communication and operational technologies to bring digital innovation into the physical world to advance its manufacturing. In 2011, President Obama launched the Advanced Manufacturing Partnership to bring together all the stakeholders from industry, universities and the government to invest in emerging technologies and prepare the path for Industry 4.0. Later, the Revitalise American Manufacturing and Innovation Act of 2014 amended the National Institute of Standards and Technology Act to direct the Secretary of Commerce to establish a Network for Manufacturing Innovation Program to

- improve the competitiveness of U.S. manufacturing and increase production of goods manufactured predominately within the United States;
- stimulate U.S. leadership in advanced manufacturing research, innovation and technology;
- accelerate the development of an advanced manufacturing workforce; and
- create and preserve jobs

Smart Manufacturing for America's Technological Transformation (SMART) project was launched to address the need for a pool of skilled workforce. This project offers practical training to the community and technical college educators and an online platform to link educational institutions with manufacturers. Universities such as Arizona State University, Carnegie Mellon University, University of Pittsburgh, and Robert Morris University are actively contributing by creating a talent pool ready for Industry 4.0. Companies like Honeywell, Boeing, GE and Tesla are early adopters of Industry 4.0 in the USA.

UK

The UK was the birthplace of the industrial revolution, where industry and manufacturing have always been a priority. The UK has formulated the new Industrial Policy with the aim to

- place the UK at the forefront of the artificial intelligence and data revolution
- maximise the advantages for UK industry in the global shift to clean and sustainable
- become a world leader in shaping the future of mobility
- harness the power of innovation to help meet the needs of an ageing society

In 2018, the government of the UK launched UK Research and Innovation (UKRI), a non-departmental public body under the Department for Business, Energy and Industrial Strategy (BEIS). UKRI supports people, infrastructure and ideas that build a greener, healthier and more resilient UK. UKRI makes a targeted investment focused on today's most significant challenges

and opportunities, such as Net Zero, digitisation, national security and inequalities across our society, to achieve this ambition. A £147m investment from the UKRI Industrial Strategy Challenge Fund (ISCF) will support the transformation of UK manufacturing capabilities through the adoption of industrial digital technologies. "Innovate UK," part of the UKRI, has launched two programmes - Manufacturing Made Smarter and High-Value Manufacturing Catapult (HVMC). The Manufacturing Made Smarter challenge programme focuses on developing digital technology innovations within UK manufacturing. HVMC's role is to bridge the gap between business and academia, helping to turn great ideas into reality by providing access to world-class research and development facilities and expertise that would otherwise be out of reach for many businesses in the UK. The main agenda of HVMC is:

- To grow businesses and the manufacturing sector's contribution to the UK economy.
- Investigate innovative technologies or scale up new products and processes to prove they have achieved manufacturing readiness
- Work with academic partners to build on research at Universities and Research establishments in the UK and beyond.
- Use expertise to help shape UK's manufacturing policy.
- Work with UK Government and others to develop high-quality training provisions to meet industry needs.

The services offered by HVMC include technology development, workforce development, problem-solving, building manufacturing expertise, policy insights and intelligence, and research and testing.

Switzerland

Switzerland has a large manufacturing sector dominated by pharmaceuticals, precision engineering and the microelectromechanical (MEM) industry. The demographic factors are projected to cause a significant drag on industrial growth. The number of Swiss citizens aged 65 and over is increasing by 2 per cent a year. The ageing population means Switzerland's dependency ratio will rise to 67 non-working people for every 100 full-time employees, up from 49 today. Also, growth in labour productivity is at a historical low. The adoption of new digital technologies has not yet materialised on a larger scale due to transition costs and other barriers.

The government set up the Industry 2025 platform to implement emerging technologies and incorporate them into the industry. "Industry 2025" is a national initiative to promote digital transformation in Switzerland. It brings together all stakeholders and provides an introduction, support and anchoring of Industry 4.0 concepts in value networks and production companies through working groups and specific services. There are seven working groups:

- Digital strategy: create tools to raise awareness, disseminate knowledge and develop strategies
- Entry into Industry 4.0: develop toolkits to help companies in adopting Industry 4.0 technologies with a structured approach
- Thinking in business models: develop various approaches and models that can be applied
- Cyber-Physical System (CPS)-based automation: develop solutions regarding horizontal and vertical networking
- Smart data: show the right way of using data by partnering with data scientists and specialists
- Industry 4.0 security: develop a holistic integration of security over the entire life cycle
- Norms and standards Industry 4.0: create a roadmap for various standards for Industry 4.0 by taking into account the existing international norms

The Industry 2025 platform and working groups are helping the Swiss industry to adopt Industry 4.0 and boost productivity while achieving sustainability and efficiency.

Japan

Japan has always done things differently. Today, it is facing problems associated with ageing demography, labour shortages and weak nominal growth. While Germany's "Industry 4.0" framework focuses on manufacturing and smart factories, Japan's "Society 5.0" focuses on using the same tools and technologies for developing society. Japan proposed Society 5.0 in the 5th Science and Technology Basic Plan as a future society Japan should aspire to become. It follows the nomenclature beginning with hunting society (Society 1.0), then agricultural society (Society 2.0), industrial society (Society 3.0) and information society (Society 4.0). Society 5.0, according to the Comprehensive Strategy on Science, Technology and Innovation for 2017, is how far society can balance economic advancement with an inclusive society where all citizens can lead a life of high-quality, full of comfort and vitality. The concept of a people-centric society, Society 5.0, focuses heavily on the societal impact of technology and the need to create a better society.

Japan has the advantages of a robust innovation system, systematically documented data, and advanced manufacturing processes. Pressing societal challenges make Japan ideal for taking the lead in Society 5.0. To realize the goals of Society 5.0, Japan is targeting two main areas: mobility/logistics and healthcare. The Science, Technology and Innovation (STI) Comprehensive Strategy 2013 was guided by three principles: (i) act smart; (ii) implement a thinking system; (iii) think global.

Japan's Science and Technology Basic Plan aims to comprehensively and systematically advance the science and technology policy. The government formulate the plan by anticipating

the next decade and accordingly developing five-year science and technology policies. The Fifth Basic Plan of Japan is focused on four pillars, namely;

i) Acting to create new value for the development of future industry and social transformation.

- Fostering R&D and human resources that boldly challenge the future
- Realizing a world-leading "super smart society" (Society 5.0)
- Enhancing competitiveness and consolidating fundamental technologies in a "super-smart society."

ii) Addressing economic and social challenges

- Sustainable growth and self-sustaining regional development
- Ensure safety and security for the nation and its citizens and a high-quality, prosperous way of life
- Addressing global challenges and contributing to international development
- Pioneering strategically important frontiers

iii) Reinforcing the "fundamentals" for STI (science, technology, and innovation)

- Developing high-quality human resources
- Promoting excellence in knowledge creation
- Reforming funding system

iv) Building a systemic virtuous cycle of human resource, knowledge, and funding for innovation

- Enhancing mechanisms for promoting open innovation
- Incubating small and medium-sized startup companies to tackle new business opportunities
- Strategic use of international intellectual property and standardization
- Reviewing and improving the regulatory environment for innovation
- Developing innovation systems that contribute to "regional revitalization."
- Cultivating opportunities for generating innovation in anticipation of global needs

At the 2017 CeBIT fair in Hannover, Germany, the Japanese Ministry for Economy, Trade and Industry (METI) introduced the concept of Connected Industries to realize its vision of Society 5.0. The idea of Connected Industries involves [i] realization of a new digital society in which humans and machines or systems work together, [ii] solving challenges through cooperation and collaboration, and [iii] proactive development of human resources to address the advancement of digital technologies.

Singapore

Singapore is built upon a solid industrial base and manufacturing is an essential pillar of Singapore's economy. In 2020, manufacturing contributed approximately 20 per cent of Singapore's Nominal GDP. Singapore is geographically advantaged in a region that is emerging as a destination for growth and development. Singapore remains a popular destination for startups and technology-related businesses. Singapore's open and connected economy with 22 free trade agreements with other countries enables new businesses to grow. Singapore is using three critical strategies for its competitiveness and growth:

- Transform: Introduce long term facilities and transformation initiatives
- Grow and Build: Develop new talent through R&D partnerships and programmes
- Connect: Collaborate with global and local manufacturing communities

In 2017, the Economic Development Board of Singapore (EDB) launched the Singapore Smart Industry Readiness Index to prepare companies for Industry 4.0 through Industry Transformation Maps (ITMs). Developed under the Ministry of Trade and Industry and implemented by the Future Economic Council, ITMs seek to foster collaboration among stakeholders like employers, industry associations, unions, training institutes and the government. The government also provides incentives like the Productivity Solutions Grant (PSG) and Partnership for Capability Transformation (PACT) schemes. Singapore's JTC Corporation and the Singapore Business Federation (SBF) have signed a Memorandum of Understanding to support manufacturers in adopting Industry 4.0 technologies. This initiative is targeted primarily at SMEs to help facilitate their Industry 4.0 journey or scale their current efforts by adopting technologies and solutions for business operations. This initiative provides relevant Industry 4.0 related resources to companies keen on furthering their Industry 4.0 ambitions. These include curated workshops, capability building initiatives tailored to companies' digital readiness and link-ups to a larger pool of technology partners, such as Siemens, Bosch Rexroth, Singapore Precision Engineering & Technology Association (SPETA) and its consortiums. It also helps companies develop the expertise to implement and scale Industry 4.0 solutions in their operations. Over 300 companies are expected to be supported under this initiative and undergo Industry 4.0 transformation in two years.

China

China launched Made in China 2025 plan to accelerate the adoption of Industry 4.0 to reduce reliance on foreign technology imports and invest heavily in its innovations to create Chinese companies that can compete domestically and globally. China aims to increase efficiency, productivity, innovation and quality across ten key industries. These industries

include advanced information technology; automated machine tools and robotics; aerospace and aeronautical equipment; ocean engineering equipment and high-tech shipping; modern rail transport equipment; energy-saving and new energy vehicles; power equipment; new materials; medicine and medical devices; and agricultural equipment.

The "Made in China 2025" plan proposes a three-step strategy for transforming China into a leading manufacturing power by 2049. It is focused on "innovation-driven, quality first, green development, structurally optimised and human-oriented" with "market orientation, government guidance, focus on the present, look into the future, overall promotion, key breakthroughs, independent development, and cooperation." The Chinese government has also released programs provincially to better strategise according to the background and conditions of each province. China has also launched the "Internet Plus" initiative to increase internet connectivity across the nation which will help adopt Industry 4.0.

Indonesia

The manufacturing sector accounts for 20% of Indonesia's GDP. Indonesia aims to become one of the top 10 economies in the world by 2030. To achieve this goal, Indonesia has launched the Making Indonesia 4.0 initiative. Indonesia has developed ten national priorities under this initiative, which aim to accelerate the cross-sector development of the manufacturing sector:

- Reform material flow
- Redesign industrial zones
- Embrace sustainability
- Empower SMEs
- Build a nationwide digital infrastructure
- Attract foreign investment
- Upgrade human capital
- Establish an innovation ecosystem
- Incentivize technology investment
- Reoptimize regulations and policies

With its "Making Indonesia 4.0" roadmap, Indonesia is committed to increasing R&D spending to 2% of GDP. Indonesia aims to become a global player in the food, automotive, textile, electronics, and chemicals sectors to boost the country's exports and contribute towards Indonesia's gross domestic product (GDP).

Along with this, the government has created the Indonesia Industry 4.0 Readiness Index. This Readiness Index is the benchmark index used by the government and the industry to

measure the country's level of readiness for the fourth industrial revolution. The government is also partnering with key institutions and organizations worldwide to further the adoption of Industry 4.0.

Malaysia

The manufacturing industry of Malaysia is an important sector contributing about 22% to the GDP and primarily comprises SMEs (almost 99%) of the total number of manufacturing firms. However, the Readiness for the Future of Production Report 2018 (by WEF and A.T. Kearney) highlights that Malaysia is well-positioned to benefit from the future of Industry 4.0. Malaysia aims to increase productivity per person by 30%; raise the global innovation ranking from 35 to the top 30; increase the number of skilled workers from 18% to 35% and increase the manufacturing sector's contribution to the national economy. To achieve this goal, Malaysia has launched the Industry4WRD policy. The objectives of this policy are threefold:

A-C-T

- Attract stakeholders to Industry 4.0 technologies and processes
- Create the right ecosystem for Industry 4.0 to be adopted
- Transform Malaysia's industry capabilities in holistic and accelerated manners

The implementation will be based on the FIRST strategy:

- Funding: Provide incentives and services to encourage investments
- Infrastructure: Strengthen digital connectivity, enhance digitalization and integration
- Regulations: Increase awareness, create a collaborative platform and improve data integrity, standards, sharing and security
- Skills and Talent: Enhance capabilities of existing workforce with skill development programmes and ensure future talent by providing education in Industry 4.0 technologies
- Technology: Establish labs, implement standards for interoperability, quality and safety, and intensify research, innovation, commercialization and entrepreneurship.

This strategy aims to transform the manufacturing sector and related services from 2018 to 2025.

Vietnam

With the rapid growth in manufacturing and the Free Trade Agreement with the European Union coming into effect, Vietnam's manufacturing expanded by 5.82% in 2020, which led

the way for the country's economic growth. It aims for productivity to increase, on average, by over 7% per year. By 2030, Vietnam intends to be among the top 40 countries in the world in the Global Innovation Index (GII) rankings; aiming to provide broadband access to all citizens at a low cost; the digital economy to account for over 30% of the GDP; and for labour productivity to increase by about 7.5% on average per year. The action plan to implement the national industrial development policy includes:

- By 2030, the industrial sector to contribute over 40% of GDP, in which manufacturing and processing industries will account for 30% and the manufacturing industry alone will account for 20%.
- The value proportion of high-tech products from the manufacturing and processing industries reach at least 45%.
- The average growth rate of labour productivity in the industrial sector is to grow 7.5%.
- The Competitiveness Industrial Performance index will be among the top three ASEAN countries.
- The workforce in the industrial and service sectors to surpass 70%.

The first steps of Vietnam's "digital revolution" are already underway. Polices on the development of enabling infrastructure, creative capacities, human resources and priority sectors and technologies are already in place to achieve the country's ambitions to be among the top Southeast Asian Nations in the Global Innovation Index (GII) ranking. In 2019, the Ministry of Planning and Investment (MPI) released the draft national strategy on Industry 4.0 to transform Vietnam into a digital society by the next decade.

PART II

INDIA'S ROADMAP

(1) Infrastructure Roadmap

Physical and Digital Infrastructure

The path to the future requires laying a solid foundation for physical and digital infrastructure in India. The infrastructure sector has become the most significant focus area for the Government of India. On India's 75th Independence Day, the Prime Minister announced the launch of 'PM Gati Shakti Master Plan' with an Rs. 100 lakh-crore project for developing 'holistic infrastructure', which includes the development of new economic zones and world-class manufacturing of products to help local manufacturers compete with their counterparts worldwide. The plan is expected to give a significant push to connectivity to major industrial clusters across the country, cut logistics costs and improve supply chains.

India already has the world's 2nd largest network of roads. Phase I of Bharatmala Pariyojana, a pan-India umbrella programme for optimising passenger and freight movement and bridging critical infrastructure gaps of over 34,800 km of roads, is expected to be implemented in the next two years. Multi-modal logistics parks are being developed under the Logistics Efficiency Enhancement Program (LEEP). India also has the world's 4th most extensive rail network. The government has suggested an investment of Rs. 5,000,000 crore (US$ 750 billion) for railways infrastructure from 2018-30. The Sagarmala Programme is also expected to accelerate port-led logistics and infrastructure. In March 2021, the government announced a long-term US$ 82 billion plan to invest in the country's seaports. In addition, the ongoing national and state-level initiatives, including Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Housing for All, Smart Cities, Swachh Bharat and Rurban Missions, add to the overall development of urban and rural areas of India.

In 2015, India launched the Smart Cities Mission (SCM) to improve infrastructure and services in 100 cities and towns in India by harnessing technology that leads to smart outcomes. The SCM makes localities more pedestrian-friendly, promotes transit-oriented development where housing, jobs, and services are closely integrated with mass transit systems, makes areas less vulnerable to disasters by providing early warnings, employs solar power for energy needs, ensures efficient street lighting, builds energy-efficient green buildings and make governance citizen-friendly, accountable, transparent and cost-effective.

India has made progress in digital adoption, as the collective number of internet users in India (over 825 million by March 2021) exceeds the number of internet users in some developed countries. The internet is growing and providing more value to users, businesses and governments, leading to economic growth and social change. Increased access to mobile broadband with low-cost smartphones has enabled millions of Indians to connect to the

internet for the first time. The "Digital India" program and private investment have made significant improvements in creating digital infrastructure in India. However, the Indian public spending on broadband fibre infrastructure is inadequate, a $13bn spending of which the government spends only $2bn. On the other hand, developed economies like the US and Europe have been spending ~1.2% of their GDP on digital infrastructure.

While India is progressing faster in building physical infrastructure, there is a need to accelerate investment in building digital infrastructure as it is a fundamental transformational area to achieve leadership in the fourth industrial revolution.

Initiate to Establish (2021-2025)

India has embarked on an ambitious journey to create world-class physical infrastructure; it should aim to establish much needed digital infrastructure using indigenously developed technologies and accelerate the completion of smart cities by 2025. There is a need to create digital infrastructure accessible to over a billion people and support every enterprise. Building the future factory with an entirely connected system will require access to digital infrastructure and technologies for large and small enterprises. The government should consider increasing investment in digital infrastructure, especially where private investment is not adequate.

India's telecommunication network still suffers from slow data speeds and unstable connections. The need of the hour is to accelerate the fibre network deployment across the country and enable high network capacities for managing the traffic load and better connectivity. Some significant and high-priority investment area is 5G, a critical infrastructure to kickstart the fourth industrial revolution to connect devices, machines, businesses and people. The potential of 5G in India can be game-changing with ultra-fast connectivity (multi-Gbps data speed), massive bandwidth and network capacity, ultra-low latency required for applications in IoT, AI, smart buildings, self-driving cars, automated factories, AR/VR experiences, ultra-HD live streaming, telesurgery, etc. With unprecedented levels of connectivity and 5G internet, India will be able to transform education, healthcare and agriculture in rural areas while developing smart cities and smart industries of the future. In fact, by 2035, the cumulative impact of 5G on the Indian economy is expected to touch the $1 trillion mark.

Any smart equipment requires software-embedded hardware, which enables real-time data transfer, including network infrastructural and operational parameters, as well as transaction and end-user data. India is yet to develop regulatory frameworks for personal and non-personal data. India should aim to reduce foreign dependence on this digital infrastructure layer critical to national security. India must build technological capabilities across the digital value chain with indigenously owned technologies and products to adopt national technical standards.

The Smart City Mission (SCM) should develop and successfully implement 'smart' solutions before 2025 to overcome various urban problems and improve housing, water supply, sanitation, electricity supply, health, education, mobility, safety, security and strengthening urban governance.

Integrate to Grow (2026-2035)

The next goal for India is to integrate physical infrastructure (transport, energy, water, and waste) with digital infrastructure (IoT, sensors, networks, cloud, big data and machine learning) to create a "smart" infrastructure that can communicate in real-time with end-users and fulfil their needs. The reliable, robust and meaningful information gathered and processed by the smart infrastructure can be used by AI to better understand the usage of infrastructure. Today's cellular IoT networks like NB-IoT and LTE-M, and the upcoming launches of 5G-networks, can provide solutions for nearly every thinkable application.

In the next decade, physical-digital integration could be effectively accomplished by using platforms applying the digital twin concept. A digital twin is a virtual representation of a physical "thing" or "entity" that resides on the network – for example, digital twins in cities are a virtual replica of urban networks to study how to reduce risks and improve cities' resilience; they implement the physical-digital integration in city infrastructures. A digital twin can be used to monitor the status of its physical counterpart and predict how it will behave in the future.

Digital twins are starting to transform how cities are designed and managed. The technology, which involves creating a digital clone of a real-world object or system, can revolutionise healthcare, manufacturing and logistics. It is now having a profound impact on architecture and urbanism too. The way to relax urban mobility is through intelligent, connected infrastructure. Several intermodal mobility solutions would allow commuters to use whichever mode of transportation is available at the time. Smart connectivity ensures that users always find a suitable solution, regardless of time or location.

The technology has advanced so far that it's now possible to clone entire cities; for example, Chinese company 51World has created a digital twin of Shanghai. Architects and designers believe this will revolutionise the design and operation of buildings, transport systems, streetscapes and more. Meanwhile, in New Zealand, 3D visualisation studio Buildmedia has been developing a GIS-accurate model of Wellington over the past three years, with the help of the city council. They now plan to integrate live smart city data to create a true digital twin. While not a true digital twin, virtual Helsinki, a digital replica of the Finnish capital created by VR studio Zoan, promotes tourism to virtual real estate tours. London city officials

are building out a digital version of Harrow, one of the city's 32 boroughs, starting from October 2021.

In India, the Government of Andhra Pradesh has chosen Cityzenith's Smart World Pro as its 3D city information model to develop Amaravati, a new greenfield smart city. The digital twin platform of Amaravati enables real-time construction progress monitoring, environmental and wellness monitoring via ubiquitous, multi-nodal Internet of Things (IoT) sensors, advanced mobility and traffic monitoring and simulations and a proposed digital twin user ID scheme for every Amaravati citizen that will serve as a single citizen portal for all government information, notifications, forms, and applications.

The Pune Knowledge Cluster plans to use the TCS Digital Twin for (a) the last mile connectivity and charging stations at Metro stations and (b) enabling COVID-19 effort on genome sequencing and patient surveillance for the Pune region.

By 2035, India should invest in integrating physical and digital infrastructure, build a digital twin of 100 smart cities and aim to create smart "regions" or "states" that connect cities, towns, and villages. This requires systematically investing in research to develop cutting-edge critical technologies associated with digital twin and cognitive systems to achieve leadership and become Atmanirbhar with Atmavishwas.

Multiply to Lead (2036-2047)

The next goal for India is to build a smart, connected, intelligent national infrastructure network to make it a "smart nation" to improve overall competitiveness for economic, social and sustainable development. The smart nation national network should integrate large cities, rural areas, small towns and semi-urban areas, and infrastructure connecting networks of cities, rural and urban areas. Well-functioning rural and urban links can be indispensable for sustainable development.

According to the UN report, India's urban population is expected to increase from 461 to 877 million between 2018 and 2050. The "smart nation" platform-of-platforms can offer solutions to the challenges associated with the rapid increase in the urban population:

- Production and consumption of energy, housing, water supply, waste management, lack of sufficient parking, traffic jams, increased pollution and responding to the needs of youth, disabled, ageing population living in dense urban centres.
- Minimising the risk of vulnerability to natural and human-made disasters leading to land degradation, increase in rainfall, flooding, drought frequency and severity, heat stress, dry

spells, wind, sea-level rise and wave action, or epicentres of crises as with COVID-19.

The process by which a country shifts from mostly rural to urban has implications for agriculture, industry and providing public services at scale. Frontier technologies could unlock rapid urbanisation while enhancing efficiency across most areas of human activity. Analysis of big data through artificial intelligence, for instance, can mimic, simulate and predict human and natural patterns and reduce congestion, enhance road safety, reliability and predictability, improve efficiency in logistics and help cut carbon emissions and improve access to essential services.

Technological innovation will be important in enabling India to connect networks of cities and link to surrounding rural areas. "Smart grids" and renewable energy networks, modern waste disposal techniques, reuse, recycling and repurposing practices facilitate the transition to a circular economy. The use of big data in congestion management, distribution systems and the planning of public transportation are all examples of how technology and sustainable urbanisation are intertwined.

A digital nation is already under development in Singapore (Virtual Singapore), where an open data platform with 3D maps of the city is under construction. Eventually, this platform will offer several benefits to users, such as policy and business analysis, decision making, test-bedding of ideas and community collaboration. In practical terms, Virtual Singapore will be able, for example, to provide information on the amount of sunlight and ambient temperature, which is beneficial information for a city planner to build comfortable atmospheres for citizens. Another real-life use of the platform will be the possibility of visualising the city landscape with all its physical abruptions, allowing, therefore, to plan emergency paths under emergencies. Singapore's digital twin development allows to narrow the gap between reality and virtual life, and it will be essential to empower nations.

While the smart nation accelerates the use of digital technologies, there is a need to tread carefully on data collection, infringement on people's privacy, security breaches in security agencies, power grids, nuclear plants and financial institutions. More regulatory measures are needed on the ethical use of big data and digital technologies.

India should aim to multiply the progress made between 2025 and 2035 by evolving into a "smart nation" with an intelligent national infrastructure network to ensure its leadership in the fourth industrial revolution. Smart infrastructure that is self-aware and autonomously manages its maintenance reduces costs, decreases downtimes and allows greater operational efficiency. With exponential technologies' rapid growth and convergence, a smart nation with autonomous decision-making capabilities will no longer be science fiction but a very probable future reality. Government, industry, civil society and other stakeholders need to develop policies that facilitate this transition to global leadership.

(2) Technology Roadmap

Key Technologies to Lead in the Industry 4.0

There is a revolution happening in the field of technology that has been gaining momentum in this decade. Technology, which had only made inroads into human lives until the end of the 20th century, has massively altered every sphere of life since the start of the 21st century. Recent breakthroughs and advancements in IoT, AI, advanced robots, cloud computing, augmented reality, 3D printing, big data analytics and nanomaterials, among others, make products perform complex tasks at remarkable speeds and significantly lower costs. This is reflected in the emergence of digital businesses and the dominance of technology companies in the stock market. Technology has swept across every sector, dramatically changing the global landscape and blurring the boundaries between industries.

According to the 2021 report of UNCTAD, a group of 11 technologies - artificial intelligence (AI), the Internet of Things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology and solar photovoltaic is expected to create economic value of over $3.2 trillion by 2025.

This section provides brief details of core technologies powering Industry 4.0 and required for achieving leadership.

Internet of Things (IoT)

The Internet of Things is the umbrella technology that enables machine-to-machine communication for various tasks within a networked environment. While the internet was built for humans to communicate with each other, today, the number of human-independent devices that collect data, run services and power platforms far exceeds the number of internet users. With an interconnected set of devices, any environment can be automated quickly and made more fault-tolerant and robust. IoT is a powerful technology because it is at the crossroads of robotics and automation, and AI. IoT devices in the industrial setting generally consist of sensors, actuators and other control systems, which can provide access to real-time data and the ability to act upon that data with great speed. The data collected can be analysed using modern machine learning techniques to provide predictive maintenance scheduling, quality assurance, and optimisation capabilities.

India's first draft IoT Policy was launched by the Ministry of Electronics and Information Technology (MEITY) in 2016 to build a robust governance framework for the holistic implementation and execution of IoT-related policies and campaigns. The smart cities initiative is expected to help in the development and adoption of IoT in the country. In partnership

with MEITY, NASSCOM has established IoT CoEs to revolutionise the Indian IoT ecosystem with modern infrastructure, co-create IoT solutions and build the "next wave" of talent with incubation, funding, acceleration, networking and mentoring via IoT's startup program.

India is becoming a hotspot for IoT development and deployments for various applications, including CCTV and surveillance applications for safety, collision avoidance systems for semi high-speed trains, customer engagement, supply chain management, and virtual conferencing. With this, India has the potential of becoming a leader in IoT and creating a real-time digital world.

Big Data and Artificial Intelligence

Big Data and Artificial Intelligence are the two sister technologies driving the never-before-seen pace at which the world is changing. Big Data involves collecting, storing and analysing millions of data points in a given domain. The complexity and size of such data make it difficult to analyse it and use it productively – this is where AI brings forth cutting-edge algorithms for modelling the data for building predictive capabilities. In essence, Big Data enables the data collection process, while AI helps convert this data into knowledge.

Modern AI algorithms can analyse a variety of data types to tackle different business problems. Computer Vision, Natural Language Processing, Signal Processing with Machine Learning and Data Mining techniques are just a few examples of AI approaches where data from images, text, sensor data and tabular data (respectively) can be modelled. Moreover, techniques like Reinforcement Learning allow models to learn continuously as new data streams. While understanding and developing business-specific AI solutions can be complex, cloud platform providers like Google and Amazon simplify the process by building easy-to-use or plug-and-play machine learning solutions to accelerate development.

Implementing Big Data and AI entails extensive data collection from IoT devices and users of the products. This data can be stored in affordable cloud-based solutions. The data collected can be very beneficial in making faster and better business decisions, including predicting supply and demand, customer satisfaction and expectations, and deeper insights useful for new product development and manufacturing. The combination of Big Data Analytics and Artificial Intelligence can provide enormous benefits for businesses, and both of these technologies are some of the top trending technologies right now.

The US has committed around $6 billion for AI-related research for the year 2021, and Europe is slated to increase investment for AI research by 33 per cent between 2020 and 2023. (according to International Data Corporation (IDC)). India has a big stake in the AI technology leadership to establish itself as an advanced economy. The Indian government has increased

the outlay for the Digital India initiative to $477 million in 2020 to boost AI, IoT, big data, cybersecurity, machine learning and robotics. The Indian government has launched several initiatives to boost AI and Big Data capability, including;

US-India AI Initiative: The US-India Artificial Intelligence Initiative was launched on 18th March 2021 to foster AI innovation by exchanging ideas and experiences, identifying new opportunities in research and development and bilateral collaboration.

Applied AI Research Centre in Telangana: The Centre was launched in October 2020 at the International Institute of Information Technology, Hyderabad, focused on solving India's healthcare and smart mobility challenges.

National Research Foundation: On 3rd March 2021, the government has allocated 50,000 crores for NRF, an autonomous body under the new National Education Policy (NEP) 2020 established to boost research across different areas, including AI.

Responsible AI for Youth: The platform was established by the National e-Governance Division of Ministry of Electronics and Information Technology to help the students develop a new-age technology mindset and empower the young generation to become AI-ready and reduce the skill gap in India.

The National Data Center Policy 2020 aims at making India a Global Data Center hub by promoting investment in the sector and enabling provisions for trusted hosting infrastructure to propel growth in the digital economy. With various programs and initiatives, India can leap ahead in AI by designing and developing scalable solutions.

Autonomous Robots

Autonomous robots are intelligent machines that accomplish tasks without direct human intervention. They are built with a combination of technologies from Robotics, IoT and AI. Autonomous robots may have sensors to perceive the environment around them and take decisions based on the information they gather and the task they have to accomplish. They can be faster and more precise than humans and perform complex or dangerous tasks with higher efficiency. While autonomous robots are particularly prevalent in the manufacturing sector on production lines, other autonomous robots can help serve customers in retail stores, access difficult and dangerous areas for the military, optimise agriculture processes and cultivation on farms and transport heavy goods safely in warehouses or logistics ports.

A functional factor key to the development of autonomous robots is tackling how they will interact with humans. Human-robot collaboration is fundamental to successfully implementing this technology so that robots can work in tandem with humans in rapidly changing environments. Another factor is the standardisation of communication interfaces – a universal way for robots to communicate with each other regardless of the manufacturer.

In 2014, India established the Centre for Artificial Intelligence and Robotics (CAIR) as part of the DRDO for research and development in AI, robotics and mission-critical products for battlefield communication and management systems. The Ministry of Education has a robotics outreach program e-Yantra at IIT Bombay to harness the talent of young engineers to solve problems using robotics technology for agriculture, manufacturing, defence, home, smart-city maintenance and service industries.

India has made a good beginning in developing noteworthy humanoid robots used by defence, research and industry – DRDO has developed the Remotely Operated Vehicle (ROV) "Daksha" which is an automated mobile platform for multi-purpose payloads, "Mitra" is the first indigenously built humanoid robot, which is capable of interacting with humans smartly and "Manav" is India's first 3D-printed humanoid robot.

Cloud and Edge Computing

The most significant advantage of cloud computing is its flexibility for businesses to get resources like storage, servers, databases and software, and compute on-demand, at a recurring price, without the need to invest in physical infrastructure and employees to build a custom solution. This implies that businesses can invest less upfront and move the cost to operating expenditure as the need arises.

Cloud-based solutions simplify the process of managing critical business data. Built-in security, data backup and recovery, software updates, and reliability and uptime in cloud platforms reduce companies' need to have big IT and security teams to manage resources. Data analysis and AI services built into cloud platforms provide businesses with many options to model big data. However, the significant downside to cloud-based solutions is the high latency in real-time applications and the large bandwidth required to upload data to the cloud databases. Therefore, a significant amount of processing and inference is moving to edge computers, including IoT and mobile devices.

The "Edge" refers to any computer that is local to the work environment, where data is collected and used. The advantage that edge computers have over cloud computers is the very low latency while performing real-time analysis. While the cloud can be used to collect, store

and build models from existing Big Data, these models can be downloaded to edge computers to provide real-time inference and predictions based on novel data as it is being collected.

India has already taken several initiatives in the cloud for accelerating e-governance programs. The government announced a cloud computing initiative called "Meghraj" to expedite the delivery of e-governance services while optimising the ICT spending of the government. The 2018 National Digital Communications Policy aims to make India a global hub for cloud computing by establishing international data centres, content delivery networks and interconnect exchanges.

Cloud-based solutions have helped India ensure the success of national initiatives, including a landmark initiative, the Government e-Marketplace (GeM), which uses a multi-cloud scalable architecture that serves over 50,000 buyer organisations with a listing of over 19 lakh products and more than 80,000 services. Another successful example is DigiLocker, a cloud-based platform for issuing, sharing, and verifying critical lifelong documents or certificates with more than 57.13 million users and 4.27 billion issued documents. NITI Aayog has proposed the creation of an AI-based cloud computing platform called AIRAWAT (AI Research, Analytics and Knowledge Assimilation) as the foundation for enabling the growth of emerging technologies such as AI.

Simulation and Digital Twin

A simulation is the imitation of a particular scenario or process from the real world in the virtual world. It uses models of real-world entities that represent their state and/or behaviour and can predict the outcome of applying a scenario or a process to the model. Building a model to be simulated requires data from IoT devices and running complex simulations will require cloud computing and AI. The major factors fuelling the simulation market include increasing demand for an effective solution to reduce production expenses and training costs and increasing simulation capabilities regarding advanced technologies such as digital twins, AR/VR and 3D printing.

A simulation that comprehensively models a real-world process can be considered to be a "digital twin." A digital twin can be used for monitoring, testing, optimisation, predictive maintenance and supply chain optimisation and can show (or predict) behaviour for actions that cannot be performed in the real world. This method is relatively cost-effective and safe while allowing dangerous outcomes or complex situations to be predictable. This technology can be used to maximise innovation by testing a particular hypothesis without building an actual prototype.

Digital twin requires multidisciplinary capabilities in the intelligent use of data and applying multi-system simulation and modelling of complex physical assets. Indian organisations have unique capabilities in advanced simulation and modelling of complex systems and are well poised to open up countless possibilities for research, innovation and optimisation.

Virtual and Augmented Reality

Virtual Reality (VR) uses a computer-generated digital environment and a headset that can render this environment so that one can interact with it in real-time. VR is commonly used as a tool to visualise physical objects such as machines and can be paired with digital twinning technology to make for an interactive simulation. VR can be helpful in training workers to use robots and machinery in a factory in a more intuitive fashion or to view and conduct experiments on digital twin simulations that could be dangerous in the real world.

Augmented Reality (AR) takes a different approach. Instead of using a wholly digital environment, it involves a headset that projects information on the real environment. While AR was restricted to science fiction for a long time, modern AR headsets can accurately map the real world and place virtual projections. This technology is far more helpful in assisting workers as they work on complex machinery with multiple parts, where the manual can be projected on real objects or for drivers in logistics to identify the optimal path to navigate.

Both AR and VR can enhance workers' productivity by quickly training and assisting them while they work. This is especially useful in Industry 4.0 factories in remote condition monitoring and maintenance of machines. In addition, AR and VR have applications across industries including education, healthcare, transport, construction, tourism and entertainment.

In August 2021, the Indian Institute of Technology Madras (IIT-M) announced the launch of the country's first consortium for virtual reality called 'Consortium for VR/AR/MR Engineering Mission in India' (CAVE) to create new advanced technologies and applications in virtual reality, augmented reality, mixed reality (XR) and haptics together. Another Centre of Excellence for Virtual and Augmented Reality (VARCoE) has been established at IIT-Bhubaneshwar in partnership with the Government of Odisha, Software Technology Parks of India (STPI). The centre is focused on virtual, augmented and mixed reality as well as mobile computing, epigenetic and evolutionary robotics, haptic communication and developing advanced algorithms for near-real 3D user interfaces and exploratory data analysis in virtual environments.

Additive Manufacturing

Additive manufacturing or AM, better known as 3D printing, revolutionises product design and on-location manufacturing globally. Additive manufacturing involves using computer-aided design (CAD) models to provide the design and direct hardware to perform layer-by-layer printing or depositing of material to manufacture relatively simple structures. The main advantage of AM is that we can produce small production parts quickly without the need for heavy machinery and/or tools. Other benefits include creating rare or complex shapes that are difficult to manufacture with traditional manufacturing, combining manufacturing and assembly processes, and generating less waste. Though manufacturers have adopted AM worldwide, it has gained momentum in India after most industries underwent supply chain disruptions due to COVID. Indian manufacturers have been able to produce locally, invent new products on-demand with increased adoption of AM technologies, which is expected to grow over 30% year on year.

The Ministry of Electronics and Information Technology invited comments on the Draft National Strategy for Additive Manufacturing. The strategy aims at creating a conducive ecosystem for design, development and deployment, and building capabilities in machines, materials, software and designs to leverage the untapped business opportunities in this emerging technology. This is also expected to help overcome technical and economic barriers for local manufacturers to seamlessly adopt AM and facilitate the creation of a support base of domestic manufacturers for setting up operations with supporting ancillaries in India by Indian and global companies. Hyderabad is in the race to host the National Centre for Additive Manufacturing (NCAM) that the Central government has proposed to accelerate the digital revolution of industrial production. The plan is to establish a National Centre on AM for harnessing AM transformation and driving capabilities by continuously engaging all key stakeholders.

Cyber Security

Increasing digitalisation and automation require strong cybersecurity protection of industrial networks and infrastructure. While organisations across the industry sectors are embarking on a journey of Industry 4.0, industrial cybersecurity lags behind IT security, posing a challenge for IoT security. The operational technology is becoming highly vulnerable to cyberattacks as IoT connects to the external environment. There is a lack of investment in finding solutions to industrial cybersecurity, which can have serious consequences, particularly in the context of geopolitical tensions.

India is one of the top three target countries in the world for cyber-attacks. Cybercrimes in India have increased by almost 500% during the global pandemic, and there are emerging threats for drones and IoT devices. India has taken several initiatives to ensure a safe, secure

and trusted cyberspace, including the Indian Computer Emergency Response Team (CERT-In), which operates as the national agency for tackling the country's cybersecurity. India is expected to release a new cyber security strategy later this year for a safe, secure, resilient, vibrant, and trusted cyberspace covering the entire ecosystem. The strategy includes cyber audits, building new indigenous capabilities, and data as a national resource.

Initiate to Establish (2021-2025)

India has initiated several programs to build national capability in core technology areas with the aim to succeed in Industry 4.0. When compared to other countries, India lags behind in research, innovation and deployment of technologies at a scale. This is the time for India to accelerate its missions to systematically build strong capabilities in at least five core technology areas and aim to become one of the top 3 countries in the world before 2025. Based on India's strength in ICT technologies, India has the potential to become a global leader in:

- Data Science and Artificial Intelligence
- Internet of Things (IoT)
- Cloud Computing
- Simulation and Digital Twin
- Additive Manufacturing

India is already on the list of top 10 countries globally in some of the technological areas. India must build its own indigenous technologies and capabilities to fulfil the dream of becoming an Atmanirbhar India and lead in the fourth industrial revolution.

Integrate to Grow (2026-2035)

Industry 4.0 is likely to peak during this period. The power of Industry 4.0 lies in technological convergence, which is advancing at a very rapid rate. The next step for India in this journey is to integrate information, operational and biological technologies to develop larger technology platforms/systems. Companies across sectors ranging from transportation to healthcare now feel the need to collect actionable data from almost all their processes and products. This requires a connection between Operational Technology (OT) and Information Technology (IT). OT is the domain of asset automation where data generation takes place. IT is the domain of process automation where data consumption takes place. Cyber-physical system (CPS), which is a building block in Industry 4.0, combines digital (cyber) elements with physical objects (machines) in a dynamic environment. Cyber-physical systems are poised to transform manufacturing, mobility, health care, agriculture, security, power generation and distribution, and emergency response.

India has launched National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) to build the nation's scientific, engineering, technological and innovation capabilities for industrial and economic competitiveness. With a total outlay of Rs. 3660 Crore for five years, the mission aims to create a strong foundation and a seamless ecosystem for CPS technologies by establishing a network of 15 Technology Innovation Hubs (TIHs), 6 Sectoral Application Hubs (SAHs) and 4 Technology Translation Research Parks (TTRPs). The goal is to integrate nationwide efforts of knowledge creation, technology and product development, innovation and commercialisation, and human resource development. India has initiated programs to build national capabilities in CPS for India's overall competitiveness. India needs to systematically progress from building semi-autonomous systems to autonomous cyber-physical systems that are capable of making decisions and operating independently. India should aim to establish itself as a global leader in CPS during this phase by 2035. Besides CPS, India has unique opportunities to build digital twin, cognitive systems, and bio-intelligent systems to achieve leadership in new frontiers of Industry 4.0.

Digital twin solutions help in efficient real-time tracking and monitoring, predictive analysis, user experience, improving the product, assisting in decision-making and controlling inventory shrinkage in supply chains. A digital twin enables small and large companies to increase reliability, optimise the use of resources, minimise downtime and improve performance and efficiency. As a result, large and small organisations across industries can benefit from the capabilities of digital twin solutions.

Cognitive Systems involve cognitive automation, production, analytics and computation designed to operate in a way that mimics human behaviour where machines perform a task in a considered smart or intelligent way. Cognitive systems can transform the entire manufacturing value chain by utilising connected sensors, analytics, and cognitive capabilities to derive intelligent and actionable insight to drive the manufacturing environment's productivity, quality and efficiency. A cognitive system is an emerging field with huge potential compared to big data analytics because it unlocks the potential of new human-machine capabilities.

Bio-intelligent systems are being developed to extend cognitive capabilities. Bio-intelligent systems involve creating self-organising systems in which technology replicates and optimises itself. Moving away from classical and traditional designs can help make a future industry where humans and machines truly work together, not with one dependent on the other, but in true partnership.

Digital twin, cognitive and bio-intelligent systems are emerging fields that hold massive opportunities because they unlock the potential of new man-machine capabilities. India has an excellent opportunity to develop and implement these areas to drive forward innovation and competitiveness. The economic, industrial and societal impact of such platforms and

systems is far more significant and expected to reshape our world with more responsive, precise, reliable and efficient systems that can address some of the most pressing societal, industrial and national priorities.

Multiply to Lead (2035-2047)

After establishing leadership in key technology areas and achieving growth by creating systems and platforms with integration technologies, the next step is to develop self-aware, autonomous, intelligent, connected and sustainable systems and networks of "system-of-systems" to achieve leadership in the fourth industrial revolution. Innovations that ride on the back of the system-of-systems concept to create an interoperable, synergised ecosystem have crucial applications in solving the complex requirements and challenges worldwide. According to the World Economic Forum, by 2025, digital ecosystems could account for more than $60 trillion in revenue, and yet, only 3% of companies have adopted this strategy till now.

A 'system' (or a platform) is mainly hierarchical, where a subsystem influences other parts of the system and removing it will halt the functioning of the entire system. A 'system-of-systems (or a platform-of-platforms) model, on the other hand, is where a diverse set of large-scale integrated systems that can operate independently on their own are networked together for a common purpose. Individually, these systems may have different technologies, contexts, operations, geographies, or conceptual frameworks.

In addition, as Artificial Intelligence is accelerating exponentially, machines would be capable of predicting human intuition and actions and may very well be autonomous and intelligent. Algorithms are being taught to anticipate human actions by feeding years of data. Intelligent, machine-like robots can now be designed to be deployed to work in extreme conditions and manoeuvre delicate procedures. Factories will function autonomously with the creation of intelligent and self-aware machines. These machines will be able to accomplish specific tasks in the presence of uncertainty and variability and self-simulate to adapt to novel situations. They will also be capable of self-diagnosis and repair. Artificial Intelligence, combined with data analytics on the data from operational and biological systems, will enable new lifestyles, cities and industries in this era.

India needs to think and start investing beyond technology leadership and building large scale systems. The system-of-systems approach allows India to pursue large innovation opportunities. The Fourth Industrial Revolution is fast enabling smart, intelligent, self-aware, autonomous and networked machines and ecosystems to grow and thrive. India needs to architect a 'system-of-systems for both industry and delivery of government services to grow exponentially by maximising network effects. This is also a time for India to lay the foundation for the fifth industrial revolution.

(3) Industry Roadmap

Indian Industry

India's share of the world income was 22.6% in 1700. In 1750, India was a leader in the textile industry. But, India lost its economic leadership beginning in 1815 as steam and electric power that led first and second industrial revolutions made industrial production more competitive in Europe and the USA. These first two industrial revolutions bypassed India, which resulted in slow and stagnating industrial and economic development for almost two centuries. In the 1980s, the rise of the internet, automation and digital computing led to the third industrial revolution, giving birth to new economic thinking and renewed industrial development in India. The steady growth of the industry in India beginning from 1991 is attributed to the economic liberalisation, FDI, increase in exports, the rise of IT, telecom and retail, along with the entrepreneurial energy of industry houses and aspirational youth. Earlier industrial revolutions brought waves of economic prosperity to nations in Europe, the USA and other countries, and the fourth industrial revolution is no different. Backed by steady economic development in the last four decades and with access to technology and talent, India has a once in a century opportunity to prepare and lead in the fourth industrial revolution.

The adoption of Industry 4.0 is expected to bring the much-needed transformation in the manufacturing and services industries in the next two decades. Armed with Make in India, Atmanirbhar Bharat, Digital India and the Production Linked Incentive (PLI) initiatives, India aims to become self-reliant in manufacturing for local and global markets. The framework of incentivising prominent domestic players to boost local production will enable India to become a manufacturing hub. Indian industry can take a leap in achieving global competitiveness by adopting smart digital technologies. The potential applications of Industry 4.0 for major industry sectors are given in the section below.

Major Industry Sectors in India

Agriculture sector

Agriculture is the primary source of livelihood for about 58% of India's population. Gross Value Added (GVA) by agriculture, forestry and fishing was estimated at Rs. 19.48 lakh crore (US$ 276.37 billion) in FY20. Growth in GVA in agriculture and allied sectors stood at 4% in FY20. The agriculture, forestry and fishing GVA growth will likely be 3% in the second quarter of FY21. The Indian food industry is poised for tremendous growth, increasing its contribution

to the world food trade every year due to its immense potential for value addition, particularly within the food processing industry. The Indian food and grocery market is the world's sixth-largest, with retail contributing 70% of the sales. The Indian food processing industry accounts for 32% of the country's total food market, is one of the largest industries in India and is ranked fifth in terms of production, consumption, export and expected growth. Essential agricultural commodities export for the April-September period of 2020 increased by 43% to Rs. 53,626 crores (US$ 7.3 billion) over Rs. 37,397 crores (US$ 5.1 billion) in the same period last year.

In 2018, the World Government Summit published its report Agriculture 4.0 – The Future of Farming Technology, collaborating with Oliver Wyman. It highlights four key challenges in the agriculture industry: increase in demographics, stress on natural resources, climate change, and food waste. As the population is rising, the demand for food is increasing. An increase in urbanisation also leads to a change in people's diet, increasing demand for processed foods and animal-sourced food. The net sown area is around 140 million hectares, and the area under forests and non-agricultural uses has increased. In the process, the quality of the total stock of agricultural land has deteriorated as good quality agricultural land in the urban fringe has gone out of cultivation, and comparatively inferior quality land in the form of wasteland has come under cultivation. Lack of diversification of crops, a slowdown in public and private investment in agriculture, slow growth in the use of technology, and soil erosion have resulted in the stagnation of agriculture. Labour productivity has also declined. Droughts are another primary concern that is affecting this industry. There is still 41 per cent of land under cultivation that is not irrigated.

We can use the latest technologies to increase the efficiency of food chains. These technologies include vertical/urban farming, genetic modification, cultured meats, and 3D printing. We can apply Industry 4.0 techniques like Artificial Intelligence, Big Data Analytics, IoT, Blockchain to improve the food supply chain. Nanotechnology, precision agriculture and crowd-farming are some other techniques that can be used. Drone technology can be used for monitoring and land analysis. Mobile and autonomous robots can be used in larger farms.

Automobile and Auto Component

India became the fourth largest auto market in 2019, displacing Germany with about 3.99 million units sold in the passenger and commercial vehicles categories. The two-wheeler segment dominates the market due to a growing middle class and a young population. Moreover, the ever-increasing interest of automobile companies in exploring rural markets further aided the sector's growth. India is also a prominent auto exporter and has strong export growth expectations for the near future.

The automobile sector is the largest consumer of robots which are used in manufacturing and assembly. Analysis of Big Data marks the beginning of the increased potential for the automotive industry to negate existing challenges and look beyond customer expectations. Customer behaviour, risk management, resource optimisation and process improvement are the four broad categories where manufacturers look to utilise relevant data insights. Such an approach will give vehicle manufacturers a view into the imminent trends that will help them structure research and guide investments while avoiding risks and associated losses. By connecting the production line to suppliers, all stakeholders can understand interdependencies, the flow of materials and process cycle times. Hence, cloud and big data analytics are handy tools. As the use of digital technology in cars increases, so does the importance of cyber security. AI is being used for the automation of cars leading to self-driving cars. IoT is used heavily in the manufacturing and assembly process, along with autonomous robots. AI in logistics also increases the efficiency of the assembly line. There is a rising trend of moving to smart and intelligent factories to produce automobiles. 3D printing is also being looked at as an alternative for manufacturing small parts. However, achieving all this will require attention and investment from all stakeholders involved.

The automobile industry is set to become one of the leading industries in India. Domestic automobile production increased at 2.36% CAGR between FY16-20, with 26.36 million vehicles being manufactured in FY20. Domestic automobiles sales increased 1.29% CAGR between FY16-FY20, with 21.55 million vehicles being sold in FY20. The Indian auto-components industry has experienced healthy growth over the last few years. The auto-components industry expanded by a CAGR of 6% over FY16 to FY20 to reach US$ 49.3 billion in FY20. The auto-components industry accounts for 2.3% of India's Gross Domestic Product (GDP) and employs as many as 1.5 million people directly and indirectly. A stable government framework, increased purchasing power, a large domestic market, and an ever-increasing development in infrastructure have made India a favourable destination for investment. As per Automobile Component Manufacturers Association (ACMA), automobile component export from India is expected to reach US$ 80 billion by 2026. The Indian auto component industry aims to achieve US$ 200 billion in revenue by 2026.

Pharmaceuticals and Biotechnology

India enjoys an important position in the global pharmaceuticals sector. India is the largest provider of generic drugs globally. Indian pharmaceutical sector supplies over 50% of global demand for various vaccines, 40% of generic demand in the US and 25% of all medicine in the UK. The country also has a large pool of scientists and engineers with the potential to steer the industry ahead to greater heights. Presently, over 80% of the antiretroviral drugs used globally to combat AIDS (Acquired Immune Deficiency Syndrome) are supplied by Indian

pharmaceutical firms. India is among the top 12 destinations for biotechnology worldwide. The country is also the world's third-largest producer of recombinant Hepatitis B vaccine and the second-largest producer of BT cotton (genetically modified pest-resistant plant cotton).

Compared to many other industries, pharmaceutical production underlies more demanding regulations. Changes to production mean changes to the machines, processes and ultimately the product itself. To ensure consistently high product quality, authorities like the U.S. FDA and the EU Commission issue strict guidelines on Good Manufacturing Practice (GMP). Accordingly, companies have their fair share of reservations when it comes to implementing new and untried technologies. While technologies like Big Data Analytics, AR and VR, Digital Twin can significantly optimise manufacturing operations and supply chain, the adoption rate will be somewhat slow. Automation in packaging and logistics will be boosted as it requires less regulation and strengthens the supply chain.

Technologies such as automation, machine learning and artificial intelligence (AI) will disrupt the biopharmaceutical industry, helping it overthrow traditional production models in favour of new models consistent with Industry 4.0 and the deep integration of the physical and the digital in manufacturing. 3D printing is apparently only limited by the complexity of the design. It extends to so-called "bio-printing." Bioprinting and 3D biological printing are believed to have potential uses in unique dosage forms, more complex drug release profiles, printing living tissue, and others.

The Indian pharmaceutical sector is expected to grow to US$ 100 billion, while the medical device market is expected to grow US$ 25 billion by 2025. Pharmaceuticals export from India stood at US$ 16.3 billion in FY20. Pharmaceutical export includes bulk drugs, intermediates, drug formulations, biologicals, Ayush and herbal products and surgical items. As of November 2020, India exported pharmaceuticals worth US$ 15.86 billion in FY21. Pharmaceutical exports from India stood at US$ 16.28 billion in FY20 and US$ 2.07 billion in October 2020.

The Indian biotechnology industry amounted to US$ 63 billion in 2019 and is forecast to reach US$ 102 billion by 2025, with a CAGR of 10.9%. By 2025, the contribution of the Indian biotechnology industry to the global market is expected to grow to 19% from 3% in 2017. Biopharmaceutical is the largest segment that contributed ~58% to the Indian biotechnology market in 2019, followed by bio-agriculture, which accounted for 19% and bio-services, which accounted for 15% in 2019. Bio-services, accounted for 15% of the biotechnology industry in India, which is becoming a leading destination for clinical trials, contract research and manufacturing activities.

Chemical

Covering more than 80,000 commercial products, India's chemical industry is highly diversified and broadly classified into bulk chemicals, speciality chemicals, agrochemicals, petrochemicals, polymers and fertilisers. India accounts for ~16% of the world production of dyestuffs and dye intermediates. Indian colourants industry has emerged as a key player with a global market share of ~15%. India's proximity to the Middle East, the world's source of petrochemicals feedstock, enables it to benefit economies of scale.

Technologies like Big Data Analytics and AI can be used here because chemical manufacturing typically has a large amount of data collected throughout the manufacturing process. Smart factories equipped with IoT can add massive value to the manufacturing process. The productivity of chemicals plants can be improved by various smart manufacturing techniques: predictive asset management, process control and production simulations, among others.

The Indian chemical industry stood at US$ 178 billion in 2019 and is expected to reach US$ 304 billion by 2025, registering a CAGR of 9.3%. The demand for chemicals is expected to expand by 9% per annum by 2025. In September 2020, the production of critical chemicals was 8,36,435 MT, and petrochemicals were 17,26,502 MT. Speciality chemicals constitute 22% of the total chemicals and petrochemicals market in India. The demand for speciality chemicals is expected to rise at a 12% CAGR in 2019-22. The petrochemicals demand is expected to record a 7.5% CAGR between 2019 and 2023, with polymer demand increasing at 8%. The agrochemicals market is expected to witness an 8% CAGR to reach US$ 3.7 billion by FY22 and US$ 4.7 billion by FY25.

Electronics System Design and Manufacturing (ESDM)

India witnessed a substantial spike in demand for electronic products in the last few years, mainly attributed to India's position as the second-largest mobile phone manufacturer worldwide and a surge in internet penetration rate. The Government of India attributes high priority to electronics hardware manufacturing as it is one of the crucial pillars of Make in India, Digital India and Startup India programmes. The Electronics System Design and Manufacturing (ESDM) sector plays a vital role in the government's goal of generating US$ 1 trillion of economic value from the digital economy by 2025. With various government initiatives aiming to boost domestic manufacturing, India has already started witnessing initial movement with increased production and assembly activities across products such as mobile phones and other consumer electronic items.

The automation of electronic manufacturing services (EMS) and Printed Circuit Boards (PCB) assembly is critical to maintain competitiveness and improve productions processes, reducing room for mistakes and therefore manage production accurately for anything relating to manufacturing and assembly of electronics products such as consumer electronics, connected devices, green technology products, etc. In addition, the integration of a smart supply chain allows much more complex tasks to be carried out than if humans managed them. Thanks to robotics, smart supply chain services, and EMS, supply chain management has been completely transformed. AI printed circuit board designs and engineering processes bring further flexibility and create a new generation of products, such as connected objects, smart home devices, smart building, and IoT devices. Furthermore, EMS companies and smart factories with their own AI system for supply chain, combining machine learning and big data, are innovating for smart devices.

The electronics market has witnessed a growth in demand, with market size increasing from US$ 145 billion in FY16 to US$ 215 billion in FY19—the market saw a growth of 14% CAGR from 2016-19. In FY19, imports accounted for US$ 75 billion, which was 35% of the electronics market demand; it is expected to decrease to 12.6% (US$ 68 billion) of the total electronics market by FY25. Between April 2020 and October 2020, exports of electronic goods stood at US$ 5.05 billion. Samsung led the Indian smartphone market with a 24% shipping share, followed by Xiaomi at 23%.

Fast Moving Consumer Goods (FMCG)

The fast-moving consumer goods (FMCG) is India's fourth-largest sector, with household and personal care accounting for 50% of FMCG sales in India. Growing awareness, more accessible access and changing lifestyles have been the key growth drivers for the sector. The urban segment (with a revenue share of around 55%) is the most significant contributor to the overall revenue generated by the FMCG sector in India. However, in the last few years, the FMCG market has grown faster in semi-urban and rural India compared to urban India. FMCG products account for 50% of the total rural spending.

Quality control is another segment where Industry 4.0 can contribute significantly. The use of IoT can bring a greater level of control to the quality of the goods produced. System integration plays a vital role in this sector as it can boost efficiency and productivity. Predictive maintenance also plays an important role in keeping the production running without hiccups. Lastly, supply chain optimisation will play a significant role in this sector too.

The retail market in India is estimated to reach US$ 1.1 trillion by 2020 from US$ 840 billion in 2017, with modern trade expected to grow at 20-25% per annum, which is likely to

boost the revenue of FMCG companies. Revenue of FMCG sector reached Rs. 3.4 lakh crore (US$ 52.75 billion) in FY18 and is estimated to reach US$ 103.7 billion in 2020. FMCG market is expected to grow at 9-10% in 2020. The rise in rural consumption will drive the FMCG market. It contributes around 36% to the overall FMCG spending. In the third quarter of FY20 in rural India, FMCG witnessed a double-digit growth recovery of 10.6% due to various government initiatives (such as packaged staples and hygiene categories), high agricultural produce, reverse migration and a lower unemployment rate.

Major Initiatives taken by India towards Industry 4.0

Make in India:

The Make in India initiative launched by the Government of India in 2014 aims to transform India into a global design and manufacturing hub. The government is striving to create an environment favourable for investment and infrastructure development and to open up new sectors for foreign capital. The objectives of Make in India include:

- To enhance the growth of the manufacturing industry of India by 12-14% annually.
- To create 100 million additional manufacturing jobs in the Indian economy by 2022.
- To ensure that the contribution of the manufacturing sector in GDP is increased by 25% by 2022.

The Make in India initiative aims to improve India's Ease of Doing Business Index, and India had made the jump from Rank 142 in 2014 to Rank 63 in 2020. The Make in India programme is based on four pillars: New processes, new infrastructure, new sectors and a new mindset. Some notable schemes implemented under Make in India include:

- Production Linked Incentive Scheme: The PLI scheme is implemented for multiple sectors, but with the same goal: to offer a production linked incentive to boost domestic manufacturing and attract large investments.
- Credit Guarantee Trust Fund for Micro and Small Enterprises (CGTMSE) - Established by Ministry of MSME and Small Industries Development Bank of India (SIDBI) to provide collateral-free loans (up to INR 1 Crore) to individual Micro and Small Enterprises (MSEs).
- Financial Support to MSMEs in ZED Certification Scheme: The scheme aims to inculcate Zero Defect and Zero Effect (ZED) practices in manufacturing. Under the scheme, the Government of India provides up to 80% subsidy to MSMEs.
- National Manufacturing Competitiveness Programme (NMCP) - An umbrella scheme which aids MSMEs through the following sub-schemes:

- Credit Linked Capital Subsidy for Technology Upgradation (CLCSS)
- Marketing Support/Assistance to MSMEs (Bar Code)
- Lean Manufacturing Competitiveness for MSMEs
- Design Clinic for Design Expertise to MSMEs
- Technology and Quality Upgradation Support to MSMEs
- Entrepreneurial and Managerial Development of SMEs through Incubators
- Enabling Manufacturing Sector to be Competitive through Quality Management Standards (QMS) and Quality Technology Tools (QTT)
- Building Awareness on Intellectual Property Rights (IPR)

Recently, the Ministry of Commerce and Industry has launched a draft National Logistics Policy (NLP) to replicate the success of countries like Korea and Germany. The policy aims to streamline and strengthen India's logistics sector by standardisation, digitisation and integrating local supply chains with global supply chains for India's competitiveness in the international market.

Digital India

Digital India is a flagship programme of the Government of India with a vision to transform India into a digitally empowered society and knowledge economy. It has the following goals:

- Digital Infrastructure as a Core Utility to Every Citizen: This includes the availability of high-speed internet for all citizens, building a lifelong digital identity, providing all citizens with a mobile phone and a bank account, easy access to government services, and safe and secure cyberspace.
- Governance and Services on Demand: This includes the seamless integration of government services across departments or jurisdictions, providing real-time services on online and mobile platforms, making financial transactions electronic and cashless, leveraging Geospatial Information Systems (GIS) for decision support systems and development.
- Digital Empowerment of Citizens: This includes digital literacy, universally accessible resources in local languages, collaborative platforms for participation in governance and submitting virtual documents instead of physical.

Some key initiatives under Digital India that are relevant to Industry 4.0 include:

- Centre for Excellence for Internet of Things (COE-IT): The Centre of Excellence for IoT was announced as a part of the Digital India Initiative to jump start the IoT ecosystem taking advantage of India's IT strengths and help the country attain a leadership role in the convergent area of hardware and software. The main objective of the centre is to create innovative applications and domain capability. Additionally, the centre will help build industry capable talent, a startup community and an entrepreneurial ecosystem for

IoT. It was established in association with NASSCOM, and some strategic partners include Bosch, Intel, GE, Cisco, TCS and Microsoft.

- Electronic Development Fund (EDF): This is part of the 'Digital India' agenda of the Government to develop the Electronics System Design and Manufacturing (ESDM) sector to achieve 'Net Zero Imports' and making India an ESDM hub to cater to the domestic Indian demand as well as exports. It is with this objective that an Electronic Development Fund (EDF) is set up as a "Fund of Funds" to participate in professionally managed "Daughter Funds," which in turn will provide risk capital to companies developing new technologies in the area of electronics, nano-electronics and Information Technology (IT).
- National Super Computing Mission (NSM): National Super Computing Mission has been envisaged to empower the national academic and R&D institutions spread across the country by installing a vast supercomputing grid comprising more than 70 high-performance computing facilities. These supercomputers will also be networked on the National Supercomputing grid over the National Knowledge Network (NKN).

Industry 4.0 Initiatives from Department of Heavy Industries (DHI)

SAMARTH Udyog Bharat 4.0

The vision of this initiative is to facilitate and create an ecosystem for the propagation of Industry 4.0 set of technologies in every Indian manufacturing by 2025, be it MNC, a large, medium or small-scale Indian company. There are five main projects under this initiative.

- C4i4 Lab, Pune: C4i4 Lab, founded in 2018, prepares use cases of Industry 4.0 and demonstrates its benefits to companies. It provides access to technology and resources to support Industry 4.0 pilot projects in companies. It also partners with leading companies to utilise their resources, equipment and expertise to demonstrate technologies in the experience centres. The lab works in the following domains: skilling, workshops, demo labs, maturity testing and project advisory.
- The IITD-AIA Foundation for Smart Manufacturing: IIT Delhi and the Automation Industry Association (AIA) to set up a fully integrated Smart Manufacturing and Learning Facility for discrete and hybrid manufacturing segments such as automotive, consumer durables and processed foods. The project will imbibe technologies from Europe, Japan, the USA and India. A demo cum experience facility along with skills training, MSME consultancy and multi-industry-academia partnerships is expected to increase the competitiveness of Indian manufacturing.
- Industry 4.0 for India at Indian Institute of Science (IISc), Bangalore: The Centre for Product Design and Manufacturing, Indian Institute of Science had initiated India's first indigenous smart factory platform in 2014. With funding from the Department of Heavy Industries (DHI), Government of India under its SAMARTH Udyog Bharat 4.0 programme, is turning

this into a complete factory testbed with two parts: A labour-intensive toolroom with a connected set of legacy machines that represent the MSMEs of India; and an automation-intensive factory that integrates 3D (metal, polymer) printers, metal laser routers, five-axis CNCs, using industrial robots, collaborative robots and automated guided vehicles. The aim is to demonstrate the power of smart and connected intelligence in enhancing quality, productivity, efficiency, flexibility, and sustainability for manufacturing across sectors and research into future factories. The IISc Bangalore offers two courses: MTech in Smart Manufacturing (2 years course) and PhD in Advanced Manufacturing (3.5 years course).

- Smart Manufacturing Demo and Development Cell at CMTI: This cell was established with the intent to create a platform at Central Manufacturing Technology Institute (CMTI) for Indian manufacturing industries encompassing machinery OEMs, sub-system developers, users, component manufacturers, solution developers, startups and so on to explore, experience, experiment, evaluate and adopt Smart Manufacturing / Industry 4.0 technologies with expert assistance from CMTI. In particular, Micro, Small and Medium Enterprises (MSMEs) will benefit from the CEFC services to gear up for full-scale I4.0 based production and enhance their global competitiveness.
- CoE in Advanced Manufacturing Technology at IIT Kharagpur: The Centre of Excellence offers a unique platform for collaborative, consortium driven infusion of advanced technologies in the manufacturing area, in harmony with the 'Make-in-India' initiative of the Government of India. The centre will initiate innovative, top-quality research focused on speciality materials, design and automation, additive manufacturing, digital manufacturing and the Industrial Internet of Things. It will boost innovative interventions in the advanced manufacturing domain by enabling an ecosystem among institutes of repute, heavy industries and MSMEs and startups. It also houses an Innovation Lab to facilitate the culture of innovation and open engineering. The Innovation Lab invites MSMEs and startups to grab end-to-end support from experts, including access to various state-of-the-art facilities for early prototyping of their product.

In addition, on July 02, 2021, India launched a new initiative to create six technology innovation platforms under the Department of Heavy Industries (DHI) to develop innovative, indigenous technologies to boost domestic manufacturing on par with its global counterparts.

- Automotive Solutions Portal for Industry Research and Education (ASPIRE): The programme is focused on enhancing the technological capabilities of the Indian automotive sector by sharing knowledge and experience and making the industry self-reliant. ASPIRE will be part of the International Centre for Automotive Technology (ICAT).
- SanRachna: It is a platform established to boost the creation of a network of industry, academia and experts for developing indigenous technologies to help the engineering and manufacturing industries to increase efficiency and production. SanRachna will be part of Bharat Heavy Electricals Limited (BHEL).

- TechNovuus: The platform focuses on developing new technologies and innovations to shape the future of mobility by promoting collaborative research and technological development, technology transfer and foster an entrepreneurial mindset through open innovation. TechNovuus will be part of the Automotive Research Association of India (ARAI).
- HMT TechPort: The platform has been created to boost the machine tools industry by aggregating technology and innovation through collaborative approaches. It will assist the industry in new initiatives, solve manufacturing challenges and deliver business results quicker. TechPort will operate at the Hindustan Machine Tools Limited (HMT).
- Knowledge Integration for Technology Enrichment (KITE): A manufacturing technology eco-platform will implement smart, digital and discrete manufacturing with indigenous technology. KITE will be part of IIT-Madras.
- Design, Research and Innovation by Harvesting Science and Technology for Industries (DRISHTI): An online platform that brings together innovators and manufacturing companies in mechanical, civil, IoT, robotics, vision, nano-technology and allied topics. DRISHTI will be part of the Central Manufacturing Technology Institute (CMTI).

These platforms will help develop indigenous manufacturing technologies by converging India's technical resources on each of them. The technology areas covered by these platforms include manufacturing, mobility, advanced materials, additive manufacturing, robotics & automation, mechatronics, sensor control and power electronics, machine learning and artificial intelligence.

Initiate to Establish (2021-2025)

India has made a good start by initiating multiple large scale programs with significant investment outlay to make India a global manufacturing hub. These initiatives have great potential to lay a strong foundation for India's journey towards Industry 4.0 in the coming decades. Today, India has surpassed the United States as the world's second most desired manufacturing destination, according to Cushman & Wakefield's 2021 World Manufacturing Danger Index, indicating the growing interest shown by the global manufacturers in India as a preferred manufacturing hub. However, the adoption of digital technologies and Industry 4.0 by Indian companies is still at a nascent stage, with only 17% of the businesses in India really "attempting to transform" themselves. A significant portion of the Indian industry has not even reached the Industry 3.0 phase while Covid-19 accelerates the adoption of automation worldwide.

India should design and conduct a nation-wide Industry 4.0 maturity assessment of large and small enterprises based on the local context across the sectors to know where India stands currently in terms of IT and OT systems implementation, process automation, availability of

'insightful data' to make easy and quick decisions, cost overheads, pockets of optimisation (of cost of operations) and other relevant parameters. The outcome of this study will provide direction, focus and relevance to various government programs.

The Micro, Small and Medium Enterprises (MSME) segment, which is the backbone of the Indian economy, has very little access to knowledge, digitally aware talent and technology. The future of MSMEs depends mainly on their capacity to respond to the industry needs by improving industrial management processes with proper planning, optimal use of resources, controlled production and continuously evaluating operational performance to maintain a competitive advantage in the market. Adopting Industry 4.0 for MSME can positively impact costs, revenues, equipment maintenance, design and customer interface for their overall growth. To make MSMEs adapt to these changes and become an active part of the global supply chain, India needs a special program dedicated only for MSMEs to mentor systematically and handhold enterprises by creating awareness, building organisational and talent capability, designing specific solutions for demonstration and providing right digital solutions for implementation. Along with Indian government initiatives, in a bid to uplift and revitalise the MSME sector, recently the World Bank has launched a $500 million programme - Raising and Accelerating Micro, Small and Medium Enterprise Performance (RAMP), aimed at improving the performance of 555,000 MSMEs which can boost and accelerate the adoption of digital and smart manufacturing for longer-term productivity-driven growth.

Before 2025, India should aim to transform a large part of Indian enterprises to reach the level of Industry 3.0 with the support of various government initiatives. In addition, India should identify 25 lighthouse projects across industry sectors to showcase successful enterprises that have adopted and benefited from Industry 4.0. The lighthouse factories should demonstrate connected and intelligent factories, interconnected supply chains and distribution networks, real-time monitoring, tracking and tracing to improve productivity and prevent downtime, machine-to-machine and machine-to-human interactions, resources optimisation, and safety. India needs to create a dedicated online platform to showcase lighthouse projects and share experiences from successful manufacturing companies. The idea of lighthouses originated at World Economic Forum (WEF) to show the way for the world's manufacturing companies interesting in implementing Industry 4.0.

The fourth industrial revolution originated in developing countries to address challenges associated with ageing demographics and higher cost of labour by introducing extreme automation in industrial operations. In contrast, India has young demographics with 60 per cent of its population under 29 with an abundant workforce needing employment. India has a unique situation to deal with – India must adopt industry 4.0 to remain competitive while creating more and more jobs for the youth. This challenge can be converted into an opportunity by empowering the Indian workforce with new-age skills and becoming the world's talent factory.

One of the most valuable intangible assets of any country is its human capital. If India wants to be competitive in the fourth industrial revolution, it must upgrade its human capital with 21st-century skills. The changes caused by Industry 4.0 are likely to be radically faster than anything experienced yet. We need to create new talent and reskill & upskill the existing workforce to meet the industry's growing requirements. Like any other revolution, Industry 4.0 also demands a new type of education and skilling to achieve national competitiveness and leadership.

Integrate to Grow (2026-2035)

The adoption of Industry 4.0 will rise during this period. The power of Industry 4.0 lies in the integration of physical assets with digital technologies in a dynamic environment for a smart and intelligent production system. A traditional factory consists of sourcing, procurement, design, production, quality and maintenance working in silos with limited collaboration and communication. In smart factories, these silos are integrated into one large system with benefits of reduced cost and improved efficiency, quality and productivity, to stay competitive in the global market.

During this period, Indian industry needs to transform into a smart and connected enterprise by integrating the horizontal and vertical parts of the organisation using cyber-physical systems that enable self-controlling and self-sustaining production by data integration across production value chain, connecting and controlling machines from a remote location, smart analytics (prediction, intelligence, decision-making capability), the extent of simulation-based production planning, and smart control (the ability to automatically and remotely control machines and production).

Advancing further, enterprises need to develop capabilities in digital twin, cognitive and bio-intelligent systems to increase reliability, optimise the use of resources, minimise downtime and improve performance and efficiency. As a result, large and small organisations across industries can become competitive to produce goods capable of mass customisation and become part of global supply chains.

While manufacturing companies progress towards Industry 4.0, Indian IT companies can offer smart solutions to Indian and global markets. It is estimated that smart factories could add multi-trillion dollars in value to the global economy during this period. Today, India is the world's largest sourcing destination for the IT industry, employing about 4 million professionals. Industry 4.0 sees massive usage of IT in the manufacturing sector and requires smart solutions on assembly lines. Extending India's current strength of IT to operational technologies (OT) would make the current IT industry reach over a trillion dollars by 2030 as adoption will accelerate in this period.

Indian entrepreneurship has evolved from its first wave of IT-based businesses, then moved to the second wave of consumer-driven startups, and is now in its third wave of deep-tech and IP-driven innovative products from India for the world. Industry 4.0 offers a multi-billion dollar opportunities for the next generation of deep-tech entrepreneurs having innovative products and solutions for large and small companies. India can create a new generation of high impact entrepreneurs in Industry 4.0 during this period that will benefit MSMEs and large companies alike.

Digital businesses run on data. Data is the currency in this digital economy, which has reinvented conventional means of doing business. This is the period where data will become the new, all-precious resource for enterprises. With an ever-increasing number of sensors and wireless connectivity, enterprises produce large amounts of data that allows them to gain insights, model future trends, predict behaviours of objects and people and even enhance collaboration. Data usage by the enterprise is more important than the quantity of data. The correct data used most effectively helps an organisation establish itself as a leader in the global market with scale and efficiency.

The current challenge in the data economy is to regulate the flow of data. Companies want to protect the data they collect as business assets leading to complicated regulatory challenges for data collection and sharing. For a fair data economy to flourish, new institutions need to be established.

The growth of digital businesses and their eventual success has had a massive impact on global GDP. A WEF report suggests that in the past 30 years, $1 invested in digital technology increased GDP by $20. At the same time, the same amount invested in non-digital sectors increased GDP by only $3. The report goes on to say that by 2025, 24.3% of global GDP will come from digital technologies like AI and cloud computing. With data playing such a vital role in the global economy and enabling the development of new economies, it would be a period when India becomes a global hub for data and digital economy.

Multiply to Lead (2035-2047)

The next goal for Indian enterprises is to transform from a smart and connected enterprise to an intelligent, self-aware and autonomous, sustainable and networked enterprise to achieve leadership in the fourth industrial revolution. The data produced from operational and biological systems will grow exponentially, and the power of AI multiplies to make machines capable to predict actions and be autonomous and intelligent. Intelligent robots manoeuvre delicate procedures and can work in extreme conditions. Enterprises are able to function autonomously, with intelligent and self-aware machines to accomplish specific tasks in the

presence of uncertainty and variability and self-simulate to adapt to novel situations. Systems will also be capable of self-diagnosis and repair.

During this period, industry structures and business models will be disrupted. The largest and most successful companies in the world during this period will be platform companies. An estimated 70% of the new value created in the economy will be based on digitally enabled platform business models. The next wave of innovations for enterprises will be on the back of the platforms and ecosystem of multiple platforms. A diverse set of large-scale integrated systems that can operate independently on their own are networked together for a common purpose. The new-age companies rely on the principle of demand economics rather than supply economics and grow through network effects.

India's prospects for the future lie in the new wave of wealth creators by unleashing India's entrepreneurial spirit. The lower costs of infrastructure and assets pave the way for more suppliers, inspiring healthy competition among businesses and promoting entrepreneurship, in turn triggering a culture of fast-paced innovation to ensure survival. In emerging economies like India, this competition makes for a thriving market, thus pushing the economy to further growth. What's more, the pandemic saw the acceleration and expansion of digital technology in sectors like e-commerce, telehealth and education. Industry 4.0 is opening up new opportunities for businesses and the innovative implementation and other technological frontiers as platforms are giving birth to new startups, transforming India economics like never before.

Conclusion

The fourth industrial revolution has arrived. Like the previous three, this will determine the development of nations. The first two industrial revolutions bypassed India. The third whizzed past with India trying hard to catch up with the more industrially advanced countries of the world. Now is the time, in the fourth industrial revolution for us to gird our loins, plan futuristically and adopt progressive policies that will catapult our country into a global leadership position in industry.

The paper provides a blueprint or roadmap for India to use this opportunity and become a world leader, for it is presently well-placed economically, technically and industrially, with strong demographic advantages over many other nations. This paper presents a three-step framework for rapid, inclusive and sustainable development that will put India among the world leaders in industry by the 100th year of its independence.

The three phases will be in the form of Mission 2025, which will be 'Initiate to Establish,' Mission 2035, which will be 'Integrate to Grow' and Mission 2047, which will be 'Multiply to Lead.' Doubtless, the roadmap requires concerted efforts and diligent implementation to deliver the desired results.

The proposed framework envisages digital and data sensors and automation that will lay the foundation for Industry 4.0. In addition, there will be enhanced digital and physical infrastructure with 5G connectivity and a target of 100 smart cities. This phase will also promote cutting edge indigenous capabilities in core technologies such as Data, AI, Cloud, IoT, Simulation and Modelling and Digital Twin. By 2025, Digital (Industry 3.0) Enterprises will become functional with demonstration of 25 Industry 4.0 lighthouse enterprises.

The second phase of ten years between 2025 and 2035 will focus on connected and smart new products, services and platforms. There will be smart, digital integrated national infrastructure, digital twins of cities, connected cities, towns and even villages, for a smart state. This will lead to technological platform solutions, integrated information as well as operational and bio-technologies like cognitive and bio-intelligent systems. Industry and MSMEs will be smart and connected with cyber-physical production systems with mass customization and new platform business models.

From here to the centenary year of independence in 2047, we should aim to progress from Industry 4.0 towards Industry 5.0 through networked platform-of-platforms. Our technological capabilities should by then include intelligent, sustainable, self-driven autonomous but interconnected platforms which will pave the way for Industry 5.0. Industries and enterprises

will not only be intelligent, networked and autonomous, but will also use local resources with distributed local production that will energise the entire industrial value chain.

Government of India has already taken a number of steps to meet these challenges with initiatives like 'Make in India,' 'Production Linked Incentive,' 'National Manufacturing Competitiveness Programme,' 'National Logistics Policy', 'Digital India,' 'Samarth Udyog Bharat 4.0' and other similar programmes. While this is a good start, it needs to be backed and sustained by entrepreneurs, educators and the skilled work force who will have to work in tandem and use the opportunities that have been opened up by the government and will be opened up in the times to come, if we are to realize our dream of being USD 40 Trillion economy by the centenary year of our independence.

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PART II: INDIA'S ROADMAP

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